Pearson BTEC Level 3 Award in Advanced Manufacturing Engineering (Development Technical Knowledge) – 360 GL

Pearson BTEC Level 3 Certificate in Advanced Manufacturing Engineering (Development Technical Knowledge) – 540 GL

Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge) – 720 GL

Pearson BTEC Level 3 Extended Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge) – 1080 GL

Specification

New Apprenticeship Standards – Specialist Qualification (England only)

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1 Introducing BTEC Specialist qualifications for the New Apprenticeship Standards

Overview

In October 2013, the government began the implementation of the plan to reform apprenticeships in England. The reform includes changes that move the design of apprenticeships into the hands of employers, with the aim of making them more rigorous and responsive to employers' needs. Employer groups, referred to as Trailblazers, now lead on the development of apprenticeships for occupations where they identify the need for apprentices.

Pearson has been working closely with Trailblazer employer groups in the development of different types of assessment programmes and qualifications, to support the delivery of these new apprenticeships.

As work-related qualifications, BTEC Specialist qualifications are well suited to the new apprenticeships. Through close collaboration with Trailblazer employer groups, these BTEC Specialist qualifications are designed to underpin the development of occupational competencies by giving learners the knowledge, understanding and skills relevant to the Apprenticeship Standards.

BTEC Specialist qualifications put learning into the context of the world of work, giving learners the opportunity to apply their research, skills and knowledge in relevant and realistic work contexts. This applied, practical approach also means that learners are further supported to progress in their career or further study.

Employers, or colleges and training centres, working in partnership with employers, can offer these qualifications as long as they have access to appropriate physical and human resources and that the necessary quality assurance systems are in place.

Sizes of BTEC Specialist qualifications

For all regulated qualifications, we specify a total number of hours that learners are expected to undertake in order to complete and show achievement for the qualification – this is the Total Qualification Time (TQT). The TQT value indicates the size of a qualification.

Within the TQT, we identify the number of Guided Learning Hours (GLH) that a centre delivering the qualification needs to provide. Guided learning means activities that directly or immediately involve tutors and assessors in teaching, supervising, and invigilating learners, for example lectures, tutorials, online instruction and supervised study.

As well as guided learning, there may be other required learning that is directed by tutors or assessors. This includes, for example, private study, preparation for assessment and undertaking assessment when not under supervision, such as preparatory reading, revision and independent research.

As well as TQT and GLH, qualifications can also have a credit value – equal to one tenth of TQT, rounded to the nearest whole number.

TQT and credit values are assigned after consultation with employers and training providers delivering the qualifications.

BTEC Specialist qualifications for the New Apprenticeship Standards are generally available in the following sizes:

- Award – a qualification with a TQT value of 120 or less (equivalent to a range of 1–12 credits)
- Certificate – a qualification with a TQT value in the range of 121–369 (equivalent to a range of 13–36 credits)
- Diploma – a qualification with a TQT value of 370 or more (equivalent to 37 credits and above).

Other size references, such as Extended Diploma, may be used in a suite of qualifications depending on the specific needs of different sectors and Trailblazer employer groups.

2 Qualification summary and key information

Qualification title	Pearson BTEC Level 3 Award in Advanced Manufacturing Engineering (Development Technical Knowledge)
Qualification Number (QN)	601/9053/X
Regulation start date	20th June 2016
Operational start date	1st Sept 2016
Approved age ranges	16–18 19+ Please note that sector-specific requirements or regulations may prevent learners of a particular age from embarking on this qualification. Please refer to *Section 7 Access and Recruitment*.
Assessment	Internal assessment.
Guided learning (GL)	360
Total Qualification Time (TQT)	492
Grading information	The qualification is graded Pass/Merit/Distinction. The internally assessed units are graded Pass/Merit/Distinction.
Entry requirements	No prior knowledge, understanding, skills or qualifications are required before learners register for this qualification. However, centres must follow our access and recruitment policy (see *Section 7 Access and recruitment*).
Funding	The Trailblazer Apprenticeship funding rules can be found on the Skills Funding Agency's website at www.gov.uk/government/collections/sfa-funding-rules

Qualification title	Pearson BTEC Level 3 Certificate in Advanced Manufacturing Engineering (Development Technical Knowledge)
Qualification Number (QN)	601/9049/8
Regulation start date	20th June 2016
Operational start date	1st Sept 2016
Approved age ranges	16–18 19+ Please note that sector-specific requirements or regulations may prevent learners of a particular age from embarking on this qualification. Please refer to *Section 7 Access and Recruitment*.
Assessment	Internal assessment.
Guided learning (GL)	540
Total Qualification Time (TQT)	736
Grading information	The qualification is graded Pass/Merit/Distinction. The internally assessed units are graded Pass/Merit/Distinction.
Entry requirements	No prior knowledge, understanding, skills or qualifications are required before learners register for this qualification. However, centres must follow our access and recruitment policy (see *Section 7 Access and recruitment*).
Funding	The Trailblazer Apprenticeship funding rules can be found on the Skills Funding Agency's website at www.gov.uk/government/collections/sfa-funding-rules

Qualification title	Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)
Qualification Number (QN)	601/9063/2
Regulation start date	20th June 2016
Operational start date	1st Sept 2016
Approved age ranges	16–18 19+ Please note that sector-specific requirements or regulations may prevent learners of a particular age from embarking on this qualification. Please refer to *Section 7 Access and Recruitment*.
Assessment	Internal assessment.
Guided learning (GL)	720
Total Qualification Time (TQT)	982

Grading information	The qualification is graded Pass/Merit/Distinction. The internally assessed units are graded Pass/Merit/Distinction.
Entry requirements	No prior knowledge, understanding, skills or qualifications are required before learners register for this qualification. However, centres must follow our access and recruitment policy (see *Section 7 Access and recruitment*).
Funding	The Trailblazer Apprenticeship funding rules can be found on the Skills Funding Agency's website at www.gov.uk/government/collections/sfa-funding-rules

Qualification title	**Pearson BTEC Level 3 Extended Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)**
Qualification Number (QN)	601/9060/7
Regulation start date	20th June 2016
Operational start date	1st Sept 2016
Approved age ranges	16–18 19+ Please note that sector-specific requirements or regulations may prevent learners of a particular age from embarking on this qualification. Please refer to *Section 7 Access and Recruitment*.
Assessment	Internal assessment.
Guided learning (GL)	1080
Total Qualification Time (TQT)	1476
Grading information	The qualification is graded Pass/Merit/Distinction. The internally assessed units are graded Pass/Merit/Distinction.
Entry requirements	No prior knowledge, understanding, skills or qualifications are required before learners register for this qualification. However, centres must follow our access and recruitment policy (see *Section 7 Access and recruitment*).
Funding	The Trailblazer Apprenticeship funding rules can be found on the Skills Funding Agency's website at www.gov.uk/government/collections/sfa-funding-rules

Learners must complete, as a minimum requirement, the 720 GL BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge) to achieve the Development phase Technical Knowledge.

Some learners may want to extend the specialist nature of the subjects they studied on the 720 GL BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge) and elect to complete the 1080 GL Pearson BTEC Level 3 Extended Diploma Advanced Manufacturing Engineering (Development Technical Knowledge) to achieve the Development phase Technical Knowledge.

Centres should use the Qualification Number (QN) when seeking funding for their learners.

The qualification title, units and QN will appear on each learner's certificate. You should tell your learners this when your centre recruits them and registers them with us. Further information about certification is in our *UK Information Manual*, available on our website.

3 Qualification purpose

Qualification objective

The Pearson BTEC Level 3 Advanced Manufacturing Engineering (Development Technical Knowledge) suite of qualifications have been developed through close collaboration with the Advanced Manufacturing Engineering Apprenticeship Employer Group, professional bodies and other awarding organisations.

The qualifications are for learners employed as apprentices in the role of Mechatronics Maintenance Technician

The qualifications gives learners the opportunity to:

- study three mandatory units including the following topics: communication for engineering technicians, mathematics for engineering technicians and health and safety in the engineering workplace
- develop the technical knowledge, understanding and skills required to meet the Advanced Manufacturing Engineering Apprenticeship Standards. This includes areas such as calculus, engineering drawing, vehicle engine systems and business operations in engineering
- develop a range of positive attitudes and professional attributes that support successful performance in the manufacturing engineering work environment
- achieve a nationally-recognised Level 3 qualification.

Purpose of the Pearson BTEC Level 3 Award in Advanced Manufacturing Engineering (Development Technical Knowledge)

The Level 3 Award in Advanced Manufacturing Engineering has been designed to meet the minimum requirements of the Foundation phase of many of the Trailblazer standards including the Mechatronics Maintenance Technician. It has been designed to provide a basic understanding of engineering principles including maths and science.

Purpose of the Pearson BTEC Level 3 Certificate in Advanced Manufacturing Engineering (Development Technical Knowledge)

The Level 3 Certificate in Advanced Manufacturing Engineering has been designed to meet the requirements of the Foundation phase of many of the Trailblazer standards in Engineering including the Mechatronics Maintenance Technician. It is for learners, providers and employers who wish to complete more knowledge units in order to progress to an Extended Diploma in the Development Phase. It enables the learner to complete additional optional units to allow for greater specialism in their chosen areas.

Purpose of the Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)

The Level 3 Diploma in Advanced Manufacturing Engineering has been designed to meet the minimum requirements of the Development phase of many of the Trailblazer standards in Engineering including the Mechatronics Maintenance Technician. It has been designed as a progression opportunity from the Award and includes the same mandatory units. Learners completing the Diploma will have to complete a number of additional optional units to meet the minimum requirements, and the structure will allow employers to select optional units that meet the needs of their business. **The achievement of this qualification is part of the gateway process towards End Point Assessment and will enable a learner to achieve their Apprenticeship Standard.**

Purpose of the Pearson BTEC Level 3 Extended Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)

The Level 3 Extended Diploma in Advanced Manufacturing Engineering has been designed for learners, providers or employers who wish to complete a larger size qualification as part of their on-programme delivery and assessment activity. The larger size will enable learners to select a greater number of optional units in additional specialist areas as required by their employers and will also enable easier progression to higher education.

Apprenticeships

The Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge) is a mandatory requirement within the Advanced Manufacturing Engineering Mechatronics Apprenticeship Standard [Job role: Mechatronics Maintenance Technician]. Learners must achieve this qualification before progressing to the End-point Assessment.

Role Profile

This Apprenticeship is designed for learners who intend to work in the role of Mechatronics Maintenance Technician. People in this role ensure that plant and equipment perform to the required standard to facilitate production targets regarding Safety, Quality, Delivery and Cost within High Value Manufacturing. The work would cover a broad range of activities including installation, testing, fault-finding and the on-going planned maintenance of complex automated equipment.

Academic Knowledge: The academic learning that is required to underpin the above vocational skills will allow the apprentice to demonstrate a thorough breadth and depth of understanding of relevant maintenance principles, appropriate to and in the context of their company's needs. **As a core, the technician needs to cover 720 GL** in order to have a solid grasp of:

- analytical and scientific methods for engineers
- project design, implementation and evaluation
- instrumentation and control principles and applications
- mathematics for technicians
- mechanical, electrical, electronic and digital principles and applications
- quality assurance principles within mechatronic systems
- applications of pneumatics and hydraulics
- health, safety and risk assessment in engineering
- plant and process principles and applications
- condition monitoring and fault diagnosis
- business improvement techniques.

The published Mechatronics Apprenticeship Standard [Job role: Mechatronics Maintenance Technician] and Assessment Plan can be found at:
https://www.gov.uk/government/publications/apprenticeship-standard-mechatronics-maintenance-technician

Progression opportunities

Learners who achieve the Pearson BTEC Level 3 Diploma and/or Extended Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge) qualification will have achieved 10% of the overarching Apprenticeship requirements. On completing their Apprenticeship, learners can apply for Engineering Technician (EngTech) certification.

Learners who have achieved the qualification and not completed the full Apprenticeship could progress to Engineering Operative or Semi-skilled Fitter job roles within the engineering industry or to other qualifications such as the Pearson BTEC Level 3 Foundation Diploma in Engineering and the Pearson Edexcel Level 3 NVQ Diploma in Engineering Maintenance.

Industry support and recognition

These qualifications are supported by:

- the Advanced Engineering and Manufacturing Apprenticeship Employer Group, which includes, Jaguar LandRover, Toyota, Ford, BMW, GM Vauxhall, Aston Martin, Nissan, GTA England
- the Institute of Engineering and Technology (IET) Professional society for the engineering and technology community
- the Institute of Mechanical Engineers (IMechE) Professional engineering institution
- SEMTA, the Sector Skills Council for the Engineering sector
- the National Forum of Engineering Centres (NFEC)

4 Qualification structures

Pearson BTEC Level 3 Award in Advanced Manufacturing Engineering (Development Technical Knowledge)

The learner will need to meet the requirements outlined in the Qualification Units Table below before the qualification can be awarded.

Minimum number of GL that must be achieved	360	3 mandatory, at least 2 optional units
Number of mandatory GL that must be achieved	180	
Number of optional GL that must be achieved	180	
Total Qualification Time (TQT)	492	

Pearson BTEC Level 3 Certificate in Advanced Manufacturing Engineering (Development Technical Knowledge)

The learner will need to meet the requirements outlined in the Qualification Units Table below before the qualification can be awarded.

Minimum number of GL that must be achieved	540	3 mandatory, at least 5 optional units
Number of mandatory GL that must be achieved	180	
Number of optional GL that must be achieved	360	
Total Qualification Time (TQT)	736	

Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)

The learner will need to meet the requirements outlined in the Qualification Units Table below before the qualification can be awarded.

Minimum number of GL that must be achieved	720	3 mandatory, at least 8 optional
Number of mandatory GL that must be achieved	180	
Number of optional GL that must be achieved	540	
Total Qualification Time (TQT)	982	

Pearson BTEC Level 3 Extended Diploma in Advanced Manufacturing Engineering (Development Technical Knowledge)

The learner will need to meet the requirements outlined in the Qualification Units Table below before the qualification can be awarded.

Minimum number of GL that must be achieved	1080	3 mandatory, at least 14 optional units
Number of mandatory GL that must be achieved	180	
Number of optional GL that must be achieved	900	
Total qualification Time (TQT)	1476	

QUALIFICATION UNITS TABLE				
Unit number	**Mandatory units**	**Level**	**GL**	**How assessed**
1	Health and Safety in the Engineering Workplace	3	60	Internal
2	Communications for Engineering Technicians	3	60	Internal
3	Mathematics for Engineering Technicians	3	60	Internal
Unit number	**Optional units**	**Level**	**GL**	**How assessed**
4	Engineering Project	3	120	Internal
5	Calculus to Solve Engineering Problems	3	60	Internal
6	Further Engineering Mathematics	3	60	Internal
7	Properties and Applications of Engineering Materials	3	60	Internal
8	Further Mechanical Principles of Engineering Systems	3	60	Internal
9	Applications of Mechanical Systems in Engineering	3	60	Internal
10	Organisational Efficiency and Improvement	3	75	Internal
11	Electro, Pneumatic and Hydraulic Systems and Devices	3	60	Internal
12	Engineering Drawing for Technicians	3	60	Internal
13	Computer Aided Drafting in Engineering	3	60	Internal
14	Advanced Mechanical Principles and Applications	3	60	Internal
15	Engineering Primary Forming Processes	3	60	Internal
16	Engineering Secondary and Finishing Techniques	3	60	Internal
17	Fabrication Processes and Technology	3	60	Internal
18	Welding Technology	3	60	Internal

19	Selecting and Using Programmable Controllers	3	60	Internal
20	Applications of Computer Numerical Control in Engineering	3	60	Internal
21	Welding Principles	3	60	Internal
22	Computer Aided Manufacturing	3	60	Internal
23	Electronic Circuit Design and Manufacture	3	60	Internal
24	Principles and Applications of Electronic Devices and Circuits	3	60	Internal
25	Engineering Maintenance Procedures and Techniques	3	60	Internal
26	Monitoring and Fault Diagnosis of Engineering Systems	3	60	Internal
27	Principles and Applications of Engineering Measurement Systems	3	60	Internal
28	Electrical Technology	3	60	Internal
29	Electrical Installation	3	60	Internal
30	Electronic Measurement and Testing	3	60	Internal
31	Features and Applications of Electrical Machines	3	60	Internal
32	Three-Phase Motors and Drives	3	60	Internal
33	Further Electrical Principles	3	60	Internal
34	Manufacturing Planning	3	60	Internal
35	Setting and Proving Secondary Processing Machines	3	60	Internal
36	Business Operations in Engineering	3	60	Internal
37	Industrial Plant and Process Control	3	60	Internal
38	Industrial Process Controllers	3	60	Internal
39	Principles and Operation of 3-Phase Systems	3	60	Internal
40	Industrial Robot Technology	3	60	Internal
41	Vehicle Electronic Ancillary and Information Systems	3	60	Internal
42	Light Vehicle Suspension, Steering and Braking Systems	3	60	Internal
43	Mechanical Measurement and Inspection Techniques	3	60	Internal

44	Vehicle Engine Principles, Operation, Service and Repair	3	60	Internal
45	Vehicle System Fault Diagnosis and Rectification	3	60	Internal
46	Applications of Vehicle Science and Mathematics	3	60	Internal
47	Electrical and Electronic Principles for Vehicle Technology	3	60	Internal
48	Vehicle Electrical Charging and Starting Systems	3	60	Internal
49	Function and Operation of Vehicle Petrol Injection Systems	3	60	Internal
50	Diesel Fuel Injection Systems for Compression Ignition Engines	3	60	Internal
51	Operation and Testing of Vehicle Electronic Ignition Systems	3	60	Internal
52	Vehicle Engine Management Systems	3	60	Internal
53	Operation and Maintenance of Light Vehicle Transmission Systems	3	60	Internal
54	Operation of Vehicle Chassis Systems	3	60	Internal
55	Mechanical Principles of Engineering Systems	3	60	Internal
56	Electrical and Electronic Principles in Engineering	3	60	Internal

5 Programme delivery

Centres are free to offer these qualifications using any mode of delivery that meets learners' and employers' needs. It is recommended that centres make use of a wide range of training delivery methods, including direct instruction in classrooms, simulated demonstrations, research or applied projects, e-learning, directed self-study, field visits and role play. Whichever mode of delivery is used, centres must make sure that learners have access to the resources identified in the specification and to the subject specialists delivering the units.

Centres must adhere to the Pearson policies that apply to the different models of delivery. Our policy *Collaborative Arrangements for the Delivery of Vocational Qualifications* is available on our website.

Those planning the programme should aim to involve employers as far as possible in the delivery of the qualification. This could be by:

- spending time with employers to better understand their organisational requirements and the methods of training that are most suitable, taking into consideration available resources and working patterns
- collaborating with employers to ensure that learners have opportunities in the workplace to implement the knowledge and skills developed through the training programme
- having regular meetings with employers to discuss learner progress, providing feedback and agreeing how any issues will be resolved
- developing projects or assessments with input from employers
- developing up-to-date and relevant teaching materials that make use of scenarios relevant to the sector and relevant occupations
- using 'expert witness' reports from employers to support assessment
- making full use of the variety of experience of work and life that learners bring to the programme.

Where legislation is taught, centres must ensure that it is current and up to date.

For further information on the delivery and assessment of the new Apprenticeships please refer to *The Trailblazer Apprenticeship Funding Rules*, at: www.gov.uk/government/collections/sfa-funding-rules

6 Centre resource requirements

As part of the approval process, centres must make sure that the resource requirements below are in place before offering the qualification.

General resource requirements

- Centres must have appropriate physical resources (for example IT, learning materials, teaching rooms) to support the delivery and assessment of the qualification.
- Staff involved in the delivery and assessment process must have relevant expertise and occupational experience.
- There must be systems in place that ensure continuing professional development (CPD) for staff delivering and assessing the qualification.
- Centres must have in place appropriate health and safety policies relating to the use of equipment by learners.
- Centres must have in place robust internal verification procedures to ensure the quality and authenticity of learners’ work as well as the accuracy and consistency of assessment decisions between assessors operating at the centre. *Further guidance will be provided to centres, following registration.*
- Centres must deliver the qualifications in accordance with current equality legislation. For further details on Pearson’s commitment to the Equality Act 2010, please see *Section 7 Access and recruitment.* For full details of the Equality Act 2010, please go to www.legislation.gov.uk

7 Access and recruitment

Our policy on access to our qualifications is that:

- they should be available to everyone who is capable of reaching the required standards
- they should be free from barriers that restrict access and progression
- there should be equal opportunities for all wishing to access the qualifications.

Centres must ensure that their learner recruitment process is conducted with integrity. This includes ensuring that applicants have appropriate information and advice about the qualification to ensure that it will meet their needs.

Centres should review applicants' prior qualifications and/or experience, considering whether this profile shows that they have the potential to achieve the qualification.

All learners undertaking an Apprenticeship Standard must be employed and have a contract of employment at the start of the first day of their Apprenticeship programme.

Prior knowledge, skills and understanding

No prior knowledge, understanding, skills or qualifications are required before learners register for this qualification.

Access to qualifications for learners with disabilities or specific needs

Equality and fairness are central to our work. Pearson's Equality Policy requires all learners to have equal opportunity to access our qualifications and assessments and that our qualifications are awarded in a way that is fair to every learner.

We are committed to making sure that:

- learners with a protected characteristic (as defined by the Equality Act 2010) are not, when they are undertaking one of our qualifications, disadvantaged in comparison to learners who do not share that characteristic
- all learners achieve the recognition they deserve from undertaking a qualification and that this achievement can be compared fairly to the achievement of their peers.

For learners with disabilities and specific needs, the assessment of their potential to achieve the qualification must identify, where appropriate, the support that will be made available to them during delivery and assessment of the qualification. Please see the information regarding reasonable adjustments and special consideration in *Section 8 Assessment*.

8 Assessment

In administering internal assessments, centres need to be aware of the specific procedures and policies that apply to, for example, registration, entries and results. More information can be found in our *UK Information Manual*, available on our website.

Language of assessment

Assessments for all units are in English only.

A learner taking the qualification may be assessed in British or Irish Sign Language where it is permitted for the purpose of reasonable adjustment.

For further information on access arrangements, please refer to *Reasonable adjustments* later in this section.

Internal assessment

All units in this qualification are internally assessed and subject to external standards verification. This means that centres set and mark the final summative assessment for each unit, using the examples and support that Pearson provides. Centres need to be, if they are not already, approved to offer the qualification before conducting assessments. *Section 9 Centre recognition and approval* gives information on approval for offering these qualifications.

Assessment through assignments

For internally assessed units, the format of assessment is an assignment taken after the content of the unit, or part of the unit if several assignments are used, has been delivered. An assignment may take a variety of forms, including practical and written types. An assignment is a distinct activity, completed independently by learners, that is separate from teaching, practice, exploration and other activities that learners complete with direction from tutors and assessors.

An assignment is issued to learners as an assignment brief with a defined start date, a completion date and clear requirements for the evidence that they need to provide. Assignments can be divided into tasks and may require several forms of evidence. A valid assignment will enable there to be a clear and formal assessment outcome based on the assessment criteria.

Designing effective assignments

To ensure that final assessment decisions meet the required standard, assignments must be fit for purpose as a tool to measure learning against the defined content and assessment criteria.

Centres should make sure that assignments enable learners to produce valid, sufficient, authentic and appropriate evidence that relates directly to the specified criteria within the context of the learning outcomes and unit content. Centres need to ensure that the generation of evidence is carefully monitored and controlled and that it is produced to an appropriate timescale. This helps to make sure that learners are achieving to the best of their ability and that at the same time the evidence is genuinely their own.

An assignment that is fit for purpose and suitably controlled is one in which:

- the tasks that the learner is asked to complete provide evidence for a learning outcome that can be assessed using the assessment criteria
- the time allowed for the assignment is clearly defined and consistent with what is being assessed
- the centre has the required resources for all learners to complete the assignment fully and fairly
- the evidence the assignment will generate will be authentic and individual to the learner
- the evidence can be documented to show that the assessment and verification has been carried out correctly.

Recommended assignments are provided in the *Further information for tutors and assessors* section of each unit. In designing assignments, centres need to work within the structure of these assignments. They need to consider the following points when developing their assignment briefs.

- Centres may choose to combine all or parts of different units into single assignments provided that all units and all their associated learning outcomes are fully addressed in the programme overall. If this approach is taken, centres need to make sure that learners are fully prepared so that they can provide all the required evidence for assessment, and that centres are able to track achievement in the records.
- An outcome must always be assessed as a whole and must not be split into two or more assignments.
- The assignment must be targeted to the learning outcomes but the learning outcomes and their associated criteria are not tasks in themselves. Criteria are expressed in terms of the outcome shown in the evidence.

- Centres do not have to follow the order of the outcomes of a unit in developing assignments but later learning outcomes often require learners to apply the content of earlier learning outcomes and they may require learner to draw their learning together.
- Assignments must be structured to allow learners to demonstrate the full range of achievement at all grade levels. Learners need to be treated fairly by being given the opportunity to achieve a higher grade if they have the ability.
- As assignments provide a final assessment, they will draw on the specified range of teaching content for the learning outcomes. The specified content is compulsory. The evidence for assessment need not cover every aspect of the teaching content as learners will normally be given particular examples, case studies or contexts in their assignments. For example, if a learner is carrying out one practical performance, or an investigation of one organisation, then they will address all the relevant range of content that applies in that instance.

Providing an assignment brief

A good assignment brief is one that motivates learners to provide appropriate evidence of what they have learned through providing challenging and realistic tasks. An assignment brief should include:

- a vocational scenario, context or application for the tasks to be completed
- clear instructions to the learner about what they are required to do, normally set out through a series of tasks
- an audience or purpose for which the evidence is being provided
- an explanation of how the assignment relates to the unit(s) being assessed.

Forms of evidence

Centres may use a variety of forms of evidence, provided that they are suited to the type of learning outcome being assessed. For many units, the practical demonstration of skills is necessary and for others, learners will need to carry out their own research and analysis. The units give information on what would be suitable forms of evidence. Centres may choose to use different suitable forms for evidence to those proposed. Overall, learners should be assessed using varied forms of evidence.

Some of the main forms of evidence include:

- written task or reports
- projects
- time-constrained simulated activities with observation records and supporting evidence
- observation and recordings of performance in the workplace
- sketchbooks, working logbooks, reflective journals
- presentations with assessor questioning.

The form(s) of evidence selected must:

- allow the learner to provide all the evidence required for the learning outcome and the associated assessment criteria at all grade levels
- allow the learner to produce evidence that is their own independent work
- allow a verifier to independently reassess the learner to check the assessor’s decisions.

For example, when you are using performance evidence you need to think about how supporting evidence can be captured through recordings, photographs or task sheets.

Centres need to take particular care that learners are enabled to produce independent work. For example, if learners are asked to use real examples, then best practice would be to encourage them to use their own experiences.

For information on the requirements for implementing assessment processes in centres, please refer to the *BTEC UK Quality Assurance Handbook* on our website.

Making valid assessment decisions

Authenticity of learner work

Once an assessment has begun, learners must not be given feedback on progress towards fulfilling the targeted criteria.

An assessor must assess only work that is authentic, i.e. learners' own independent work. Learners must authenticate the evidence that they provide for assessment through signing a declaration stating that it is their own work.

Assessors must ensure that evidence is authentic to a learner through setting valid assignments and supervising learners during assessment period. Assessors must take care not to provide direct input, instructions or specific feedback that may compromise authenticity.

Assessors must complete a declaration that:

- the evidence submitted for this assignment is the learner's own
- the learner has clearly referenced any sources used in the work
- they understand that false declaration is a form of malpractice.

Centres may use Pearson templates or their own templates to document authentication.

During assessment an assessor may suspect that some or all of the evidence from a learner is not authentic. The assessor must then take appropriate action using the centre's policies for malpractice. More information is given later in this section.

Making assessment decisions using unit-based criteria

Assessment decisions for the qualifications are based on the specific criteria given in each unit and set at each grade level. The assessment criteria for a unit are hierarchical and holistic. For example, if an M criterion requires the learner to show 'analysis' and the related P criterion requires the learner to 'explain', then to satisfy the M criterion a learner will need to cover both 'explain' and 'analyse'. The unit assessment grid shows the relationships between the criteria so that assessors can apply all the criteria to the learner's evidence at the same time.

Assessors make judgements using the criteria and must show how they have reached their decisions in the assessment records. The evidence from a learner can be judged using all the relevant criteria at the same time. The assessor needs to make a judgement against each criterion that evidence is present and sufficiently comprehensive. For example, the inclusion of a concluding section may be insufficient to satisfy a criterion requiring 'evaluation'.

Assessors should use the following information and support in reaching assessment decisions:

- the *Assessment guidance* section of each unit, which gives examples and definitions related to terms used in the assessment criteria
- the centre's Lead Internal Verifier and assessment team's collective experience supported by the information provided by Pearson.

When a learner has completed the assessment for a unit then the assessment team will give an assessment outcome for the unit. This is given according to the highest level for which the learner is judged to have met all the criteria. Therefore:

- to achieve a Distinction, a learner must have satisfied all the Distinction criteria (and therefore the Pass and Merit criteria); these define outstanding performance across the unit as a whole
- to achieve a Merit, a learner must have satisfied all the Merit criteria (and therefore the Pass criteria) through high performance in each learning outcome
- to achieve a Pass, a learner must have satisfied all the Pass criteria for the learning outcomes, showing coverage of the unit content and, therefore, attainment at the stated level of the qualification. The award of a Pass is a defined level of performance and cannot be given solely on the basis of a learner completing assignments. Learners who do not satisfy the Pass criteria should be reported as Unclassified.

Dealing with late completion of assignments

Learners must have a clear understanding of the centre's policy on completing assignments by the stated deadlines. Learners may be given authorised extensions for legitimate reasons, such as illness at the time of submission, in line with centre policies.

For assessment to be fair, it is important that learners are all assessed in the same way and that some learners are not advantaged by having additional time or the opportunity to learn from others.

If a late completion is accepted, then the assignment should be assessed normally using the relevant assessment criteria.

Issuing assessment decisions and feedback

Once the assessment team has completed the assessment process for an assignment, the outcome is a formal assessment decision. This is recorded formally and reported to learners.

The information given to the learner:

- must show the formal decision and how it has been reached, indicating how or where criteria have been met
- may show why attainment against criteria has not been demonstrated
- must not provide feedback on how to improve evidence
- must be validated by an Internal Verifier before it is given to the learner.

Resubmissions and retakes

On 1 September 2014, Pearson introduced a framework to support centres in delivering high-quality internal assessments for BTEC Firsts and Nationals, the framework can be found on the BTEC delivery pages of our website. Within this framework, only one opportunity for resit can be authorised by the Lead Internal Verifier and retakes are not available. These rules do not apply to BTEC Specialist programmes at Entry Level to Level 3 but we do recommend the approach as best practice. As the rules are, therefore, not mandatory for BTEC Specialist programmes, they will not be checked as part of the standards verification and quality assurance process for these qualifications.

Administrative arrangements for internal assessment

Records

Centres are required to retain records of assessment for each learner. Records should include assessments taken, decisions reached and any adjustments or appeals. Further information can be found in our *UK Information Manual*. We may ask to audit centre records so they must be retained as specified.

Reasonable adjustments to assessments

Centres are able to make adjustments to assessments to take account of the needs of individual learners, in line with the guidance given in the Pearson document *Supplementary guidance for reasonable adjustment and special consideration in vocational internally assessed units*. In most instances, adjustments can be achieved by following the guidance, for example allowing the use of assistive technology or adjusting the format of the evidence. We can advise you if you are uncertain as to whether an adjustment is fair and reasonable. Any reasonable adjustment must reflect the normal learning or working practice of a learner in a centre or a learner working within the occupational area.

Further information on access arrangements can be found in the Joint Council for Qualifications (JCQ) document *Adjustments for candidates with disabilities and learning difficulties, Access Arrangements, Reasonable Adjustments and Special Consideration for General and Vocational qualifications*.

Both documents are on the policy page of our website.

Special consideration

Centres must operate special consideration in line with the guidance given in the Pearson document *Supplementary guidance for reasonable adjustment and special consideration in vocational internally assessed units*. Special consideration may not be applicable in instances where:

- assessment requires the demonstration of practical competence
- criteria have to be met fully
- units/qualifications confer licence to practice.

Centres cannot apply their own special consideration; applications for special consideration must be made to Pearson and can be made on a case-by-case basis only. A separate application must be made for each learner. Certification claims must not be made until the outcome of the application has been received.

Further information on special consideration can be found in the Joint Council for Qualifications (JCQ) document *Adjustments for candidates with disabilities and learning difficulties, Access Arrangements, Reasonable Adjustments and Special Consideration for General and Vocational qualifications*.

Both of the documents mentioned above are on our website.

Appeals against assessment

Centres must have a policy for dealing with appeals from learners. Appeals may relate to assessment decisions being incorrect or assessment not being conducted fairly. The first step in such a policy is a consideration of the evidence by a Lead Internal Verifier or other member of the programme team. The assessment plan should allow time for potential appeals after learners have been given assessment decisions.

Centres must document all learners' appeals and their resolutions. Further information on the appeals process can be found in the document *Enquiries and Appeals about Pearson Vocational Qualifications policy*, which is available on our website.

Dealing with malpractice in assessment

Malpractice means acts that undermine the integrity and validity of assessment, the certification of qualifications and/or may damage the authority of those responsible for delivering the assessment and certification.

Pearson does not tolerate actions (or attempted actions) of malpractice by learners, centre staff or centres in connection with Pearson qualifications. Pearson may impose penalties and/or sanctions on learners, centre staff or centres where incidents (or attempted incidents) of malpractice have been proven.

Malpractice may arise or be suspected in relation to any unit or type of assessment within the qualification. For further details on malpractice and advice on preventing malpractice by learners, please see Pearson's *Centre Guidance: Dealing with Malpractice*, available on our website.

The procedures we ask you to adopt vary between units that are internally assessed and those that are externally assessed, however, there are only internally assessed units in this qualification.

Internal assessment

Centres are required to take steps to prevent malpractice and to investigate instances of suspected malpractice. Learners must be given information that explains what malpractice is for internal assessment and how suspected incidents will be dealt with by the centre. The *Centre Guidance: Dealing with Malpractice* document gives full information on the actions we expect you to take.

Pearson may conduct investigations if we believe that a centre is failing to conduct internal assessment according to our policies. The above document gives further information and examples, and details the penalties and sanctions that may be imposed.

In the interests of learners and centre staff, centres need to respond effectively and openly to all requests relating to an investigation into an incident of suspected malpractice.

Learner malpractice

The head of centre is required to report incidents of suspected learner malpractice that occur during Pearson examinations. We ask centres to complete JCQ Form M1 (www.jcq.org.uk/malpractice) and email it with any accompanying documents (signed statements from the learner, invigilator, copies of evidence, etc.) to the Investigations Team at pqsmalpractice@pearson.com. The responsibility for determining appropriate sanctions or penalties to be imposed on learners lies with Pearson.

Learners must be informed at the earliest opportunity of the specific allegation and the centre's malpractice policy, including the right of appeal. Learners found guilty of malpractice may be disqualified from the qualification for which they have been entered with Pearson.

Teacher/centre malpractice

The head of centre is required to inform Pearson's Investigations Team of any incident of suspected malpractice by centre staff, before any investigation is undertaken. The head of centre is requested to inform the Investigations Team by submitting a JCQ M2(a) form (downloadable from www.jcq.org.uk/malpractice) with supporting documentation to pqsmalpractice@pearson.com. Where Pearson receives allegations of malpractice from other sources (for example Pearson staff, anonymous informants), the Investigations Team will conduct the investigation directly or may ask the head of centre to assist.

Incidents of maladministration (accidental errors in the delivery of Pearson qualifications that may affect the assessment of learners) should also be reported to the Investigations Team using the same method.

Heads of centres/principals/chief executive officers or their nominees are required to inform learners and centre staff suspected of malpractice of their responsibilities and rights, please see 6.15 of *JCQ Suspected Malpractice in Examinations and Assessments Policies and Procedures*.

Pearson reserves the right in cases of suspected malpractice to withhold the issuing of results/certificates while an investigation is in progress. Depending on the outcome of the investigation, results and/or certificates may not be released or they may be withheld.

We reserve the right to withhold certification when undertaking investigations, audits and quality assurances processes. You will be notified within a reasonable period of time if this occurs.

Sanctions and appeals

Where malpractice is proven, we may impose sanctions or penalties.

Where learner malpractice is evidenced, penalties may be imposed such as:

- mark reduction for affected external assessments
- disqualification from the qualification
- debarment from registration for Pearson qualifications for a period of time.

If we are concerned about your centre's quality procedures we may impose sanctions such as:

- working with centres to create an improvement action plan
- requiring staff members to receive further training
- placing temporary blocks on the centre's certificates
- placing temporary blocks on registration of learners
- debarring staff members or the centre from delivering Pearson qualifications
- suspending or withdrawing centre approval status.

The centre will be notified if any of these apply.

Pearson has established procedures for centres that are considering appeals against penalties and sanctions arising from malpractice. Appeals against a decision made by Pearson will normally be accepted only from the head of centre (on behalf of learners and/or members or staff) and from individual members (in respect of a decision taken against them personally). Further information on appeals can be found in our *Enquiries and appeals about Pearson vocational qualification policy* on our website. In the initial stage of any aspect of malpractice, please notify the Investigations Team (via pqsmalpractice@pearson.com) who will inform you of the next steps.

9 Centre recognition and approval

Centres offering mandatory qualifications for the New Apprenticeship Standards must be listed on the Skills Funding Agency's Register of Training Organisations and have a contract to deliver the New Apprenticeships Standards.

Centres that have not previously offered BTEC Specialist qualifications need to apply for and be granted centre recognition and approval to offer individual qualifications.

Existing Pearson centres seeking approval to offer BTEC Specialist qualifications for the New Apprenticeship Standards, will be required to submit supplementary evidence for approval, aligned with the associated new standards and assessment requirements.

Guidance on seeking approval to deliver BTEC qualifications is available on our website.

Approvals agreement

All centres are required to enter into an approval agreement with Pearson, in which the head of centre or principal agrees to meet all the requirements of the qualification specification and to comply with the policies, procedures, codes of practice and regulations of Pearson and relevant regulatory bodies. If centres do not comply with the agreement, this could result in the suspension of certification or withdrawal of centre or qualification approval.

10 Quality assurance

Quality assurance is at the heart of vocational qualifications and Apprenticeships.

Centres are required to declare their commitment to ensuring quality and to giving learners appropriate opportunities that lead to valid and accurate assessment outcomes.

Pearson uses external quality assurance processes to verify that assessment, internal quality assurance and evidence of achievement meet nationally defined standards.
Our processes enable us to recognise good practice, effectively manage risk and support centres to safeguard certification and quality standards.

Our Standards Verifiers provide advice and guidance to enable centres to hold accurate assessment records and assess learners appropriately, consistently and fairly. Centres offering BTEC Specialist qualifications as part of the New Apprenticeship Standards will receive at least one visit from our Standards Verifier, followed by ongoing support and development. This may result in more visits or remote support, as required to complete standards verification. The exact frequency and duration of Standards Verifier visits/remote sampling will reflect the level of risk associated with a programme, taking account of the:

- number of assessment sites
- number and throughput of learners
- number and turnover of assessors
- number and turnover of internal verifiers
- amount of previous experience of delivery.

If a centre is offering a BTEC Specialist qualification alongside other qualifications related to the same Apprenticeship Standard, wherever possible, we will allocate the same Standards Verifier for both qualifications.

Following registration, centres will be given further quality assurance and sampling guidance.

11 Understanding the qualification grading

This section explains the rules that we apply in providing an overall qualification grade for each learner. It shows how all the qualifications in this sector are graded. The final grade awarded for a qualification represents a holistic performance across all of the qualification. As the qualification grade is an aggregate of the total performance, there is some element of compensation in that a higher performance in some units will be balanced by a lower outcome in others.
In the event that a learner achieves more than the required number of optional units, the mandatory units along with the optional units with the highest grades will be used to calculate the overall result, subject to the eligibility requirements for that particular qualification title.

Awarding and reporting for the qualification

The awarding and certification of these qualifications will comply with the requirements of the Office of Qualifications and Examinations Regulation (Ofqual).

Eligibility for an award

To achieve any qualification grade learners must:

- achieve a Pass grade, or higher in for all units within a valid combination, and
- achieve the minimum number of points at a grade threshold.

It is the responsibility of the centre to ensure that a correct unit combination is adhered to.

Calculation of the qualification grade

The qualification grade is an aggregation of a learner's unit level performance. The Award, Certificate, Diploma and Extended Diploma are awarded at the grade ranges shown in the table below.

Qualification	Available grade range
Award	P to D
Certificate	P to D
Diploma	P to D
Extended Diploma	P to D

The *Calculation of Qualification Grade* table, shown further on in this section, shows the minimum thresholds for calculating these grades.
Learners who do not meet the minimum requirements for a qualification grade to be awarded will be recorded as Unclassified (U) and will not be certificated. They may receive a Notification of Performance for individual units. Our *Information Manual* (available on our website) gives more information.

Points available for internal units

The table below shows the number of **points** available for internal units. For each internal unit, points are allocated depending on the grade awarded.

	Unit size 60 GL	Unit size 75 GL	Unit size 120 GL
U	0	0	0
Pass	6	6	12
Merit	10	10	20
Distinction	16	16	32

Claiming the qualification grade

Subject to eligibility, Pearson will automatically calculate the qualification grade for your learners when the internal unit grades are submitted and the qualification claim is made. Learners will be awarded qualification grades for achieving the sufficient number of points within the ranges shown in the applicable *Calculation of Qualification Grade* table.
To allow for a weaker performance in some units to be balanced by a stronger performance in others, there is an element of compensation built into the grading model.

Points thresholds

Applicable for registration from 1 September 2016.

Award		**Certificate**		**Diploma**		**Extended Diploma**	
360 GL		**540 GL**		**720 GL**		**1080 GL**	
Grade	**Points threshold**	**Grade**	**Points threshold**	**Grade**	**Points threshold**	**Grade**	**Points threshold**
U	0	U	0	U	0	U	0
P	36	P	54	P	72	P	108
M	52	M	78	M	104	M	156
D	74	D	108	D	144	D	216

Examples of grade calculations

Example 1: Achievement of a Diploma with a P grade

	GL	**Type (Int/Ext)**	**Grade**	**Unit points**
Unit A	60	Int	Pass	6
Unit B	120	Int	Pass	12
Unit C	60	Int	Pass	6
Unit D	60	Int	Merit	10
Unit E	60	Int	Merit	10
Unit F	60	Int	Pass	6
Unit G	60	Int	Pass	6
Unit H	60	Int	Pass	6
Unit I	60	Int	Pass	6
Unit J	60	Int	Pass	6
Unit K	75	Int	Pass	6
Totals	**735**		**P**	**80**

The learner has exceeded the 72-point pass threshold and has passed all units.

The learner has sufficient points for a P grade

Example 2: Achievement of a Diploma with a D grade
Example 2

	GL	Type (Int/Ext)	Grade	Unit points
Unit A	60	Int	Merit	10
Unit B	120	Int	Merit	26
Unit C	60	Int	Pass	6
Unit D	60	Int	Merit	10
Unit E	60	Int	Merit	10
Unit F	60	Int	Pass	6
Unit G	60	Int	Distinction	16
Unit H	60	Int	Distinction	16
Unit I	60	Int	Distinction	16
Unit J	60	Int	Distinction	16
Unit K	75	Int	Distinction	16
Totals	**735**		**D**	**148**

The learner has exceeded the 144 threshold for Distinction and has passed all units

Example 3: An Unclassified result for a Diploma

	GL	Type (Int/Ext)	Grade	Unit points
Unit A	60	Int	Merit	10
Unit B	120	Int	Pass	12
Unit C	60	Int	Pass	6
Unit D	60	Int	Merit	10
Unit E	60	Int	Merit	10
Unit F	60	Int	Pass	6
Unit G	60	Int	Pass	6
Unit H	60	Int	Merit	10
Unit I	60	Int	U	0
Unit J	60	Int	Merit	10
Unit K	60	Int	Merit	10
Totals	**720**		**U**	**90**

The learner has sufficient points for P (72) but has not passed all units. Hence, the grade is U.

Example 4: Extended Diploma Pass

	GL	Type (Int/Ext)	Grade	Unit points
Unit A	60	Int	Pass	6
Unit B	120	Int	Pass	12
Unit C	60	Int	Pass	6
Unit D	60	Int	Pass	6
Unit E	60	Int	Pass	6
Unit F	60	Int	Merit	10
Unit G	60	Int	Merit	10
Unit H	60	Int	Distinction	16
Unit I	60	Int	Pass	6
Unit J	60	Int	Merit	10
Unit K	60	Int	Merit	10
Unit L	60	Int	Pass	6
Unit M	60	Int	Pass	6
Unit N	60	Int	Pass	6
Unit O	60	Int	Pass	6
Unit P	60	Int	Pass	6
Unit Q	60	Int	Pass	6
Totals	**1080**		**P**	**134**

The learner has exceeded the 108 point pass threshold, and has passed all units.

Example 5: Extended Diploma Distinction

	GL	Type (Int/Ext)	Grade	Unit points
Unit A	60	Int	Distinction	16
Unit B	120	Int	Pass	12
Unit C	60	Int	Pass	6
Unit D	60	Int	Distinction	16
Unit E	60	Int	Distinction	16
Unit F	60	Int	Distinction	16
Unit G	60	Int	Distinction	16
Unit H	60	Int	Distinction	16
Unit I	60	Int	Pass	6
Unit J	60	Int	Pass	6
Unit K	60	Int	Distinction	16
Unit L	60	Int	Distinction	16
Unit M	60	Int	Distinction	16
Unit N	60	Int	Distinction	16
Unit O	60	Int	Distinction	16
Unit P	60	Int	Pass	6
Unit Q	60	Int	Merit	10
Totals	**1080**		**D**	**222**

The learner has exceeded the 216-point distinction threshold and has passed all units

Example 6: An Unclassified result for an Extended Diploma

	GL	Type (Int/Ext)	Grade	Unit points
Unit A	60	Int	Merit	10
Unit B	120	Ext	U	0
Unit C	60	Int	Pass	6
Unit D	60	Int	Pass	6
Unit E	60	Int	Pass	6
Unit F	60	Int	Merit	10
Unit G	60	Int	Merit	10
Unit H	60	Int	Pass	6
Unit I	60	Int	Pass	6
Unit J	60	Int	Merit	10
Unit K	60	Int	Merit	10
Unit L	60	Int	Pass	6
Unit M	60	Int	Pass	6
Unit N	60	Int	Pass	6
Unit O	60	Int	Pass	6
Unit P	60	Int	Pass	6
Unit Q	60	Int	Pass	6
Totals	**1080**		**U**	**116**

The learner has exceeded the 108 point pass threshold but has not passed all units.

12 Units

Each unit in the specification is set out in a similar way. There is only one type of unit format in this qualification:

- internal units

This section explains how the units are structured. It is important that all tutors, assessors, internal verifiers and other staff responsible for the programme review this section.

Internal units

Section	Explanation
Unit number	The number is in a sequence in the specification. Where a specification has more than one qualification, numbers may not be sequential for an individual qualification.
Unit title	This is the formal title that will always be used and which will appear on certificates.
Level	All units and qualifications have a level assigned to them. The level assigned is informed by the level descriptors defined by Ofqual, the qualifications regulator.
Unit type	This says if the unit is mandatory or optional for the qualification. See structure information in *Section 5* for full details.
Assessment type	This says how the unit is assessed – i.e. whether it is internal or external. See information in *Section 4 Qualification structure* for details.
GL	This indicates the number of hours of activities that directly or immediately involve tutors and assessors in teaching, supervising, and invigilating learners Units may vary in size.
Unit introduction	This is designed with learners in mind. It indicates why the unit is important, what will be learned and how the learning might be applied in the workplace.
Learning outcomes	These help to define the scope, style and depth of learning of the unit.
Unit content	This section sets out the required teaching content of the unit. Content is compulsory except when shown as 'e.g.'. Learners should be asked to complete summative assessment only after the teaching of content for the unit or learning outcome(s) has been covered.
Assessment and grading criteria	Assessment criteria specify the standard required by the learner to achieve each learning outcome. Each learning outcome has Pass criteria. In addition to Pass criteria, each learning outcome has Merit or both Merit and Distinction criteria.

Section	Explanation
Essential guidance for tutors	This section gives information to support the implementation of assessment. It is important that this information is used carefully, alongside the assessment criteria. This information gives guidance for each learning outcome or assignment of the expectations for Pass, Merit and Distinction standard. This section contains examples and essential clarification.
Programme of suggested assignments	This section shows a programme of suggested assignments that covers the Pass, Merit and Distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.
Essential resources	This section lists any specific resources that are needed to be able to teach and assess the unit.
Indicative reading for learners	Lists resource materials that can be used to support the teaching of the unit, for example books, journals, websites.

Unit 1: Health and Safety in the Engineering Workplace

Level:	**3**
Unit type:	**Mandatory**
Assessment type:	**Internal**
Guided learning:	**60**

Unit introduction

The welfare of people working or operating within any manufacturing or engineering environment is of prime importance. All workers should expect to be able to carry out their work in a safe manner that has no negative effect on their health and wellbeing. In fact, many organisations not only reduce risks and make improvements to the working environment but try to make their own working environment superior to others, making it a competitive aspect when recruiting staff.

Health and safety in the workplace is about measures designed to protect the health and safety of employees, visitors and the general public who may be affected by workplace activities. Safety measures are concerned with controlling and reducing risks to anyone who might be affected by these activities.

Health and safety is controlled largely by legislation and regulations and the law is continually being revised and updated. It is important that organisations are aware of these changes and keep up to date with developments.

This unit will give learners an understanding of hazards and risks associated with health, safety and welfare in an engineering workplace, the associated legislation and regulations and of their roles in complying with the related legal obligations. Learners will also be required to undertake full risk assessments and to appreciate the significant risks encountered in the workplace and the measures taken to deal with them. They will also study the principles of reporting and recording accidents and incidents, again within a legal context.

This unit could form a key component within many learning programmes since the content is highly applicable to many manufacturing, engineering and industrial situations.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand health and safety legislation and regulations

2 Know about hazards and risks in the workplace

3 Understand the methods used when reporting and recording accidents and incident.

Unit content

1 Understand health and safety legislation and regulations

Key features of legislation and regulations: The general contents of legislation and regulations or other relevant international equivalents and how they are satisfied by safe systems of work/procedures, including:

- Health and Safety at Work Act 1974 – duties of employers, employees, Health and Safety Executive (HSE) and others, general prohibitions
- Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013 (as amended) – duties of employers, self-employed and people in control of work premises (the Responsible Person) to report certain serious workplace accidents, occupational diseases and specified dangerous occurrences
- Personal Protective Equipment (PPE) at Work Regulations 1992 (as amended) – appropriate if risk cannot be controlled in any other way, types, assessing suitable PPE given the hazard, supply, instructions/training, correct use, maintenance and storage
- Control of Substances Hazardous to Health Regulations 2002 (as amended) – identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information
- Manual Handling Operations Regulations 1992 (as amended) – avoid the need for manual handling, types of hazard, assess risk of injury when manual handling is required, control and reduce the risk of injury, training in use of techniques/mechanical aids
- Environmental legislation and EU directives: Environmental Protection Act; Pollution Prevention and Control Act; Clean Air Act; Radioactive Substances Act; Controlled Waste Regulations; Dangerous Substances and Preparations and Chemical Regulations

Roles and responsibilities of those involved: employers; employees; Health and Safety Executive (HSE) e.g. span of authority, right of inspection, guidance notes and booklets; others e.g. management, subcontractors, public, suppliers, customers, visitors

Application of environmental management systems: ISO 14000 (family of standards, a management tool); environmental management (What an organisation does to minimise the harmful effects on the environment caused by its activities); ISO 14004 (guidelines on the elements of an environmental management system and its implementation, and examines principle issues involved); ISO 14001 (specifies the requirements for such an environmental management system)

2 Know about hazards and risks in the workplace

Within the workplace: methods to identify hazards e.g. statements, analysis of significant risks, prediction of results or outcomes of those risks, use of accident data, careful consideration of work methods

Working environment: consideration of the workplace and its potential for harm e.g. confined spaces, working over water or at heights, electrical hazards, chemicals, noise

Hazards which become risks: identification of trivial or significant risk; potential to cause harm; choosing appropriate control measures; electrical safety e.g. identify and control hazards, cause of injury, effects of electricity on the body, circuit overloading; mechanical safety e.g. identify and control hazards, cause of injury, rotating equipment, sharp edges; safety devices e.g. residual current device (RCD), fuses, guards, fail safe, sensors

Risk assessments: items/area to be assessed e.g. machine operation, work area; five steps (principal hazards, who is likely to be injured/harmed, evaluation of the risks and decisions on adequacy of precautions, recording findings, review assessment)

Use of control measures: e.g. removing need (design out), use of recognised procedures, substances control, guarding, lifting assessments and manual handling assessments, regular inspection, use of Personal Protective Equipment (PPE), training of personnel, other personal procedures for health, safety and Welfare

Application of aids to lift or move loads, e.g. pinch bars, rollers, skates, pallet trucks, scissor lifts, forklift trucks, wall and overhead cranes; ancillary equipment e.g. block and tackle, pull lifts, slings (chain, rope, polyester), shortening clutches, lifting/plate clamps, eye bolts (dynamo, collar), shackles (dee, bow)

Regulations e.g. Provision and Use of Workplace Equipment Regulations (PUWER), Lifting Operations and Lifting Equipment Regulations (LOLER)

Procedures: Safe Working Loads (SWL) capacity of equipment; 1200 maximum spread on slings when lifting; ensuring clearway and not moving loads over others heads; not transporting people on loads; correct hand signals from floor staff to crane drivers; protection of chains and slings from sharp corners; setting hooks and sling/chain lengths correctly

Storage of gases, oil, acids, adhesives and engineering materials: COSHH regulations; structure of storage buildings, stillages and shelving; control of ventilation, extraction and temperature; good housekeeping and stock management; storage of flammable liquids/compressed gases, oil, acids and adhesives

3 Understand the methods used when reporting and recording accidents and incidents

Principles: why employers keep records of serious accidents, incidents and emergencies; responsibilities of competent persons; cost of accidents e.g. direct, indirect, human consequences; trends e.g. major causes, fatal and serious injury, methods of classification, statistics.

Recording and reporting procedures: regulations on accident recording and reporting e.g. Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995, accident book, company procedures; procedures to deal with near misses or dangerous occurrences.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the key features of relevant regulations on health and safety as applied to a working environment in two selected or given engineering organisations	M1 explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities in a given health and safety situation	D1 assess the extent to which legislation and regulations are satisfied in a given health and safety situation
P2 describe the roles and responsibilities under current health and safety legislation and regulations, of those involved in two selected or given engineering organisations		
P3 explain the key features of the relevant legislation and EU directives with regard to environmental management	M2 explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities with regard to environmental management	

P4 explain the requirements for the safe disposal of waste		
P5 describe the methods used to identify hazards in a working environment	M3 explain how hazards which become risks can be controlled	D2 justify the methods used to deal with hazards in accordance with workplace policies and legal requirements
P6 carry out a risk assessment on a typical item/area of the working environment	M4 explain the importance of carrying out all parts of a risk assessment in a suitable manner	
P7 suggest suitable control measures after a risk assessment has been carried out and state the reasons why they are suitable		
P8 suggest a suitable process or equipment to assist in moving different loads correctly and safely		
P9 describe the precautions needed for the safe storage of gases, oil, acids, adhesives and engineering materials		
P10 explain the principles that underpin reporting and recording accidents and incidents		
P11 describe the procedures used to record and report accidents, dangerous occurrences or near misses.	M5 explain how control measures are used to prevent accidents.	D3 assess the potential costs and implications for the organisation and the individual as a result of an accident in the workplace.

Essential guidance for tutors

Assessment

Evidence of criteria can be collected from case studies, assignments and projects which should enable learners to explore the application of legislation and regulations and hazards and risks in the workplace.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require answers that demonstrate additional depth and/or breadth of treatment.

To achieve a pass, learners must demonstrate an understanding of health, safety and welfare issues as applied to engineering processes and companies. They will need to explain the key features of legislation and regulations and describe a range of roles and responsibilities. They will have an understanding of the connection between hazard identification, risk assessment and accident prevention. Learners will need to carry out a risk assessment, suggest suitable controls and show they understand the principles and procedures for reporting and recording accidents and other occurrences relative to health and safety.

This unit could be assessed through three assignments. The first assignment could have a series of written tasks. The first task could ask learners to research and then explain the key features of relevant regulations as applied to two separate working environments (P1). It would be expected that at least four regulations should be considered across the two selected or given engineering organisations.

Another task could require them to describe the roles and responsibilities of those involved in the environments selected above (P2). The organisations selected could include learners' places of work, or a training workshop or machine shop environment. A combination of one electrical and one mechanical type would be most appropriate. The assignment should cover legislation and regulations. It is not expected that all the legislation and regulations listed in the content would be covered, just those applicable to the given context.

The roles and responsibilities of those involved could include employers, employees, the Health and Safety Executive and any one from the list of others within the unit content. A further task could then be used asking learners to explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities in one of these situations (M1). For the same situation learners could carry out research to assess how the legislation and regulations are satisfied (D1). They might consider reviewing workplace incident/accident records/reports.

P3 and M2 could be achieved using a similar approach and applying this to environmental management. All responses could be in a written format, although for the pass criteria a presentation to the class or annotated poster could be used. In these cases it must be remembered that the presentation skills or poster design skills are not being assessed.

The second assignment could cover P4 to P9 along with the higher criteria M3, M4 and D2. The whole assignment could be based on a practical activity to produce a risk assessment on a typical item or area of a working environment. Again, this working environment could be the learner's workplace or one from the centre's own workshops. Whichever item or area is chosen it should have a range of hazards that can be identified, for example a machining operation or electrical assembly/wiring type activity could be used.

Written tasks would have to be set to give learners opportunities to achieve the explanations required for P4 to P9, M3 and M4, and the justification required for D2. P7 could be achieved through an oral question and answer session after carrying out the risk assessment. A standard template can be used to capture the outcomes of the risk assessment as this is what would be found in normal company use. A witness statement/observation record could be used to show learner performance against the requirement of P6.

The final assignment could cover the remaining criteria P10, P11, M5 and D3, with a written task given for each. Learners should be given opportunities to investigate trends in an area they are interested in, which again may be an area similar to their workplace. The assignment should include a range of data given to each learner, some of which may have been researched and collected during the delivery of this part of the unit content.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Health and Safety Legislation and Regulations	A written activity requiring learners to explain the key features of relevant legislation and regulations and describe the roles and responsibilities of the personnel involved and management.	A report containing written responses about the key features, responsibilities and management of health and safety legislation and regulations set within a relevant context for the learner.
P4, P5, P6, P7, P8, P9, M3, M4, D2	Controlling Hazards and Risks in the Workplace	A practical activity to carry out a risk assessment plus a written report and oral questioning.	A report, carried out under controlled conditions, describing the methods used to identify hazards and how hazards become risks. A written risk assessment of a typical working environment. A report with written responses that identify control measures and their justification. A record of observation by the tutor of the learner's practical risk assessment.
P10, P11, M5, D3	Reporting and Recording Accidents and Incidents	A written activity requiring learners to explain principles of reporting	A report, carried out under controlled conditions, explaining

		accidents, incidents and near misses.	reporting accidents, incidents and near misses.

Essential resources

Learners will require access to a wide range of safety literature. Ideally, the centre will be able to provide access to health and safety legislation and learning materials on DVD.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *Level 3 BTEC National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *Level 3 BTEC National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Health and Safety Executive – *Essentials of Health and Safety at Work* (HSE Books, 2006) ISBN 9780717661794

Health and Safety Executive – *Management of Health and Safety at Work* (HSE Books, 2000) ISBN 9780717624881

Health and Safety Executive – *Health and Safety in Engineering Workshops* (HSE Books, 2004) ISBN 9780717617173

Websites

HSE website www.hse.gov.uk

Unit 2: Communications for Engineering Technicians

Level: 3

Unit type: Mandatory

Assessment type: Internal

Guided learning: 60

Unit introduction

The ability to communicate effectively is an essential skill in all aspects of life. The usual methods of communication – speaking, reading and writing – receive considerable attention and learning time during all stages of education. For engineers, these skills are of no less importance, but there are further complications with the need to also convey technical information such as scale, perspective and standards of working.

The drive towards greater use of information and communication technology (ICT) is also very much a part of modern life and this again is certainly the case for engineering. The engineering industry is in the front line of working towards paperless communication methods, for example the electronic transfer of data from the concept designer straight to the point of manufacture.

This unit will provide a foundation for employment in a wide range of engineering disciplines (for example manufacturing, maintenance, communications technology) in addition to providing a foundation for further study. It aims to develop learners' ability to communicate using a diverse range of methods. These include visual methods, such as drawing and sketching, and computer-based methods, such as two-dimensional (2D) computer aided drawing (CAD) and graphical illustration packages. It will also develop learners' ability to write and speak within a framework of technology-based activities using relevant and accurate technical language appropriate to the task and the audience.

The unit will also introduce learners to a variety of skills and techniques to obtain and use information, for example the presentation of technical reports, business and technical data and the use of visual aids for presentations. Learners will also consider how to make best use of ICT within technological settings that are relevant to their programme of study or area of employment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information
2. Be able to use verbal and written communication skills in engineering settings
3. Be able to obtain and use engineering information
4. Be able to use information and communication technology (ICT) to present information in engineering settings.

Unit content

1. Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information

Interpret: obtain information and describe features e.g. component features, dimensions and tolerances, surface finish; identify manufacturing/assembly/process instructions e.g. cutting lists, assembly arrangements, plant/process layout or operating procedures, electrical/electronic/communication circuit requirements; graphical information used to aid understanding of written or verbal communication e.g. illustrations, technical diagrams, sketches.

Engineering sketches/circuit/network diagrams: freehand sketches of engineering arrangements using 2D and 3D techniques e.g. components, engineering plant or equipment layout, designs or installations; electrical/electronic circuit diagrams, system/network diagrams; use of common drawing/circuit/network diagram conventions and standards e.g. layout and presentation, line types, hatching, dimensions and tolerances, surface finish, symbols, parts lists, circuit/component symbols, use of appropriate standards (British (BSI), International (ISO)).

2. Be able to use verbal and written communication skills in engineering settings

Written work: note taking e.g. lists, mind mapping/flow diagrams; writing style eg business letter, memo writing, report styles and format, email, fax; proofreading and amending text; use of diary/logbook for planning and prioritising work schedules; graphical presentation techniques e.g. use of graphs, charts and diagrams.

Verbal methods: speaking e.g. with peers, supervisors, use of appropriate technical language, tone and manner; listening e.g. use of paraphrasing and note taking to clarify meaning; impact and use of body language in verbal communication.

3. Be able to obtain and use engineering information

Information sources: non-computer-based sources e.g. books, technical reports, institute and trade journals, data sheets and test/experimental results data, manufacturers' catalogues; computer-based sources e.g. inter/intranet, CD ROM-based information (manuals, data, analytical software, manufacturers' catalogues), spreadsheets, databases.

Use of information: e.g. for the solution of engineering problems, for product/service/topic research, gathering data or material to support own work, checking validity of own work/findings.

4. Be able to use information and communication technology (ICT) to present information in engineering settings

Software packages: word processing; drawing e.g. 2D CAD, graphics package; data handling and processing e.g. database, spreadsheet, presentation package, simulation package such as electrical/electronic circuits, plant/process systems; communication e.g. email, fax, inter/intranet, video conferencing, optical and speech recognition system.

Hardware devices: computer system e.g. personal computer, network, plant/process control system; input/output devices e.g. keyboard, scanner, optical/speech recognition device, printer, plotter.

Present information: report that includes written and technical data e.g. letters, memos, technical product/service specification, fax/email, tabulated test data, graphical data; visual presentation e.g. overhead transparencies, charts, computer-based presentations (PowerPoint).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 interpret an engineering drawing/circuit/ network diagram		
P2 produce an engineering sketch/circuit/ network diagram		
P3 use appropriate standards, symbols and conventions in an engineering sketch/circuit/ network diagram		
P4 communicate information effectively in written work	M1 evaluate a written communication method and identify ways in which it could be improved	D1 justify choice of a specific communication method and the reasons for not using a possible alternative
P5 communicate information effectively using verbal methods		
P6 use appropriate information sources to solve an engineering task	M2 review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected	
P7 use appropriate ICT software packages and	M3 evaluate the effectiveness of an ICT	D2 evaluate the use of an ICT presentation

hardware devices to present information.	software package and its tools for the preparation and presentation of information.	method and identify an alternative approach

Essential guidance for tutors

Assessment

Unit 4: Engineering Project could provide an excellent vehicle for an integrated approach to the assessment of this unit. The project work undertaken will require learners to use communication skills to interpret information, prepare sketches and drawings, give presentations, develop and use data sheets, produce technical reports and letters etc. Other units within the programme could also be used to provide effective and relevant learning and formative or even summative assessment opportunities. However, using *Unit 4: Engineering Project* for assessment has the advantage of providing a structured focus for the work and a coherent source of relevant evidence.

To achieve a pass, learners should be able to interpret (P1) and produce (P2) engineering sketches (2D and 3D)/circuit/network diagrams and sketches. This will need to be at a level sufficient for them to understand and communicate technical information. This must include identification and use of appropriate standards, symbols and conventions (P3). The use of 'sketches/circuit/network diagrams' in the criteria P1 and P2 is intended to indicate a choice that will depend on the focus of the learning programme in which this unit is being delivered. For example, an learner on a mechanical programme is likely to choose to interpret and produce sketches of components, whilst an learner studying electrical/electronics is more likely to interpret and produce circuit diagrams.

A single assessment activity could be used to link and capture evidence for the first three pass criteria (P1, P2 and P3). The activity would need to ensure that learners had an opportunity to obtain information, describe features, identify instructions and make use of graphical information (P1). For example, the task could be to work with written operating instructions that include supporting diagrams and sketches (2D and 3D). From the initial investigation, the activity could then require learners to produce their own drawing and sketches (P2). The criterion P3 would need to be applied to both the interpretation (identify) and the production (use) of their working document.

Learners should also be able to use written (P4) and verbal (P5) communication methods. The written work must include evidence of note taking, the ability to use a specific writing style, proofread and amend text, use a diary/logbook and use graphical presentation techniques. It might be that all of these will not necessarily occur in a single task/activity. If not, it would be acceptable for a number of pieces of assessment evidence to be brought together to meet this criterion.

The use of verbal methods (P5) will require learners to demonstrate speaking and listening skills and an understanding of the impact and use of appropriate body language. The evidence for this should come from one task/activity so that all three aspects are being dealt with at the same time. This could be a meeting with either peers and/or a supervisor, or could come from a presentation delivered by the learner to a group.

It would be important to ensure that the learner had to take questions from the group to enable the tutor to capture evidence of their ability to listen. The evidence for this criterion is likely to be a tutor observation record or witness statement.

P6 can be assessed using any structured activity that requires learners to identify and use appropriate information sources to solve an engineering task. It is essential that the information comes from both computer-based and non-computer-based sources. The evidence for this criterion could be as simple as suitably referenced work (a bibliography would not be sufficient).

However, it would be preferable to have a record of the original source and a hard copy, annotated to show the information identified and used for the task (or at least an example of this process).

The final pass criterion (P7), could also be assessed using any relevant tasks that require learners to select and use appropriate ICT software packages and hardware devices to present information. It is essential that the task or tasks chosen for this criterion provide learners with opportunities to use appropriate software to cover all the ICT applications listed in the content, i.e. there must be evidence of learners' selection and use of ICT for word processing, drawing, data handling and communication (such as email). The requirement for hardware devices is limited to the choice and use of a computer system and relevant input/output devices that would be needed for the task carried out. It is expected that the range of information presented using ICT will include a technical report and visual presentation material, for example overhead transparencies, chart, computer-based presentation (PowerPoint).

As already suggested, *Unit 4: Specialist Engineering Project* could provide an excellent vehicle for assessment of this unit since it could provide a central focus and therefore a source of coherent assessment evidence. Any alternatives should try to establish a similar coherence and avoid fragmentation of the pass criteria wherever possible.

To achieve a merit, learners should be able to evaluate a written communication method and identify ways in which it could be improved (M1). This could be learners' own written work or the written work of someone else. The important aspect of this criterion is the learners' ability to use their skills and understanding of communication methods to appraise the work and identify enhancements.

In addition, learners will need to be able to review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected (M2). This criterion is about reflection and the need to carefully consider, measure and express the value (or not) of other people's work as a source of information. Learners need to have identified both non-computer-based and computer-based information sources for P6 and it is this material that they should be reviewing for M2. Achievement might well be implicit if the task undertaken for P6 has reached a satisfactory solution. However, the expected evidence for this criterion would be a copy of the source material used, suitably annotated to explain its value or why it has been rejected.

Finally, merit criterion M3 requires learners to evaluate an ICT software package and its tools for the preparation and presentation of information. This criterion requires learners to have taken time to reflect on their work and consider the use of software tools available (for example good/consistent use of font size/colour, alignment of text, positioning on the page, use of automated labels, legends and titles for graphs).

To achieve a distinction, learners should be able to justify their choice of a specific communication method and the reasons for not using a possible alternative (D1). This could be any communication method that the learner has chosen to use (for example drawings, written, verbal).

It does require learners to have considered at least one possible alternative during the initial selection of the method used. Learners will therefore need to be briefed to collect evidence of this selection process, which might otherwise be lost or ignored (for example initial outlines/drafts, notes of any consultation with others on method to be employed). The key issue for this criterion is learners' ability to reflect and evaluate. At pass level, learners will have shown their ability to communicate information effectively and, at merit, to be critical of the content of their own or other people's work. At distinction level, they should be critical of the choice of communication method used.

D2 requires learners to evaluate their use of an ICT presentation method and identify an alternative approach. This criterion is about the method of presentation and not the method of communication. It also has a direct link with related pass (P7) and merit (M3) criteria. At pass, learners needed to be able to use ICT to present information and, at merit, to evaluate the effectiveness of the presentation. For D2, learners should consider the overall approach taken. For example, could a word-processed technical report have been presented using a computer-based presentation package, such as PowerPoint, including automated routines and animated graphics or video clips? The evidence for this is likely to be a written evaluation. A rough outline illustrating their identified alternative approach or even a small section of the original reworked using an alternative approach could be used to support the written evaluation.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

P1, P2 and P3	Communicating Technical Information	Explore a product/circuit/ network and interpret and prepare appropriate engineering sketches/circuit/ network diagrams.	A written report providing the learner's interpretation of the information and features found. Engineering sketches/circuit/network diagram prepared by the learner.
P4, P5, M1 and D1	Writing, Talking and Listening	A series of tasks focused on written work and verbal communication methods.	A portfolio of evidence containing examples of note taking, writing styles, use of diary/logbook and use of graphical presentation techniques. Tutor observation of speaking, listening and use of body language.

P6, M2	Finding and Using Information	Solving an engineering problem through research and use of information.	A written report with suitable reference to the range of sources found and used including non-computer-based and computer-based resources.
P7, M3, D2	The Use of ICT in Engineering	Presenting engineering information using ICT	A written report on the selection and use of computer hardware devices. A portfolio of evidence of the use of word processing, drawing, data handling and communication software packages to present engineering information.

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Learners should be provided with a variety of sample written materials (letters, memos, technical reports, data sheets, catalogues) and sketches. Centres will need to provide access to appropriate presentation and graphics software (for example Microsoft PowerPoint, Visio), spreadsheet/database software (for example Microsoft Excel/Access) and computer hardware (for example scanners, printers, optical character recognition and speech recognition software, barcode readers).

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 3: Mathematics for Engineering Technicians

Level: 3

Unit type: Mandatory

Assessment type: Internal

Guided learning: 60

Unit introduction

One of the main responsibilities of engineers is to solve problems quickly and effectively. This unit will enable learners to solve mathematical, scientific and associated engineering problems at technician level. It will also act as a basis for progression to study other units both within the qualification, such as the Unit 6: Further Engineering Mathematics for, and at BTEC Higher National level.

This unit enables learners to build on knowledge gained at GCSE and use it in a more practical context for their chosen discipline. Learning outcome 1 will develop learners' knowledge and understanding of algebraic methods, from a look at the use of indices in engineering to the use of the algebraic formula for solving quadratic equations. Learning outcome 2 involves the introduction of the radian as another method of angular measurement, the shape of the trigonometric ratios and the use of standard formulae to solve problems involving surface areas and volumes of regular solids. Learning outcome 3 requires learners to be able to represent statistical data in a variety of ways and calculate the mean, median and mode. Finally, learning outcome 4 is intended as a basic introduction to the arithmetic of elementary calculus.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to use algebraic methods
2. Be able to use trigonometric methods and standard formulae to determine areas and volumes
3. Be able to use statistical methods to display data
4. Be able to use elementary calculus techniques.

Unit content

1. Be able to use algebraic methods

Indices and logarithms: laws of indices ($a^m \, x \, a^n = a^{m+n}, \frac{a^m}{a^n} = a^{m-n}, (a^m)^n = a^{mn}$) laws of logarithms ($\log A + \log B = \log AB, \log A^n = n \log A, \log A - \log B = \log \frac{A}{B}$) e.g. common logarithms (base 10), natural logarithms (base e), exponential growth and decay.

Equations and graphs: linear equations e.g. $y = mx + c$; straight line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line); quadratic graph y= $ax^2 + bx + c$; experimental data e.g. Ohm's law; pair of simultaneous equations in two unknowns (two linear or one linear and one quadratic).

Factorisation and quadratics: multiply expressions in brackets by a number, symbol or by another expression in a bracket; by extraction of a common factor e.g. $ax + ay, a(x + 2) + b(x + 2)$; by grouping e.g. $ax - ay + bx - by$; quadratic expressions e.g. $a^2 + 2ab + b^2$; roots of an equation e.g. quadratic equations with real roots by factorisation, and by the use of formula.

2. Be able to use trigonometric methods and standard formulae to determine areas and volumes

Circular measure: radian; degree measure to radians and vice versa; angular rotations (multiples of π radians); problems involving areas and angles measured in radians; length of arc of a circle ($s = r\theta$); area of a sector ($A = ½ r^2 \theta$)

Triangular measurement: functions (sine, cosine and tangent); sine/cosine wave over one complete cycle; graph of tan A as A varies from 0° and 360° ($tan A = sin A / cos A$); values of the trigonometric ratios for angles between 0° and 360°; periodic properties of the trigonometric functions; the sine and cosine rule; practical problems e.g. calculation of the phasor sum of two alternating currents, resolution of forces for a vector diagram

Mensuration: standard formulae to solve surface areas and volumes of regular solids e.g. volume of a cylinder = $\pi r^2 h$, total surface area of a cylinder = $2\pi rh + 2\pi r^2$, volume of sphere = $\frac{4}{3} \pi r^3$, surface area of a sphere = $4 \pi r^2$, volume of a cone = $\frac{1}{3} \pi r^2 h$, curved surface area of cone = $(\pi r) \, x \, \sqrt{(r^2 + h^2)}$.

3. Be able to use statistical methods to display data

Data handling: data represented by statistical diagrams e.g. bar charts, pie charts, frequency distributions, class boundaries and class width, frequency table; variables (discrete and continuous); histogram (continuous and discrete variants); cumulative frequency curves.

Statistical measurement: arithmetic mean; median; mode; discrete and grouped data.

4. Be able to use elementary calculus techniques

Differentiation: differential coefficient; gradient of a curve $y = f(x)$; rate of change; Leibniz notation ($\frac{dy}{dx}$); differentiation of simple polynomial functions, exponential functions and sinusoidal functions; problems involving evaluation e.g. gradient at a point.

Integration: integration as reverse of differentiating basic rules for simple polynomial functions, exponential functions and sinusoidal functions; indefinite integrals; constant of integration; definite integrals; limits; evaluation of simple polynomial functions; area under a curve e.g. $y = x(x - 3)$, $y = x^2 + x + 4$

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 manipulate and simplify three algebraic expressions using the laws of indices and two using the laws of logarithms		
P2 solve a linear equation by plotting a straight-line graph using experimental data and use it to deduce the gradient, intercept and equation of the line	M1 solve a pair of simultaneous linear equations in two unknowns	D1 solve a pair of simultaneous equations, one linear and one quadratic, in two unknowns
P3 factorise by extraction and grouping of a common factor from expressions with two, three and four terms respectively	M2 solve one quadratic equation by factorisation and one by the formula method	
P4 solve circular and triangular measurement problems involving the use of radian, sine, cosine and tangent functions		
P5 sketch each of the three trigonometric functions over a complete cycle		
P6 produce answers to two practical engineering problems		

involving the sine and cosine rule		
P7 use standard formulae to find surface areas and volumes of regular solids for three different examples respectively		
P8 collect data and produce statistical diagrams, histograms and frequency curves		
P9 determine the mean, median and mode for two statistical problems		
P10 apply the basic rules of calculus arithmetic to solve three different types of function by differentiation and two different types of function by integration.	M3 apply the rules for definite integration to two engineering problems that involve summation	D2 apply graphical methods to the solution of two engineering problems involving exponential growth and decay, analysing the solutions using calculus

Essential guidance for tutors

Assessment

The centre's assessment strategy used will need to cover all the learning outcomes and associated pass criteria but not necessarily all the topics included in the unit content.

Criterion P1 could be assessed in the form of a short written test and could possibly also include criterion P3.

P2 could be assessed through an assignment using data from *Unit: Electrical and Electronic Principles*, which ideally would be delivered concurrently with this unit. If this is not possible, learners should be given a range of data sufficient for them to plot the graph and work out the gradient, intercept and the equation. Data forcing them to draw the line of best fit, as opposed to a set of points directly on the graphical line, might be most appropriate.

For P4, learners could be given a range of different values and assessed by an assignment or a short formal test. The problems given should collectively cover radian, sine, cosine and tangent functions. When considering the content part of this learning outcome it is important that these problems give the learner the opportunity to convert multiples of π radians to degrees and vice versa. The circular measurement problems also need to cover the length of an arc and area of a sector as well as areas and angles measured in radians. Obviously the triangular measurement problems are more basic and only expect application of the three functions.

P5 requires learners to sketch each of the three trigonometric ratios and this is probably best done as a classroom exercise. Similarly, P6 could take the form of a written assignment where learners must produce answers to two practical engineering problems involving the sine and cosine rule (for example calculate the phasor sum of two alternating currents and evaluate the resultant and the angle between two forces).

Criterion P7 requires learners to calculate the surface areas and volumes for three different regular solids. This could be achieved through an assignment or perhaps by combining it with other criteria in a short formal test.

An assignment could be used for P8 where learners collect meaningful data (for example classification of workers within their company) and display this information using different graphical methods (for example bar charts). They also need to produce a histogram and plot frequency curves (for example resistance values of 100 resistors or external diameter of pins).

For P9, learners must provide evidence that they are able to determine and then explain the relevance of the mean, median and mode for a set of discrete and grouped data (for example time taken to produce components on a machine rounded to the nearest ten seconds and the 100 resistor values or diameters of pins from P8). This could be done by an assignment. P10 may be assessed through a short formal test, with learners being given a list of the standard differential coefficients and integrals to use.

For M1, learners will need to provide evidence that they can solve a pair of simultaneous linear equations in two unknowns (for example equations formed after the application of Kirchhoff's laws, power transmitted for different belt tensions in a mechanical system). This could be extended to D1 by the introduction of a quadratic equation to be solved simultaneously with a linear equation.

It would be appropriate to use the same assessment method and instrument as P2, possibly combining these two criteria as one assessment activity.

M2 could also be assessed by assignment as it requires learners to evaluate the roots of a quadratic equation by factorisation and by the formula method (for example evaluation of an equation formed after the realisation of a practical situation).

Both the criteria required to achieve D2 could be assessed through a written assignment. Learners need to apply the graphical methods to the solution of two engineering problems involving exponential growth and decay (for example growth of voltage in a capacitor, radioactive decay, application of Taylor's tool life equation $C = VT^n$) and then analyse the results by applying the appropriate method of differential calculus to check the results.

M3 requires learners to demonstrate that they can accurately evaluate two engineering problems involving definite integration (for example area under a velocity-time graph, area under a voltage-current graph).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

P1, P2, P3, M1, M2	Algebraic Methods	A written activity/test requiring learners to complete five tasks, one for each of the criteria.	A report containing written solutions to each of the five tasks carried out under controlled conditions.
P4, P5, P6, P7	Trigonometric Methods and Standard Formulae	A written activity requiring learners to use trigonometric methods and standard formula to determine areas and volumes.	A report containing the results of calculations, and graphic evidence to support the use of trigonometric methods and standard formula for the determination of areas and volumes

P8, P9	Statistical Methods	A written activity requiring learners to collect and display data using different graphical methods, also evaluate the mean, median and mode for a set of discrete and grouped data.	A report containing bar charts, pie charts and the results of calculations to determine the mean, median and mode for a set of discrete and grouped data
P10, M3, D1,	Calculus Techniques	A written activity requiring learners to produce calculations, graphical solutions and analysis to demonstrate use of calculus techniques.	A report containing the solutions to calculations, graphs and analysis of several calculus techniques. Carried out under controlled conditions.

Essential resources

Learners will need to possess an electronic scientific calculator and have access to software packages that support understanding of the principles and their application to engineering.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Fuller A, Greer A, Taylor G W – *BTEC National Mathematics for Technicians* (Nelson Thornes, 2004) ISBN 9780748779499

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Websites

Science, Technology, Engineering and Mathematics Network – www.stemnet.org.uk

Unit 4: Engineering Project

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 120

Unit introduction

In the modern world engineers and technicians are often involved fully or in part with identifying problems and finding suitable solutions. These engineering problems may range from a very large project, such as designing and building a hydroelectric power station, to smaller projects, such as designing and producing a paper clip to keep notes secure. No matter how large or small, these problems need to be project managed in order to find engineered solutions. This unit will provide learners with opportunities to present their own solutions to engineering projects and should enable them to feel confident in carrying out project work within their chosen engineering discipline at the technician level.

The unit aims to integrate the knowledge and skills learners have gained throughout their programme of study, into a major piece of work that reflects the type of performance expected of an engineering technician. The project is intended to develop the learner's ability to identify and plan a course of action and follow this through to produce a viable solution/outcome to an agreed specification and timescale.

The end result of the project could be an engineering product, device, service or process or a modification to an existing process or product. As in the real world, the outcome of the project and its presentation are very important, although this project is also about developing the process skills necessary to carry out the project. Throughout the project learners will need to apply the technical skills developed in the other units in the qualification.

Learning outcomes

On completion of this unit a learner should:

1. Be able to specify a project, agree procedures and choose a solution
2. Be able to plan and monitor a project
3. Be able to implement the project plan within agreed procedures
4. Be able to present the project outcome

Unit content

1 **Be able to keep records, specify a project, agree procedures and choose a solution**

Project records: written e.g. notes, sketches, drawings; plans and modified plans; targets (setting, monitoring); use of planning tools e.g. paper based, electronic; recording initial concepts e.g. lists, notes, mind mapping, flow diagrams, sketches

Initial concepts: setting limits e.g. time, cost, feasibility, need; value–cost–benefit analysis; generating ideas e.g. group discussion, brainstorming, mind mapping; research techniques; lines of communication

Specification: type of project e.g. product design, plant layout/maintenance, production methods or similar engineering-related topics; technical information e.g. functionality, reliability, operational conditions, process capability, scale of operation, size, capacity, cost, style, ergonomics, present and future trends; health and safety issues; environmental and sustainability issues; quality standards and legislation; timescales; physical and human resource implications

Procedures: roles and responsibilities e.g. decision making, budget planning and control; reporting methods; resource allocation and limits

Techniques: comparison methods e.g. statistical, graphical, quality and resource requirements/limitations, process capability, fitness-for-purpose; analysis e.g. cost–benefit, feasibility

2 **Be able to plan and monitor a project**

Planning: long-term planning e.g. planners, charts and scheduling techniques (flow charts, Gantt charts, critical path methods, software packages); setting priorities; useful resource information e.g. human and physical

Monitoring: monitor and record achievement e.g. use of logbook and/or diary for record keeping (names, addresses, telephone numbers, meeting dates, email and other correspondence lists); use of logbook e.g. for recording and analysing data or performance records, modifying/updating charts/planners, recording project goals and milestones, initial concepts, project solution technical decisions and information

3 **Be able to implement the project plan within agreed procedures**

Implement: proper use of resources e.g. equipment, tools, materials, within agreed timescale, use of appropriate techniques for generating solutions, adapting project plan where appropriate, maintaining appropriate records

Checking solutions: use of evaluative and analytical techniques e.g. graphs, matrix methods, statistics, Gantt charts, sequencing, scheduling, critical path methods, computer software packages

4 **Be able to present the project outcome**

Presentation: deliver a presentation to a small group e.g. audience including known (peer group, tutors) and unknown (actual or simulated customer or client) participants; use of preparation techniques, presentation styles and techniques; preparation and use of visual aids e.g. overhead transparencies, software packages and projectors, charts, models, video/DVD clips

Project report: logbook/diary record of all events; written technical report including relevant drawings/ circuit diagrams, sketches, charts, graphs etc appropriate to the project solution; use of information and communication technology (ICT) as appropriate to present findings e.g. CAD, DTP, spreadsheets, databases, word processing

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 prepare and maintain project records from initial concepts through to solution that take account of and record changing situations	M1 maintain detailed, concurrent records throughout the project that clearly show progress made and difficulties experienced	D1 independently manage the project development process, seeking support and guidance where necessary
P2 prepare a project specification	M2 use a wide range of techniques and selection criteria to justify the chosen option	D2 evaluate the whole project development process, making recommendations for improvements.
P3 agree and prepare the procedures that will be followed when implementing the project	M3 evaluate the project solution and suggest improvements	
P4 use appropriate techniques to evaluate three potential solutions and select the best option for development	M4 present coherent and well-structured development records and final project report.	
P5 outline the project solution and plan its implementation		
P6 monitor and record achievement over the life cycle of the project		
P7 implement the plan and produce the project solution		

P8 check the solution conforms to the project specification		
P9 prepare and deliver a presentation to a small group outlining the project specification and proposed solution		
P10 present a written project report.		

Essential guidance for tutors

Assessment

Assessment of this unit will be based primarily on the learner's logbook/diary and other evidence of the work carried out and the processes adopted. Use will also be made of the learner's specification document, presentation and technical project report.

It should be noted that the logbook/diary is intended to be a working document and should contain the learner's notes and records as they are made at the time. It does not need to be a well-presented/neat document, but should be an effective tool to capture events and information as and when they happen and provide a useful source of reference for the learner when preparing their presentation and final written report. The tutor/project supervisor could also annotate the logbook/diary to indicate and record their observations and interactions with the learner, for example use of ICT, the logical formulation of ideas, use of technical knowledge, analysis and the outcomes/recommendations from these meetings.

Learners will need to include, possibly as an annexe (under separate cover) to the technical report, their own sketches, drawings/circuit diagrams, notes, lists, charts, raw calculations etc. to support their project report findings. Appropriate methods of presentation and management of the total evidence package should be discussed and used by the learner.

Learners may well be working closely with their own company/employer on their project and may be required to adopt the company's own 'house style' for the presentation of the report. This would of course be acceptable, since it will be in line with standard industry practice and report writing protocols and because it is the content of the report (i.e. its technical information, logical presentation methods and coherence) that is assessed, not its style.

Care should be taken to identify learners who may be genuinely terrified of standing in front of a group to make a presentation. The experience of making such a presentation is valuable and is recommended. However, as a minimum, learners only have to make an informal presentation to one or two people (which would reflect the typical minimum required in employment at this level) to achieve the unit.

As many of the activities undertaken by learners will be practical and skills-based, it is important to think about the method of capturing and presenting such evidence for assessment purposes. Often, witness testimony or records of tutor observation will be necessary. Copies of these will need to be placed in the final portfolio of evidence.

In order to achieve P1, learners will need to prepare and maintain project records from initial concepts through to solution that take account of and record changing situations. Evidence could be collected by tutors from the learner's logbook. It is suggested that learners prepare and submit a written project specification for scrutiny in order to provide evidence for the achievement of P2 (i.e. that they have produced a specification to an acceptable standard). As part of the project specification learners could also include written evidence for the procedures (P3) that they have agreed to follow, after discussion with their tutor, when implementing their project solution. Particular emphasis should be placed on ensuring that learners consider budgetary constraints and resource/time limitations. Evidence for the achievement of P4, concerning the evaluation of potential solutions and the techniques used to select the best option, might best be obtained from scrutiny of the learner's logbook, or again form part of the written project specification/interim report.

To achieve learning outcome 2 learners will need to outline their chosen project solution and plan for its implementation (P5), in addition to monitoring and recording achievement over the life cycle of the project (P6). Evidence of achievement will again be through the logbook. Tutors may also wish to record some of this performance as an observation record or use witness statements. The observations might well take place when learners are using computer-aided or manual planning tools in the learning centre. Additional evidence for P6 might come from the annotation of planning documentation or plans in the learner's logbook, that show the changing situations.

Learning outcome 3 is concerned primarily with the implementation of the project solution while adhering to agreed procedures (P7) and checking throughout the implementation phase that the solution produced conforms with the project specification (P8). The type of project chosen by the learner will, to a degree, dictate the methods used to provide evidence of achievement. Learners who are engaged on design/build or physical testing/modification type projects on a system or component, will be spending most of their project implementation phase in workshops and/or laboratories. Therefore, tutors will need evidence from observation records and from the physical solution itself. Evidence of achievement of P7 for those learners engaged in the production of a modified procedure/service, will provide evidence of achievement via their logbook records, presentation and final written report.

No matter what type of project learners choose, the primary source of evidence for achievement of P8 is likely to be the learner's logbook, where comparisons can be made with the agreed procedures to see whether or not learners abided by these procedures when producing their project solution.

In order to meet learning outcome 4, learners will need to prepare and deliver a presentation outlining their project specification and proposed solution to a small group (P9) and present a written project report with supporting documentation (P10). Evidence for P9 will be obtained from a combination of hard copies of the presentation, such as handouts, slides etc. and witness statements, together with the results of observation records from those present. The evidence for the achievement of P10 will come from the written report itself. Clear guidelines as to what is expected need to be given to learners well before the submission of their report.

To achieve M1, learners need to be able to work with greater autonomy and will have produced, and kept to, a workable plan. This will be demonstrated by their ability to maintain records throughout the project that are detailed, concurrent and clearly show progress made and the difficulties experienced. For M2 learners will need to have arrived at their project choice having used a wide range of techniques and from the use of these be able to justify their chosen option. The range of techniques used will need to show both statistical and graphical comparison methods for the potential solutions. Evidence will come from the learner's logbook and/or from the submitted written specification/interim report, (as was the case for achievement of P3).

Evidence for the achievement of M3 will come from observation records (particularly for design and build type solutions), scrutiny of logbook records and from the learner's reflections, written in the final report. It is expected that having evaluated their solution against the specification and/or from field evaluation and customer feedback, learners will then be able to suggest improvements that genuinely enhance the value of their project solution. Learners will have to present coherent and well-structured development records and final project report to achieve M4. The report structure is expected to adhere to standard technical report writing protocols, in order to achieve the criteria. The development records are likely to be included, as part of the learner's logbook and this should be submitted for final scrutiny, at the same time as the report.

To achieve a distinction, learners will have been able to work consistently towards a successful outcome and in doing so they will have independently managed the project development process, seeking support and guidance where necessary (D1). They will have shown the ability to reflect on their work throughout the project. Through this, they will have been able to evaluate the whole of the project development process and provide suggestions as to what they would have done differently to make improvements (D2). The evidence for both criteria is likely to come from the logbook and portfolio notes with the addition of witness statements and observation records for D1 and a separate written statement or statement in the final report, clearly evaluating the project making recommendations for improvements for D2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

P1, M1	Prepare and maintain project records	Tutor to scrutinise learner's project records and/or have completed observation record or have available independent witness testimony.	Through scrutiny of learner's logbook, observation records and/or witness testimony. Detailed and concurrent records need to be demonstrated to achieve M1.
P2, P3, P4, M2	Project specification and selection of best project option	Tutor to consider submitted work and scrutinise learner records and/or take account of observation records or witness testimony.	Marked submission of project specification to acceptable standard, including written procedures to be adopted and evidence for the evaluation of solution. A wide range of statistical and graphical comparison methods

			demonstrated to meet criterion M2.
P5, P6	Production of project plan and monitor project over its lifecycle	Tutor to scrutinise project records and take account of observation records or witness testimony	Scrutinise learner's long-term plans and logbook, identify and sanction achievement and changes made to plan, over the life of the project.
P7, P8, M3	Implement the project and produce the project solution	Tutor to observe leaner progress in the implementation of project plan and in the production of project solution.	Through scrutiny of learner's logbooks and observation records for implementation of project solution and written/ observational evidence for evaluation of solution in order to meet M3 criterion.
P9, P10, M4	Presenting the project outcome	Observation of oral presentation and consideration of written report and other project records and deliverables.	Through observation records and written oral presentation material and the marking of the final written report and consideration of all other project deliverables. Identification of well-structured and coherent development records and final report in order to meet M4.
D1, D2	Independently manage and critically evaluate the whole project	Tutor/supervisor observation records or independent witness statements and take account of learners project records and	Scrutinise learner's logbook and take account of observation records (D1) and mark written submission (D2).

		written submissions.	

Essential resources

Learners will need access to a wide variety of physical resources, dependent on the type of project they pursue. Many of these resources are detailed within the other units in the qualification. There is also a need to provide some form of access to audio-visual aids as well as access to libraries and computer aided learning centres. Learners may also require access to workshops, laboratories and specialist catalogues and other documentation. Centres should also subscribe to engineering journals and stock other useful literature, specific to the branches of engineering being covered.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Lock D – *Project Management* (Gower Publishing, 2007) ISBN 9780566087721

Melton T– *Project Management Toolkit, the Basics for Project Success* (Butterworth-Heinemann, 2007) ISBN 9780750684408

Melton T– *Real Project Planning: Developing a Project Development Strategy* (Butterworth-Heinemann, 2007) ISBN 9780750684729

Project Management Institute – *A Guide to the Project Management Body of Knowledge* (Project Management Institute, 2009) ISBN 9781933890517

Smith N J – *Engineering Project Management* (Blackwell Publishing, 2007) ISBN 9781405168021

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 5: Calculus to Solve Engineering Problems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Many of the products, components and systems that we use have been subject to a rigorous design process that will have involved the use of calculations involving mathematical calculus. During design it is important to be able to predict how a product will perform in service, for example the handling characteristics of a car or the power output from an electrical power supply. Also, investing time and resources in setting up manufacturing machinery and supply chains is very expensive – working with formulae and numbers on paper or using a computer involves a lot less cost and allows engineers to determine optimal (or near optimal) solutions.

In this unit, you will investigate how to apply differential and integral calculus methods to solve engineering problems. You will learn about the rules and procedures of calculus mathematics to obtain solutions to a variety of engineering problems. You will solve a complex problem from your specialist area of study and perhaps from a local organisation by breaking it down into a series of linked manageable steps. Each step will be solved using calculus methods learned through investigation and practice. These mathematical skills are transferable and will be used to support your study of other topics in the BTEC Nationals in the engineering programme, for example in mechanical principles and electrical systems.

As a future engineer you will need to understand and develop the skills required to solve problems using calculus and other mathematical procedures. This unit will prepare you well for progressing to higher education to study for an engineering degree or a Higher National Diploma. It will also help prepare you for an apprenticeship or employment in a range of engineering disciplines as a technician, and will help you work with professional engineers as part of a team working on cutting edge products and systems.

Learning outcomes

On completion of this unit an apprentice should:

1 Examine how differential calculus can be used to solve engineering problems

2 Examine how integral calculus can be used to solve engineering problems

3 Investigate the application of calculus to solve a defined specialist engineering problem.

Unit content

1 **Examine how differential calculus can be used to solve engineering problems**

Functions, rate of change, gradient

- Function notation, e.g. $y = f(x)$, $s = f(t)$, $Q = f(t)$
- Types of functions: polynomial, trigonometric (sine, cosine), logarithmic and exponential.
- Routine functions are differentiated in one step without the need for manipulation, using standard calculus methods and/or are not applied to an engineering context, including:
  - polynomial e.g. $s = 5t^2 - 3t + 4$
  - trigonometric (sine, cosine) e.g. $y = \sin^2 4x$
  - logarithmic, e.g. $v = 8\log_e(5x)$
  - exponential, e.g. $y = 2e^{(3x+5)}$
- Non-routine functions are differentiated in more than one step requiring manipulation, using standard calculus methods and/or may be applied to an engineering context, including:
  - polynomial e.g. $I = \left(\frac{z+3}{5-4z}\right)$
  - trigonometric (sine, cosine) e.g. $v = (\sin 2t \cos 3t)$
  - logarithmic, e.g. $y = 5x^2\log_e(3x)$
  - exponential, e.g. $v = [5e^{3t}(2t^2 - 3)]$
- Expanding or simplifying polynomial functions.
- Rate of change of a function.
- Graphical representation of a function.
- Gradient of a function – graphically by tangent.
- Time-based functions – e.g. velocity, charge rate, energy transfer.

Methods of differentiation

- Gradient of a function.
- Small change in a quantity.
- Differentiation from first principles to produce the limiting value (derivative) of a simple power function e.g. $y = 2x^2$
- Leibniz notation ($\frac{dy}{dx}$) for representing the derivative of a function.
- Engineering notation for the derivative, e.g. ($\frac{ds}{dt}$), ($\frac{dQ}{dt}$)
- Independent variable and the coding method 'with respect to' (w.r.t).
- Differentiation by standard results ($y = ax^n$, where $\frac{dy}{dx} = nax^{(n-1)}$).
- The derivatives of algebraic (power), trigonometric (sine, cosine), logarithmic and exponential functions (ax^n, $\sin ax$, $\cos ax$, $\log_e(ax)$, e^{ax}).
- Product and quotient rules – $\frac{dy}{dx} = \frac{vdu}{dx} + \frac{udv}{dx}$, $\frac{dy}{dx} = (\frac{vdu}{dx} - \frac{udv}{dx}) / v^2$
- Function of a function (chain rule) method.
- Substitution method.

Numerical value of a derivative

- Substitution of numerical vales into the expression for the derivative.
- Instantaneous gradient at a point on a curve.

- Positive, negative and zero values for gradients.
- Gradient values obtained analytically and graphically.
- Engineering examples of rate of change, e.g. velocity/acceleration of a moving object, rate of charge/discharge of a capacitor, heat flow, radioactive decay, cutting tool life, charge/discharge rate for an air receiver, hydraulic flow rates.

Second derivative and turning points

- Leibniz notation for second derivative ($\frac{d^2y}{dx^2}$)
- Second derivative of algebraic (polynomial) and trigonometric (sine, cosine) functions.
- Turning points on a function.
- Graphical representation of an algebraic function with two turning points e.g. $y = x^3 - 5x^2 + 2x + 6$
- Maximum (max), minimum (min) turning points, inflection point.
- Second derivative test for max/min points on a function.
- Numerical value of the dependent variable at the max/min points of a function.
- Engineering applications, e.g. maximising the volume of a container for a given surface area, minimising the cost of mass producing components on a machine tool, resistance matching in electrical power circuits to achieve maximum power transfer.

2 **Examine how integral calculus can be used to solve engineering problems**

Integration as the reverse/inverse of differentiation

- Symbolic representation $\int()dx$
- Algebraic expressions and the constant of integration.
- Types of functions: polynomial, trigonometric (sine, cosine), reciprocal and exponential.
- Routine functions are integrated in one step without the need for manipulation, using standard calculus methods and/or are not applied to an engineering context, including:
  - polynomial, e.g. $\int(x^2 - 3x + 4)dx$
  - trigonometric (sine, cosine), e.g. $\int(\sin 5\theta - 3\cos 4\theta)d\theta$
  - reciprocal, e.g. $\int(\frac{3}{x})dx$
  - exponential, e.g. $\int(e^{3t})dt$
- Non-routine functions are integrated in more than one step requiring manipulation, using standard calculus methods and/or may be applied to an engineering context, including:
  - polynomial, e.g. $\int x^2(x^3 + 5)^2dx$
  - trigonometric (sine, cosine), e.g. $\int(\frac{\cos\theta}{1-\sin\theta})d\theta$
  - exponential, e.g. $\int e^t \cos t dt$
- Integration of common functions by standard results – ax^n, $\sin ax$, $\cos ax$, $\frac{1}{x}$, e^{ax}
- Indefinite integrals, constant of integration, initial conditions.
- Definite integrals – limits and square bracket notation.
- Integration by substitution.
- Integration by parts.

Integration as a summating tool

- Area under a curve from first principles – strip theory (approximate area of the elemental strip= $y\delta x$).
- Area under a curve as a summation between the upper and lower limits applied to the function.
- Mean value and root mean square (RMS) value of periodic functions.
- Engineering applications, e.g. work done by force producing displacement of an object, distance travelled by a vehicle, mean and RMS values of waveforms in electrical circuits.

Numerical integration

- Trapezoidal rule, mid-ordinate rule, Simpson's rule – comparison of methods in terms of their complexity and accuracy.
- Area under a curve obtained by integrating its function – comparison with the value obtained using Simpson's method.
- Numerical integration using a spreadsheet.
- Engineering applications, e.g. determination of mechanical, electrical and thermal energy.

3 **Investigate the application of calculus to the solution of a defined specialist engineering problem**

Thinking methods

- Reductionism – considering a complex problem as the sum of its elements/parts or breaking a problem down into its parts.
- Synetics – creativity in mathematics, idea generating methods.
- Logical thinking – coherent and logical approach to solving a problem, e.g. Polya's problem solving method.

Mathematical modelling of engineering problems

- Analytical methods.
- Numerical methods.
- 'What if' repetitive calculation, 'goal seek'.
- Benefits of using mathematical modelling, e.g. design viability, structural integrity of a product, accurate prediction of how a new product will perform in service, cost benefit of accurate simulation, e.g. in the design of aircraft.
- Engineering applications, e.g. mechanical design, stress analysis, performance calculation for an electronic or fluid powered hydraulic circuit.

Problem specification and proposed solution

- Applied thinking methods to understand a given engineering problem.
- Mathematical modelling to devise a method to solve the given engineering problem.

Solution implementation

- The use of calculus and other appropriate mathematical methods to solve the given engineering problem.
- Reflection on the problem solving process and the solution obtained and make refinements if necessary.
- Presentation of the solution to the given engineering problem.

Assessment and grading criteria

In order to pass this unit, the evidence that the apprentice presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 find the first and second derivatives for each type of given routine function P2 find, graphically and analytically, at least two gradients for each type of given routine function P3 find the turning points for given routine polynomial and trigonometric functions	M1 find accurately the graphical and analytical differential calculus solutions and, where appropriate, turning points for each type of given routine and non-routine function and compare the results	D1 evaluate, using technically correct language and a logical structure, the correct graphical and analytical differential calculus solutions for each type of given routine and non-routine function, explaining how the variables could be optimised in at least two functions
P4 find the indefinite integral for each type of given routine function P5 find the numerical value of the definite integral for each type of given routine function P6 find, using numerical integration and	M2 find accurately the integral calculus and numerical integration solutions for each type of given routine and non-routine function, and find the properties of periodic functions	D2 evaluate, using technically correct language and a logical structure, the correct integral calculus and numerical integration solutions for each type of given routine and non-routine functions, including at least two set in an engineering context

integral calculus, the area under curves for each type of given routine definitive function		
P7 define a given engineering problem and present a proposal to solve it P8 solve, using calculus methods and a mathematical model, a given engineering problem	M3 analyse an engineering problem, explaining the reasons for each element of the proposed solution M4 solve accurately, using calculus methods and a mathematical model, a given engineering problem	D3 critically analyse, using technically correct language and a logical structure, a complex engineering problem, synthesising and applying calculus and a mathematical model to generate an accurate solution.

Essential guidance for tutors

Assessment

For P1, apprentices will apply the correct skills and methods when differentiating at least six given routine mathematical functions. Apprentices will correctly manipulate at least two polynomial, two trigonometric, one logarithmic and one exponential. Some functions will be sufficiently complex to enable apprentices to select and apply the correct method (product, quotient, function of a function and substitution) when producing first and second derivatives.

Apprentices will demonstrate that they can find, graphically and analytically, at least two gradients for each type of function, for P2. For the polynomial and trigonometric functions, apprentices will calculate the turning points in the context of rates of change, for P3.

Overall, apprentices must be able to demonstrate the correct use of method when differentiating functions and use the correct units. Minor arithmetic and scaling errors are acceptable. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'. Graphical presentation of functions and determination of their gradients can be done using a spreadsheet provided that formulae are visible (printed out).

For P4, P5 and P6, apprentices will demonstrate mastery in the application of integral calculus methods to the solution of given problems using mathematical functions. Apprentices will correctly and efficiently manipulate eight routine and three non-routine functions.

Apprentices must present reasoned arguments when evaluating the use of analytical and numerical integration methods on at least two non-routine functions, for example, finding work done by expressing parameters as a definite integral and then repeating the operation using Simpson's rule.

Overall, the logically structured evidence will be easy to understand by a third party with a mathematical background who may or may not be an engineer and there will be correct use of mathematical terminology. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Apprentices will work to a specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

For P7 and P8, apprentices will present the solution of a given complex engineering problem. The solution may not be complete, and there may be some inaccuracies or omissions, but there should be evidence of some proficiency in the use of differential and integral calculus. For example, apprentices solving a dynamics problem based on the acceleration and energy transfers involved with a moving vehicle would be expected to determine the maximum accelerating force and work done getting the vehicle up to given velocity.

Overall, the report should be logically structured and contain commentary on each stage of the solution. Rules of differentiation and integration should be applied correctly. It may contain some minor arithmetic errors, for example the value of a definite integral may be incorrect though the indefinite integral has been correctly deduced and the method chosen may not be optimal, for example expanding a function such as to integrate rather than using a substitution method. Minor 'carry through' errors are acceptable and there will be an appreciation of correct use of units, but there may be errors in their application.

For M1, apprentices will apply the correct skills and methods when producing the derivatives of functions and evaluating their gradients. Apprentices will correctly manipulate, six routine and six non-routine functions (four polynomial, four trigonometric, two logarithmic and two exponential). Apprentices will compare the results, obtained graphically and analytically, for the two gradients being investigated, for example, there will be discussion about the numerical accuracy of the two methods.

Overall, apprentices' numerical work will be accurate, using an appropriate degree of precision as specified by the assessor in significant figures or decimal places, and relevant units will be used for all functions. Limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For M2, apprentices will apply the correct skills and methods when producing the integrals of functions and determining the properties of periodic functions. Apprentices will correctly manipulate eight routine and three non-routine definitive functions. At least eleven functions in total, including a polynomial, a trigonometric and an exponential non-routine function.

Numerical integration will have been accurately completed for four definitive routine functions.

Overall, apprentices' numerical work will be accurate, using an appropriate degree of precision as specified by the assessor in significant figures or decimal places, and relevant units will be used for all functions. Limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For M3 and M4, apprentices will produce a reasoned analysis of a complex engineering problem, breaking it down into planned stages to obtain a solution. The method will apply differential and integral calculus appropriately at each stage, and the resulting solution will be of an acceptable degree of accuracy (as determined by the assessor).

Overall, the evidence will be logically structured, be technically accurate and easy to understand. The planned method may contain some simplification and approximations to allow a solution to be calculated. Rules of differentiation and integration should be selected and applied correctly, for example using a substitution method to integrate terms rather than by expansion.

For D1, apprentices will demonstrate mastery in the application of differential calculus methods to the solution of given problems using mathematical functions. Apprentices will correctly and efficiently manipulate six routine and six non-routine functions.

A reasoned and balanced evaluation (argument) will be presented when considering how variables can be optimised for at least two non-routine functions related to an engineering context, for example, determining the dimensions of a container of given volume so that its surface area is minimised, thereby minimising the material cost and environmental impact of the container.

Overall, the evidence will be logically structured and will be easy to understand by a third party, with a mathematical background, who may or may not be an engineer. For example, apprentices will use mathematical terminology correctly and use relevant units when working with functions set in engineering contexts. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Apprentices will work to a specified numerical precision (as determined by the assessor), through the use of appropriate significant figures or decimal places.

For D2, apprentices will demonstrate mastery in the application of integral calculus methods to the solution of given problems using mathematical functions. Apprentices will correctly and efficiently manipulate eight routine and three non-routine functions.

Apprentices must present reasoned arguments when evaluating the use of analytical and numerical integration methods on at least two non-routine functions, for example, finding work done by expressing parameters as a definite integral and then repeating the operation using Simpson's rule.

Overall, the logically structured evidence will be easy to understand by a third party with a mathematical background who may or may not be an engineer and there will be correct use of mathematical terminology. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Apprentices will work to a specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

In order to achieve D3, apprentices will demonstrate mastery in the application of calculus methods to the solution of a complex engineering problem. The identified problem must be sufficiently complex to allow apprentices to apply thinking methods, mathematical modelling and both differential and integral calculus methods to the solution of the problem. Apprentices must show that they are able to break a complex problem down into a series of manageable steps through the application of reductionism and logical thinking.

Apprentices will produce a full specification for the problem, based on gathered and given information and use this to produce a proposal; there must be evidence that this has been done before they embark on the mathematical manipulations. Evidence for this could be supported by an assessor observation record.

Overall, the evidence will be straightforward to understand by a third party with a mathematical background who may or may not be an engineer and there will be correct use of mathematical terminology and the application of relevant units. Small and large numerical values will be correctly presented in an appropriate format, i.e. engineering notation. Apprentices will work to specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

Mathematical methods will be applied efficiently to the solution of the problem, for example using a logical approach to the solution and/or efficient use of a spreadsheet for a numerical analysis.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

P1, P2, P3, M1, D1	Using differential calculus to solve engineering problems	An activity requiring apprentices to apply differential calculus methods to solve an engineering problem	A report containing the results of apprentices' analysis and calculation; carried out under controlled conditions.
P4, P5, P6 M2, D2	Using integral calculus to solve engineering problems	An activity requiring apprentices to apply integral calculus methods to solve an engineering problem	A report containing the results of apprentices' analysis and calculation; carried out under controlled conditions.
P7,P8, M3, M4, D3	Applying calculus to the solution of a specialist engineering problem	An activity requiring apprentices to apply calculus methods to solve a specialist engineering problem	A report containing the results of apprentices' analysis, planning and calculation; carried out under controlled conditions.

Essential resources

Apprentices will need access to maths support websites, spreadsheet software, e.g. http://www.mathcentre.ac.uk/students/topics/

Indicative reading for apprentices

Textbooks

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Greer A, Taylor G W – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005) ISBN 9780748794102

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 6: Further Engineering Mathematics

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

Mathematics can be used to evaluate the intended and actual performance of a product or system at every stage of its lifecycle. For example, mathematics may be used during the design of a product to determine whether it performs to specification. Statistics may be used during manufacturing processes as part of the quality control (QC) system and to determine the in-service reliability of the product. Statistics can also be used to evaluate the vast amounts of data that can be gathered about products and customers using mobile communications and the Internet of Things (IoT).

In this unit you will use algebraic techniques to solve engineering problems involving sequences, series, complex numbers and matrices; these topics support other. You will investigate the use of statistics as a data-processing and analysis tool. For example, applying techniques used by a quality assurance engineer to monitor the output from a manufacturing process.

As a future engineer you will need to understand and develop skills to solve problems using algebraic and statistical procedures. These are transferable skills and you will use them to support your study of other units in this course. This unit will help to prepare you for an apprenticeship or for employment in a range of engineering disciplines as a technician. You could also progress to a higher-level course, such as an HND or a degree in an engineering discipline.

Learning outcomes

On completion of this unit a learner should:

1 Examine how sequences and series can be used to solve engineering problems

2 Examine how matrices and determinants can be used to solve engineering problems

3 Examine how complex numbers can be used to solve engineering problems

4 Investigate how statistical and probability techniques can be used to solve engineering problems.

Unit content

1 Examine how sequences and series can be used to solve engineering problems

Arithmetic and geometric progressions

Definitions:

sequence as an ordered collection of numbers *a*, *b, c, d*

progression as a sequence that increases in a particular pattern, i.e. there is a constant relationship between a number and its successor

series as the sum of the values in a sequence *a* + *b* + *c* + *d …*

terminology – first term *a*, last term *l*, connection by law

- Routine operations involve:

Arithmetic progression (AP):

common difference *d*

general expression for a sequence in AP *a*, (*a* + *d*), (*a* + 2*d*), (*a* + 3*d*), …. (*a* + *nd*)

nth term (last term) *l* = *a* + (*n* – 1)*d*

sum of an AP to nth term (arithmetic series)

$$s=a+(a+d)+(a+2d)+\ldots(l-d)+l=\frac{1}{2}n(a+l)$$

Geometric progression (GP):

common ratio r

general expression for a sequence in GP a, ar, ar^2, ar^3, …, ar^n

$$s=a+ar+ar^2+ar^3+\ldots ar^n=\frac{a(1-r^n)}{(1-r)}$$

- sum of a GP to nth term (geometric series)

convergence

sum to infinity.

- Non-routine operations involve:

engineering applications, e.g. lathe spindle speeds, cost of deep drilling, depreciation costs of capital equipment, gear box ratios, manufacturing estimating.

Binomial expansion

- Definitions:

binomial expression that takes the form (*a* + *b*)^n

binomial theorem: when *n* is a positive integer

$$(a+b)^n=a^n+na^{n-1}b+\frac{n(n-1)}{2!}a^{n-2}b^2+\frac{n(n-1)(n-2)}{3!}a^{n-3}b^3+\ldots+b^n$$ (a finite series)

which can be written as $$(a+b)^n=\sum_{k=0}^{k=n}{}_nC_k\,a^{n-k}b^k$$ where $${}_nC_k=\frac{n!}{(n-k)!\,k!}$$

alternative form $$(1+x)^n=1+nx+\frac{n(n-1)}{2!}x^2+\frac{n(n-1)(n-2)}{3!}x^3+\ldots+x^n$$

binomial theorem when *n* is not a positive integer:

$$(1+x)^n = 1+nx+\frac{n(n-1)}{2!}x^2+\frac{n(n-1)(n-2)}{3!}x^3+...+x^n$$ for $-1<x<1$ only (an infinite series)

- Routine operations involve:
  construction of Pascal's triangle
  expansion of $(a + b)^n$ for positive values of n using Pascal's triangle.
- Non-routine operations involve:
  expansion of $(1 + x)^n$ for non-positive integer values of n using the binomial theorem
  calculation of the nth term using the binomial theorem
  engineering applications, e.g. small errors, small changes, percentage changes, approximation of errors.

Power series

- Definitions:
  - a power series as $f(x) = a_0 + a_1x + a_2x^2 + a_3x^n + ... + a_nx^n$
  - Taylor series as $f(x) = f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + ... + \frac{f^{(n)}(a)}{n!}(x-a)^n$
- Routine operations involve:
  Maclaurin series as Taylor series with $a = 0$
  convergence and divergence
  conditions for convergence and divergence
- Non-routine operations involve:
  numerical value for e using a power series
  proof that $\frac{dy}{dx}(e^x) = e^x$ using series
  engineering applications, e.g. error in area or volume for small error in measurement of length, oscillator frequency for an electrical circuit if components have small errors in their values.

2 Examine how matrices and determinants can be used to solve engineering problems

Matrices

- Definitions:
  matrix type – element and order (row x column)
  matrix terminology – element, row, column, order (row × column), equality, zero (null matrix), identity (unit) matrix, transpose, square, leading diagonal, triangular
- Routine operations involve:
  addition, subtraction, multiplication by a real number
  inverse of a (2 × 2) matrix
  solution of sets of simultaneous equations with 2 variables using inverse matrix methods
- Non-routine operations involve:
  multiplication of matrices

solution of sets of simultaneous equations with 2 variables using Gaussian elimination.

Determinants

- Definitions:
- the determinant of a matrix as a useful value that can be computed from the elements of a square matrix, denoted by $\det(A)$ or $|A|$
- a singular matrix is one with determinant $|A| = 0$
- Routine operations involve:
- determinant of a (2 × 2) matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using $|A| = ad - bc$
- inverse of a 2-dimensional matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using $A^{-1} = \frac{1}{|A|}\begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$
- Non-routine operations involve:
- determinant of a (3 X 3) matrix $A = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$ using $|A| = a\begin{pmatrix} e & f \\ h & i \end{pmatrix} - b\begin{pmatrix} d & f \\ g & i \end{pmatrix} + c\begin{pmatrix} d & e \\ g & h \end{pmatrix}$

use of Cramer's Rule to solve for sets of simultaneous equations with 2 variables

engineering applications, e.g. simultaneous linear equations with more than 2 variables (electrical circuits, vector arrays, machine cutter paths).

3 Examine how complex numbers can be used to solve engineering problems

Complex numbers

- Definitions:

algebraic form (Cartesian, rectangular notation) (*a* + *jb*)

real part, imaginary part, j notation, , j-operator, powers of j

- modulus $|a + jb| = \sqrt{a^2 + b^2}$
- argument $\arg(a + jb) = \tan^{-1}\left(\frac{b}{a}\right)$

polar form $r\angle\theta$, □ is usually expressed in radian but may be in another angular measure

complex conjugate of $y = a \pm jb$ as $y^* = a \mp jb$

- Routine operations involve:

placement of complex numbers on an Argand diagram

addition and subtraction in rectangular form

multiplication by a constant coefficient conversion between rectangular and polar forms ($r \to p \text{ and } p \to r$) using trigonometry and scientific calculator

multiplication and division of complex numbers in polar form.

- Non-routine operations involve:

  multiplication in rectangular form

  division in rectangular form using the complex conjugate

  de Moivre's theorem $(r\angle\theta)^n = r^n \angle n\theta$

  engineering applications, e.g. vectors, electrical circuit phasor diagrams, algebraic form (Cartesian, rectangular notation) (*a* + *jb*)

  real part, imaginary part, *j* notation, *j*-operator, powers of *j*

  - modulus $|a + jb| = \sqrt{a^2 + b^2}$
  - argument $\arg(a + jb) = \tan^{-1}\left(\frac{b}{a}\right)$

  polar form $r\angle\theta$, ☐ is usually expressed in radian but may be in another angular measure

  complex conjugate of $y = a \pm jb$ as $y^* = a \mp jb$

- Routine operations involve:

  placement of complex numbers on an Argand diagram

  addition and subtraction in rectangular form

  multiplication by a constant coefficient

  conversion between rectangular and polar forms ($r \to p \text{ and } p \to r$) using trigonometry and scientific calculator

  multiplication and division of complex numbers in polar form.

- Non-routine operations involve:

  multiplication in rectangular form

  division in rectangular form using the complex conjugate

  de Moivre's theorem $(r\angle\theta)^n = r^n \angle n\theta$

  engineering applications, e.g. vectors, electrical circuit phasor diagrams.

4 Investigate how statistical and probability techniques can be used to solve engineering problems

Statistical techniques

- Routine operations involve:

  discrete data, continuous data, ungrouped data, grouped data, rogue values

  presentation of data: bar charts, pie charts, histogram, cumulative frequency curves

  measures of central tendency (location): arithmetic mean, median, mode

  measures of dispersion: variance, standard deviation, range and inter-percentile ranges

  linear relationship between independent and dependent variables, scatter diagrams, approximate equation of line of regression $y = mx + c$ graphically.

- Non-routine operations involve:

  equation of linear regression line $y = mx + c$ where

$$m = \frac{N\sum_{1}^{N}(x_i y_i) - \sum_{1}^{N}(x_i)\sum_{1}^{N}(y_i)}{N\sum_{1}^{N}x_i^{\,2} - \left(\sum_{1}^{N}x_i\right)^2} \quad \text{and} \quad c = \bar{y} - m\bar{x}$$

$$\bar{x} = \frac{\sum_{1}^{N}x_i}{N} \quad \text{and} \quad \bar{y} = \frac{\sum_{1}^{N}y_i}{N}$$

correlation coefficient using Pearson's correlation

$$r_{x,y} = \frac{N\sum_{1}^{N}x_i y_i - \sum_{1}^{N}x_i \sum_{1}^{N}y_i}{\sqrt{N\sum_{1}^{N}x_i^{\,2} - \left(\sum_{1}^{N}x_i\right)^2} - \sqrt{N\sum_{1}^{N}y_i^{\,2} - \left(\sum_{1}^{N}y_i\right)^2}}$$

- Use of spreadsheets and/or scientific calculators to calculate equation of the line of regression and correlation coefficient, e.g. tabulating calculations, using trendline and CORREL() functions in a spreadsheet, or a standard scientific calculator.
- Use of spreadsheets and/or scientific calculators to identify the most appropriate type of regression line, e.g. linear, logarithmic, exponential or variable power.

Probability distributions

- Routine operations involve:

  Normal distribution – shape and symmetry, skew, tables of the cumulative distribution function, mean, variance.

  Normal distribution curve – areas under it relating to integer values of standard deviation.
- Non-routine operations involve:

  confidence intervals for normal distribution and probability calculations.

Statistical investigation

- The use of appropriate mathematical methods to solve the given engineering problem.
- Engineering applications, e.g. inspection and quality assurance, calculation of central tendencies and dispersion, forecasting, reliability estimates for components and systems, customer behaviour, condition monitoring and product performance.
- Reflection on the problem-solving process and the solution obtained and make refinements if necessary.
- Presentation of the solution to the given engineering problem.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 solve given problems using routine arithmetic and geometric progression operations	M1 solve accurately given problems using routine and non-routine arithmetic and geometric progression operations	D1 evaluate, using technically correct language and a logical structure, engineering problems using non-routine sequence and series operations, while solving accurately all the given problems using routine and non-routine operations
P2 solve given problems using routine power series operations	M2 solve accurately given problems using routine and non-routine power series operations	D2 evaluate, using technically correct language and a logical structure, engineering problems using non-routine matrices, determinant and complex operations, while solving accurately all the given problems using routine and non-routine operations
P3 solve given problems using routine matrices and determinant operations	M3 solve accurately given problems using routine and non-routine matrices and determinant operations	

P4 solve given problems using routine complex number operations	M4 solve accurately given problems using routine and non-routine complex number operations	
P5 solve an engineering problem using routine central tendency, dispersion and probability distribution operations	M5 solve accurately an engineering problem using routine and non-routine central tendency, dispersion and probability distribution operations, providing an explanation of the process	D3 evaluate the correct synthesis and application of statistics and probability to solve engineering problems involving accurate routine and non-routine operations.
P6 solve an engineering problem using routine linear regression operations.	M6 solve accurately engineering problems using routine and non-routine regression operations, providing an explanation of the process.	

Essential guidance for tutors

Assessment

For P1 and P2, learners must be able to demonstrate the correct use of routine operations (skills and methods) when working with given problems based on sequences and series.

Overall, minor arithmetic and scaling errors are acceptable, as are 'carry through' errors provided that the basic method is sound. For example, a term in a sequence may be incorrectly calculated but the value used correctly in subsequent calculation of the series, affecting the final value. Learners will demonstrate an appreciation of the need for the correct use of units, but there may be errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

For P3 and P4, learners must be able to demonstrate the correct use of routine operations (skills and methods) when working on given problems based on matrices, determinants and complex numbers.

Overall, minor arithmetic errors are acceptable, as are 'carry through' errors provided that the basic method is sound. Learners will demonstrate an appreciation of the need for the correct use of units, but there may be errors in their application. Learners will include evidence of simple checks to determine if numerical answers are 'reasonable'.

For P5 and P6, learners will present the solutions of engineering problems involving measures of central tendency, dispersion and probability distribution. Ideally, they will research their own problems but if this is not possible then they can be given to learners. The solutions may not be complete and there may be some inaccuracies or omissions but there should be evidence of some proficiency of method. Learners will apply the appropriate routine operations (skills and methods) needed to process statistical data. For example, when evaluating sampled dimensional data from a machining operation, learners will present data appropriately and determine routine values such as the mean and standard deviation for a sample but may not compare the values with historical data. They will tabulate measurements and present data in a scatter graph and they may estimate the line of regression graphically.

Overall, the report should be logically structured. It may contain some arithmetic errors which 'carry through', for example the value of the mean of a set of sampled dimensional data from a machining operation may be incorrect but that value used correctly to find the standard deviation. The methods chosen may not be optimal but the chosen statistical methods should be applied correctly. Minor errors and omissions are acceptable. For example, the axis titles on a scatter graph may be missing units. There will be an appreciation of correct use of units but there may be errors or inconsistency in their application. Learners will include evidence of simple checks to determine if numerical answers are 'reasonable'.

For M1 and M2, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on sequences and series.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor. For example, appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M3 and M4, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on matrices, determinants and complex numbers.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor. For example, appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M5 and M6, learners will present accurate solutions for engineering problems related to measures of central tendency, dispersion and probability distribution, breaking them down into planned stages to obtain solutions. They will apply appropriate routine and non-routine operations (skills and methods) needed to process statistical data accurately. For example, tabulation of data, graphical presentation, accurate calculations of mean and standard deviation comparing measured values with historical data, accurately produced annotated scatter graph (with chart title, axis titles including units and gridlines) and calculation of line of regression and correlation coefficient for a linear relationship and regression line for a non-linear relationship.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor or appropriate for the chosen problems being solved. Solutions will contain an explanation of the process that will be logically structured and the correct mathematical terminology and relevant units will be used. There may be limited number of minor errors or omissions in non-routine operations. For example, when evaluating sampled dimensional data from a machining operation, learners may determine the mean and standard deviation for a sample and find a degree of correlation between samples, but not draw conclusions from, the values.

To achieve D1, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving sequences and series. Where appropriate to the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners must demonstrate that they are able to work to specified numerical precision, as specified by the assessor, through the use of appropriate significant figures.

For D2, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving matrices, determinants and complex numbers. Where appropriate with the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners must demonstrate they are able to work to specified numerical accuracy through the use of appropriate significant figures, as specified by the assessor.

In order to achieve D3, learners will demonstrate mastery in the application of the processing and evaluation of statistical data generated from engineering sources.

The identified problems must be sufficiently complex to allow learners to apply both routine and non-routine operations (skills and methods) to their solution. For example, in terms of measures of central tendency and dispersion learners may evaluate one set of measured and four sets of equivalent historical data such as dimensional data from a machining operation or reliability data sourced from products in service. Before starting to process any data, learners will establish that the data sets are large enough to enable reliable analysis to be carried out. For regression, they will propose a theoretical relationship between two variables, collect data, calculate a mathematical relationship between dependent and independent variables using appropriate analytical and graphical methods, and reflect on the accuracy of the initial proposal for a linear and a non-linear relationship.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. There will be correct use of mathematical terminology and the application of relevant units. Learners will work to specified numerical precision, as determined by the assessor or that are appropriate for their chosen problems being solved, through the use of appropriate significant figures or decimal places. Small and large numerical values will be correctly presented in an appropriate format, i.e. engineering notation or standard form.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Sequences and Series to Solve Engineering Problems	An activity requiring learners to solve problems based on sequences and series	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P3, P4, M3, M4, D2	Matrices, Determinants and Complex Numbers to Solve Engineering Problems	An activity requiring learners to solve problems based on matrices, determinants and complex numbers	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P5, P6, M5, M6, D3	Statistical and Probability Techniques to Solve Engineering Problems	An activity requiring learners to solve engineering problems based on statistical data	An informal report containing the results of learners' analysis and calculation of measured and supplied data; carried out under controlled conditions. Where appropriate, processing of statistical data can be done by spreadsheet.

Essential resources

The special resources required for this unit includes:

- access to maths support websites, spread sheet software, e.g. www.mathcentre.ac.uk/students/topics
- spreadsheet software and/or a scientific calculator such as Casio FX-85GT.

Indicative reading for learners

Textbooks

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Greer A, Taylor G W – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005) ISBN 9780748794102

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 7: Properties and Applications of Engineering Materials

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

In-depth knowledge of the structure and behaviour of engineering materials is vital for anyone who is expected to select or specify them for applications within the engineering industry. This unit will give an understanding of the structures, classifications and properties of materials used in engineering and will enable them to select materials for different applications.

The unit is appropriate for learners engaged in manufacturing and mechanical engineering, particularly where materials are sourced in the form of stock to be used in a production process. The unit covers a range of materials, some of which learners may not be familiar with initially.

This unit will enable learners to identify and describe the structures of metals, polymers, ceramics and composites and classify them according to their properties. learners will also be able to describe the effects of processing on the behaviour of given materials. Smart materials whose properties can be altered in a controlled fashion through external changes – such as temperature and electric and magnetic fields – are also covered.

Learners will apply their understanding of the physical and mechanical properties of materials, design requirements, cost and availability to specify materials for given applications.

All materials have limits beyond which they will fail to meet the demands placed on them. The common modes of failure will be both demonstrated and explained to enable learners to recognise where an informed choice can make the difference between the success or failure of a product.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the structure and classification of engineering materials

2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials

3 Be able to use information sources to select materials for engineering uses

4 Understand about the modes of failure of engineering materials.

Unit content

- 1 **Know the structure of and classify engineering materials**

  Atomic structure: element; atom e.g. nucleus, electron; compound; molecule; mixture; bonding mechanisms e.g. covalent, ionic, metallic

  Structure of metals: lattice structure; grain structure; crystals; crystal growth; alloying e.g. interstitial, substitutional; phase equilibrium diagrams e.g. eutectic, solid solution, combination; intermetallic compounds

  Structure of polymeric materials: monomer; polymer; polymer chains e.g. linear, branched, cross-linked; crystallinity; glass transition temperature

  Structure of ceramics: amorphous; crystalline; bonded

  Structure of composites: particulate; fibrous; laminated

  Structure of smart materials: crystalline; amorphous; metallic

  Classification of metals: ferrous e.g. plain carbon steel, cast iron (grey, white, malleable, wrought iron), stainless and heat-resisting steels (austenitic, martensitic, ferritic); non-ferrous e.g. aluminium, copper, gold, lead, silver, titanium, zinc; non-ferrous alloys e.g. aluminium-copper heat treatable – wrought and cast, non-heat-treatable – wrought and cast, copper-zinc (brass), copper-tin (bronze), nickel-titanium alloy

  Classification of non-metals (synthetic): thermoplastic polymeric materials e.g. acrylic, polytetrafluoroethylene (PTFE), polythene, polyvinyl chloride (PVC), nylon, polystyrene; thermosetting polymeric materials e.g. phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde; elastomers; ceramics e.g. glass, porcelain, cemented carbides; composites e.g. laminated, fibre reinforced (carbon fibre, glass reinforced plastic (GRP)), concrete, particle reinforced, sintered; smart materials e.g. electro-rheostatic (ER) fluids, magneto-rheostatic (MR) fluids, piezoelectric crystals

  Classification of non-metals (natural): e.g. wood, rubber, diamond

- 2 **Understand material properties and the effects of processing on the structure and behaviour of engineering materials**

  Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness

  Physical properties: density; melting temperature

  Thermal properties: expansivity; conductivity

  Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity

  Effects of processing metals: recrystallisation temperature; grain structure e.g. hot working, cold working, grain growth; alloying elements in steel e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel

  Effects of processing thermoplastic polymers: polymer processing temperature; process parameters e.g. mould temperature, injection pressure, injection speed, mould clamping force, mould open and closed time

  Effects of processing thermosetting polymers: process parameters e.g. moulding pressure and time, mould temperature, curing

  Effects of processing ceramics: e.g. water content of clay, sintering pressing force, firing temperature

Effects of processing composites: fibres e.g. alignment to the direction of stress, ply direction; de-lamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets

Effects of post-production use: smart materials e.g. impact (piezoelectric), electric field (electro-rheostatic), magnetic field (magneto-rheostatic), temperature (shape memory alloys), colour change (temperature or viscosity)

- 3 **Be able to use information sources to select materials for engineering uses**

Information sources: relevant standard specifications e.g. British Standards (BS), European Standards (EN), International Standards (ISO); material manufacturers' and stockholders' information e.g. data sheets, catalogues, websites, CD ROMs

Design criteria: properties e.g. mechanical, physical, thermal, electrical and magnetic; surface finish; durability e.g. corrosion resistance, solvent resistance, impact resistance, wear resistance

Cost criteria: initial cost e.g. raw material, processing, environmental impact, energy requirements; processing e.g. forming, machining, casting, joining (thermal, adhesive, mechanical); quantity; mode of delivery e.g. bulk, just-in-time (JIT); recycling

Availability criteria: standard forms e.g. sheet and plate, bar-stock, pipe and tube, sectional, extrusions, ingots, castings, forgings, pressings, granular, powder, liquid

- 4 **Understand about the modes of failure of engineering materials**

Principles of ductile and brittle fracture: effects of gradual and impact loading e.g. tensile, compressive, shear; effects of grain size; transition temperature; appearance of fracture surfaces

Principles of fatigue: cyclic loading; effects of stress concentrations e.g. internal, external; effects of surface finish; appearance of fracture surfaces

Principles of creep: primary; secondary; tertiary; effects of temperature; strain versus time curve; creep limit; effect of grain size; effect of variations in the applied stress

Tests: destructive e.g. tensile, hardness, impact, ductility, fatigue, creep; non-destructive e.g. dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), magnetic powder, visual

Degradation processes: on metals e.g. oxidation, erosion, stress corrosion; on polymers e.g. solvent attack, radiation and ageing; on ceramics e.g. thermal shock, sustained high temperature

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the structure (including the atomic structure) associated with a given metal, polymer, ceramic, composite and smart material		
P2 classify given engineering materials as either metals or non-metals according to their properties		
P3 explain mechanical, physical, thermal and electrical and magnetic properties and state one practical application of each property in an engineering context		
P4 explain the effects on the properties and behaviour of processing metals, polymers, ceramics and composites and of post-production use of smart materials	M1 explain how the properties and structure of different given engineering materials affect their behaviour in given engineering applications	

P5 use information sources to select a different material for two given applications, using the criteria considered in the selection process	M2 explain the criteria considered in the selection process	D1 justify selection of an engineering material for one given application
P6 explain the principles of the modes of failure known as ductile/brittle fracture, fatigue and creep	M3 explain how two given degradation processes affect the behaviour of engineering materials	
P7 perform and record the results of one destructive and one non-destructive test method using one metal and one non-metallic material	M4 explain how one destructive and one non-destructive test procedure produces useful results.	D2 evaluate the results of one test procedure.
P8 explain a different process of degradation associated with each of metals, polymers and ceramics.		

Essential guidance for tutors

Assessment

Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1, P2 and P3 could be achieved by means of a written assignment following a combination of tutor-led practical and theory sessions and individual research. P2 would require the range of materials given to include at least one ferrous, one non-ferrous, one non-ferrous alloy, one thermoplastic polymer, one thermosetting polymer, an elastomer, one ceramic, one composite, one smart material and one natural material.

Achievement of P4 and M1 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with real engineering applications. For smart materials they need to consider the effects on the properties of the materials use after production. Examples here may be related to their change in properties from the effects of external stimuli. For example, when a force is applied to a piezoelectric material it produces an electric charge which can be used to trigger a car's airbag in the event of an accident. In many applications the behaviour is reversible e.g. a colour change in response to a change in temperature or a variation in the viscosity of a liquid in response to the application of an electric or magnetic field. To satisfy P5, it is likely that learners would apply the knowledge and understanding gained in meeting criteria P1 to P4. Written responses would satisfy these criteria.

P7 could be met using a combination of practical and research activities involving tutor-led demonstrations of available laboratory tests. Learners could then carry out a series of tests and produce a written record of the test results. A witness statement could confirm the learners' involvement. Depending on available resources it may be best to carry out the destructive test on the non-metallic material and the non-destructive test on the metallic material. This would allow a wider choice of tests for the latter. To achieve P6 and P8, learners could be given the opportunity to research modes of failure and degradation processes reflected in local conditions e.g. a marine environment, or, for employed learners, failure and degradation pertinent to their companies' products.

To achieve the merit grade M1, learners will need to explain how the structure and properties of given materials will affect their behaviour in use. This evidence would be best demonstrated by a written task related to the activities carried out to meet P1, P2 and P3. For M2 learners should consider design, cost and availability criteria in their explanation. To satisfy M3, learners could produce a written explanation of the test procedures followed in P7 and the usefulness of the results. In producing evidence for some of this criterion it may be appropriate to include the responses to oral questions. However, centres should ensure that such questions and the responses are recorded for verification and also that they are not the sole source of evidence. M4 could be achieved through an extension of the task given for P8. The processes used in the explanation could be selected to meet local conditions or industrial applications.

To achieve distinction criterion D1, learners need to justify their selection of one of the materials used to satisfy P5, giving reasons why other materials considered for the application were not selected. To satisfy D2, learners are expected to complete a written task to evaluate the results of one of the tests used to meet P7 and M4. The evidence would depend on the test used but it could include the mathematical results of a tensile test, the values of a hardness test or detailed information gained from a non-destructive test.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P1, P2, P3	Structure and Classification of Engineering Materials	Questions relating to the structure and classification of the range of engineering materials	A written report containing reasoned answers to the set questions
P4, M1	Properties of Engineering Materials	Questions relating to the properties and behaviour of engineering materials	A written report containing reasoned answers to the set questions
P5, M2, D1	Selection of Engineering Materials	Selection of engineering materials for given applications	A written report listing selection criteria, information sources and justification for selected materials
P6, P8, M3	Failure and Degradation of Engineering Materials	Questions relating to the range of failure modes and degradation processes in engineering materials	A written report containing reasoned answers to the set questions
P7, M4, D2	Testing Engineering Materials	Carry out and report the results of destructive and non-destructive tests on engineering materials	A written report containing an explanation of test procedure and evaluation of test results

Essential resources

Centres will need a selection of exemplar materials and components for viewing, tactile inspection and discussion. Degraded and failed component specimens will also be of value. Centres will also require access to equipment to conduct at least one destructive and one non-destructive test and related materials as specified in the unit content.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Specialist Units* (Routledge, 2010) ISBN 9780080965772

Higgins R – *Materials for Engineers and Technicians* (Routledge, 2014) ISBN 9781138778757

Timings R L – *Engineering Materials, Volume 1* (Longman, 1998) ISBN 9780582319288

Timings R L – *Engineering Materials, Volume 2* (Longman, 2000) ISBN 9780582404663

Tindell H –Engineering Materials, Crowood Metalworking Guides (The Crowood Press Ltd, 2014) 9781847976796

Unit 8: Further Mechanical Principles of Engineering Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

All machines and mechanisms consist of interconnected parts working together to produce a desired output. Engineers involved in the design, testing and servicing of mechanical systems need to have a firm grasp of the underpinning principles in order to appreciate the choice of components, the forces acting on them and the way that they relate to each other.

The study of stationary structures and their components is often referred to as 'statics'. The first two learning outcomes cover the mechanical principles that underpin the design of framed structures, simply supported beams and structural components. The aim is to give learners the means to evaluate the integrity and safety of engineering structures and to lay the foundation for structural analysis at a higher level.

A great many engineering systems are designed to transmit motion and power. These include machine tools, motor vehicles, aircraft and a range of domestic appliances. The study of the motion in mechanical systems is known as 'kinematics' and the study of the forces at work and the power they transmit is known as 'dynamics'. Learning outcomes 3 and 4 aim to extend learners' knowledge of the mechanical principles associated with these studies. Learning outcome 3 aims to provide a basic knowledge of rotational motion and the effects of centripetal force in simple rotating systems. In learning outcome 4 learners are introduced to simple machines used as lifting devices. An understanding of the mechanical principles involved in the operation of these devices and mechanisms will provide a foundation for the analysis of more complex power transmission systems at a higher level of study.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to determine the forces acting in pin-jointed framed structures and simply supported beams

2 Be able to determine the stress in structural members and joints

3 Be able to determine the characteristics of rotating systems

4 Be able to determine the operating characteristics of simple lifting machines.

Unit content

- 1 **Be able to determine the forces acting in pin-jointed framed structures and simply supported beams**

  Pin-jointed framed structures: solution e.g. graphical (such as use of Bow's notation, space and force diagram), analytical (such as resolution of joints, method of sections, resolution of forces in perpendicular directions ($F_x = F \cos\theta$, $F_y = F \sin\theta$), vector addition of forces, application of conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$)

  Forces: active forces e.g. concentrated loads; uniformly distributed loads; reactive forces e.g. support reactions, primary tensile and compressive force in structural members

  Simply supported beams: distribution of shear force and bending moment for a loaded beam e.g. concentrated loads, uniformly distributed load (UDL); types of beam arrangement e.g. beam without overhang, beam with overhang and point of contraflexure

- 2 **Be able to determine the stress in structural members and joints**

  Single and double shear joints: fastenings e.g. bolted or riveted joints in single and double shear; joint parameters e.g. rivet or bolt diameter, number of rivets or bolts, shear load, expressions for shear stress in joints subjected to single and double shear, factor of safety

  Structural members: members e.g. plain struts and ties, series and parallel compound bars made from two different materials; loading e.g. expressions for direct stress and strain, thermal stress, factor of safety

- 3 **Be able to determine the characteristics of rotating systems**

  Rotating systems with uniform angular acceleration: systems e.g. simple (such as rotating rim, flywheel, motor armature, pump or turbine rotor), complex (such as systems where combined linear and angular acceleration is present, hoist and vehicle on an inclined track); kinetic parameters e.g. angular displacement, angular velocity, angular acceleration, equations for uniform angular motion ($\omega_2 = \omega_1 + \alpha t$, $\theta = \omega_1 t + \frac{1}{2}\alpha t^2$, $\omega_2^2 = \omega_1^2 + 2\alpha\theta$, $\theta = \frac{1}{2}(\omega_1 + \omega_2)t$); dynamic parameters e.g. radius of gyration, moment of inertia ($I = mk^2$), inertia torque ($T = I\alpha$), friction torque, application of D'Alembert's principle, mechanical work ($W = T\theta$), power (*Average Power* $= W/t$, *Instantaneous Power* $= T\omega$), rotational kinetic energy ($KE = \frac{1}{2}I\omega^2$), application of principle of conservation of energy

  Rotating systems with uniform centripetal acceleration: systems e.g. simple (such as concentrated mass rotating in a horizontal or vertical plane, vehicle on a hump-backed bridge, aircraft performing a loop), complex (such as centrifugal clutch, vehicle on a curved track); kinetic parameters e.g. expressions for centripetal acceleration ($a = \omega^2 r$, $a = v^2/r$); dynamic parameters e.g. expressions for centripetal force ($F_c = m\omega^2 r$, $F_c = mv^2/r$)

4 Be able to determine the operating characteristics of lifting machines

Parameters of lifting machines: kinetic parameters e.g. input motion, output motion, velocity or movement ratio, overhauling; dynamic parameters e.g. input effort, load raised, mechanical advantage or force ratio, law of a machine, efficiency, limiting efficiency

Lifting machines: lifting machines e.g. simple (such as inclined plane, screw jack, pulley blocks, wheel and axle, simple gear train winch), differential (such as differential wheel and axle, Weston differential pulley block, compound gear train winch)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 illustrate graphically the magnitude and nature of the support reactions and primary forces acting in the members of a framed structure with at least four pin-jointed members	M1 analyse the magnitude and nature of the support reactions and primary forces acting in the members of a framed structure with at least four pin-jointed members	D1 determine the values of distribution of shear force and bending moment and locate a point of contraflexure for a simply supported beam with overhang carrying at least two concentrated loads and a continuous uniformly distributed load
P2 determine the values of distribution of shear force and bending moment for a simply supported beam without overhang carrying at least three concentrated loads		
P3 determine the values of required parameters for a single shear lap joint and a double shear butt joint for given service conditions	M2 determine the values of induced stresses and dimensional changes that occur in the materials of a series connected compound bar and a parallel connected compound bar when subjected to direct loading	
P4 determine the induced direct stress, dimensional change and factor of safety values in operation for a rigidly held plain structural member when subjected to a combination of direct and thermal loading		

P5 determine the outcomes of applied torque, work done and power dissipated in a uniformly accelerated simple rotating system to overcome the effects of inertia and friction	M3 determine the performance value of a complex rotating system due to the effects of centripetal acceleration	D2 determine the applied torque, work done and power dissipated outcomes in a uniformly accelerated complex rotating system in which both linear and rotational motion is present, to overcome the effects of inertia, friction and gravity.
P6 determine the centripetal acceleration and centripetal force values in a simple rotating system		
P7 determine the outcomes of kinetic and dynamic parameters of operation of two different simple lifting machines from given data.	M4 evaluate the kinetic and dynamic parameters of operation of a differential lifting machine.	

Essential guidance for tutors

Assessment

Ideally, assessment of this unit will be achieved through application of the mechanical principles covered to the relevant engineering settings. This could be achieved through integration with other engineering principles units, practical work that provides learners with opportunities to produce individual evidence for assessment against the criteria, and individual project/assignment tasks. Whichever approach is taken it is important to ensure that the criteria are achieved autonomously. Where centres consider a test/examination is necessary to achieve authentic evidence then they need to ensure that the test items are set in a way to enable the criteria to be met in full. Centres also need to consider how such an assessment will provide opportunities to meet the merit and distinction criteria and how to provide learners with further learning and assessment should they initially fail to achieve in the test/examination.

If learners make an arithmetic error within the solution to a problem, it is for the centre to decide the significance of such an error, assess the work accordingly and provide suitable feedback. For example, if an learner has chosen the correct approach and manipulated the necessary formulae and data correctly but has made and carried through a minor arithmetic error, then the final 'inaccurate' solution to the problem may be deemed to be good enough to meet the criterion. However, if the final solution to the problem is so obviously wrong that it should have prompted further checks for accuracy, then the solution could be deemed to be unacceptable and reassessment considered. The incorrect application of units and/or dimensions are a typical cause of such major errors, which can lead to relatively large scale errors of the magnitude 10^3 or greater.

It is possible to assess the criteria P1, P2, M1 and D1 through an assignment requiring the graphical and analytical solution of a given pin-jointed framed structure and the analysis of given simply supported beams. The magnitude and nature of the framed structure support reactions and internal forces may be illustrated graphically (P1) and confirmed analytically (M1). Learners should make use of Bow's notation in their analysis.

The simply supported beam for P2 should contain at least three concentrated loads and be supported at its free ends. The simply supported beam for D1 should overhang one of its supports and contain at least two concentrated loads and a continuous uniformly distributed load. Learners should be required to adopt an analytical approach to locate the point of contraflexure.

A second assignment could assess the criteria P3, P4 and M2. The first task might be to determine the parameters for a single shear lap joint and for a double shear butt joint (P3) for given service conditions. This might involve calculation of the rivet/bolt diameter required for a given load or the safe working load for a particular joint. The joints should contain at least three rivets/bolts (six in total for the butt joint).

A second task might be to calculate the direct stress induced in a rigidly fixed member due to direct loading and temperature change (P4). A further task could involve evaluation of the stresses and dimensional changes occurring in series and parallel connected compound bars (M2) when subjected to direct loading.

A third assignment could be used to assess the criteria P5, P6, M3 and D2. The first task might involve consideration of a simple rotating system, such as a flywheel, which is accelerated against the effects of inertia and friction (P5). A second task might involve consideration of a more complex system such as a hoist or a vehicle on an incline in which both linear and angular motion is present (M3).

The third task might be to determine the centripetal acceleration and centripetal force present in a simple rotating system (P6). A final task would require learners to determine effects of centripetal acceleration and force in a more complex rotating system (D2). This might involve determining the speed of engagement and power transmitted by a centrifugal clutch. Alternatively, learners could evaluate the active and reactive forces on a vehicle travelling round a curved level track, maximum safe speed and the banking angle required for no tendency to side-slip at a given speed. The term performance in the criterion is therefore relevant to the particular rotating system given/used.

A final assignment containing two tasks could be used to achieve the P7 and M4 criteria. The first task would involve determination of velocity ratio, mechanical advantage and efficiency of two simple lifting machines for given input conditions (P7). Exemplar machines are ranged in the unit content.

In a second task, the M4 merit criterion could be achieved by means of a practical or simulated investigation of a differential lifting device. This should involve the determination of velocity ratio and the gathering of a sufficiently wide range of load and effort values for analysis of the machine performance. Graphs of load versus effort and load versus efficiency can then be plotted from the manipulated and tabulated test data. The law of the machine can be derived from the load versus effort graph and the theoretical value of the limiting efficiency obtained. An evaluation of this limiting value can then be made by comparison with that indicated on the load versus efficiency graph. An evaluation can also be made as to the likelihood of overhauling. Again, exemplar machines for this task are ranged in the unit content.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Forces and Moments in Static Systems	Analysis of pin-jointed framed structures and simply supported beams	A written report containing required graphics and an appropriate introductory explanation to each step in the sequence of calculations and findings.
P3, P4, M2	Stress in Static System Components	Determination of parameters for riveted joints and determination of stress in plain and compound structural members	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.
P5, P6, M3, D2	Dynamic Systems	Determination of dynamic system parameters and performance	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.
P7, M4	Lifting Machines	Determination of the parameters and performance of simple lifting machines	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.

Essential resources

Centres could provide access to laboratory facilities with a range of equipment for investigation and demonstration purposes wherever possible. In particular, flywheels or other rotor systems for the determination of moment of inertia and radius of gyration, turntable apparatus for the investigation of centripetal acceleration and force and a range of simple lifting machines.

Indicative reading for learners

Textbooks

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Bolton W – *Engineering Science* (Routledge, 2006) ISBN 9780750680837

Darbyshire A – *Mechanical Engineering BTEC National Specialist Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 9: Applications of Mechanical Systems in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit Introduction

Mechanical engineering is a term that covers a wide range of activities. Mechanical systems are found in land, sea and air transport, power generation, manufacturing plant and domestic products. The design, manufacture and maintenance of such systems is the concern of engineers and technicians who must be able to apply a blend of practical and theoretical knowledge to ensure that these systems work safely and efficiently.

Moving parts usually require some form of lubrication and learning outcome 1 examines lubricant types and lubrication systems. Pressurised systems often require seals and gaskets to contain the lubricants and other working fluids. Rotating parts require bearings and mechanical systems incorporate fixing devices to hold the various components in position. A range of seals, bearings and fastenings is examined in learning outcome 2.

A prime purpose of mechanical systems is to transmit motion and power. There are many ways in which this can be achieved and learning outcome 3 examines a range of power transmission systems and components. In learning outcome 4 learners are introduced to a range of plant equipment and systems. This includes an overview of hydraulic and pneumatic systems, steam plant, refrigeration and air conditioning plant and mechanical handling equipment.

The general aim of this unit is to broaden and extend learners’ practical knowledge and understanding of mechanical engineering systems and provide a foundation for continuing work in related units.

Note that the use of ‘e.g.’ in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an ‘e.g.’ needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the purposes and uses of lubricants and lubrication systems

2 Know about the uses and applications of a range of engineering components

3 Understand the operation and uses of mechanical power transmission systems

4 Understand the operation and uses of plant equipment and systems.

Unit content

- 1 **Understand the purposes and uses of lubricants and lubrication systems**

  Lubricant purposes and types: purpose e.g. reduction of frictional resistance, reduction of wear, heat dissipation, prevention of corrosion, prevention of contamination; types e.g. mineral, vegetable and synthetic oils and greases, graphite, compressed gases, cutting fluids

  Lubrication systems and maintenance: operation of lubrication systems e.g. gravity feed, forced feed, splash lubrication, capillary action, grease cups and nipples, grease packing, compressed air/gas bearings; maintenance e.g. replenishment and renewal of lubricants, safe storage and handling

  Applications: e.g. automobile engine, automobile transmission, machine tool, pump, compressor

- 2 **Know about the uses and applications of a range of engineering components**

  Seals, packing and bearings: seals e.g. rotary lip seals, mechanical seals, piston rings; packing e.g. packed glands, gaskets, shims; bearings e.g. plain journal, thrust, ball, roller (such as parallel or tapered), needle

  Fastenings: screwed fastenings e.g. metric bolts, studs and set screws, self-tapping screws, locking devices; rivets e.g. snap head, pan head and countersunk heads, bifurcated and pop rivets

  Applications: e.g. automobile engine, automobile transmission, other automotive sub-system, machine tool, pump, compressor, other mechanical system involving rotation and fluid containment, component assembly, maintenance and replacement

- 3 **Understand the operation and uses of mechanical power transmission systems**

  Cams and linkage mechanisms: cams and followers e.g. radial plate cams, cylindrical cams, face cams, knife edge followers, flat plate followers, roller followers; linkage mechanisms e.g. slider-crank and inversions, four-bar linkage and inversions, slotted link quick return motion, Whitworth quick return motion

  Belt, chain and gear drives: belt drives e.g. flat, V-section, synchronous, tensioning device; chain drives e.g. roller (such as single, duplex, triplex), morse rocker-joint, tensioning devices; gear trains e.g. gear types (such as spur, helical, herring bone, bevel, spiral bevel, hypoid), simple, compound, worm, combinations, epicyclic

  Transmission shafts, clutches and brakes: transmission shafts and couplings e.g. sections (such as solid, hollow), flanged couplings, splined couplings, angle couplings (such as Hooke universal, constant velocity); clutches e.g. dog, flat plate, conical, centrifugal, fluid couplings; brakes e.g. friction (such as internal expanding, external contracting), disc, dynamometers (such as friction, fluid, electromagnetic)

* 4 **Understand the operation and uses of plant equipment and systems**

  Actuation and handling systems: pneumatic and hydraulic actuation systems e.g. system layout for automated plant and process operations, system components; safety and maintenance; mechanical handling systems e.g. belt conveyers, roller conveyers, workshop gantry cranes, workstation jib cranes

  Steam, refrigeration and air conditioning plant service systems: steam power generation plant e.g. system layout for power generation and process operations, system components, feed water treatment, safety and maintenance; refrigeration systems e.g. system layout for vapour compression and absorption systems, refrigerants, system components, safety and maintenance; air conditioning systems e.g. system layout for full summer and winter cycle air conditioning, system components, safety and maintenance

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the purpose and application of three different types of lubricant	M1 compare different types of lubrication and explain the benefits and limitations of each	D1 justify the use of a particular lubricant and lubrication system in a given engineering application
P2 explain the operation and maintenance of three different lubrication systems		
P3 describe the operation of one seal, one type of packing and two different types of bearing, giving a typical application for each one		
P4 describe two different types of screwed fastening and two different types of rivet giving a typical application for each one		
P5 explain the operation of two different types of cam and follower and two different types of linkage mechanism		

P6 explain the arrangement and operation of two different kinds of belt drive, two different kinds of chain drive and two different kinds of gear train		
P7 explain the arrangement and operation of two different kinds of transmission shaft and coupling, two different kinds of clutch and two different kinds of brake	M2 compare different types of mechanical power transmission systems and explain the benefits and limitations of each	D2 justify the use of a particular mechanical power transmission system in a given engineering application.
P8 explain, with the aid of diagrams, the general layout and operation of a pneumatic actuation system, a hydraulic actuation system and a mechanical handling system	M3 compare and contrast the operation and use of pneumatic and hydraulic actuation systems.	
P9 explain, with the aid of diagrams, the general layout and operation of a steam power generation plant, a refrigeration system and an air conditioning system.		

Essential guidance for tutors

Assessment

Criteria P1, P2, M1 and D1 could be achieved through an individual assignment. This should contain tasks to explain the purpose and application of three different types of lubricant (P1) and the operation and maintenance of three different lubrication systems (P2). M1 is an extension of P1 involving a comparison of the three lubricants in terms of their benefits and limitations. To achieve D1, learners should be able to fully justify the use of a particular lubricant and lubrication system in a given engineering application. This might be the lubrication system of a vehicle engine or transmission, a machine tool, pump or compressor. Alternatively, a mechanical system required to operate in a hostile service environment such as extremes of temperature may be considered.

A second assignment could be used to assess P3 and P4. This would require learners to describe the operation and application of one type of seal, one type of packing and two different types of bearing (P3). Another task would need to cover two different types of screwed fastener and two different types of rivet (P4). The applications should be general, rather than product specific, to demonstrate an understanding of purpose. Diagrams and sketches could be used to complement the descriptions.

Criteria P5 and P6, which relate to learning outcome 3 on mechanical power transmission systems, could be achieved through a third assignment. This should require learners to explain methods of transmitting/ converting motion from one form to another by means of two different types of cam and follower and two different linkage mechanisms. It will also need to include two different kinds of belt drive, two different kinds of chain drive and two different kinds of gear train. As with the previous assessment, learners should be encouraged to illustrate the descriptions with diagrams and freehand sketches.

Criteria P7, M2 and D2 relate to learning outcome 3 and could be achieved through a fourth assignment. This should contain tasks requiring learners to explain the arrangement and operation of two different kinds of transmission shaft coupling, two different kinds of clutch and two different kinds of brake (P7). To achieve M2, learners could compare and contrast the operation of manually operated and automatic friction clutches and fluid couplings. The comparisons should be of a general nature, although they may be accompanied by typical applications to illustrate usage. To achieve D2 learners should be able to fully justify the choice of bearings, seals, packing and fastenings in a given engineering system. This again might be a sub-system of a vehicle, a machine tool or any mechanical system where rotation and the containment of fluid is involved.

A final time-constrained assignment could be used to assess P8, P9 and M3. This should contain tasks requiring learners to explain, with the aid of diagrams, the general layout and operation of pneumatic and hydraulic actuation systems (P8), a steam generation plant, a refrigeration system and an air conditioning system (P9).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1 and D1	Applications of Lubricants and Lubrication Systems	Learners need to describe lubricants and the operation of lubrication systems to a new learner.	A series of three written tasks in which learners provide explanations of three lubricants and the operation of lubrication systems. They are also asked to justify the use of a lubricant for a given application.
P3 and P4	Applications of Engineering Components	Learners need to investigate different components in order to find the best to use for a particular application.	A series of three written tasks in which learners describe the application of seals, packing, bearings and fasteners
P5 and P6	Applications of Cams and Drives	Learners need to investigate mechanical power transmission systems.	Two written tasks in which learners explain the use of cams, linkage mechanisms and chains and drives.
P7, M2 and D2	Applications of Brakes and Clutches	Learners need to investigate transmission shafts, clutches and brakes.	Two written tasks in which learners explain the operation of shaft couplings, clutches and brakes, make comparisons and justify the use of one system.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9 and M3	Plant Equipment and Systems	Learners have been asked to produce a report on some new plant equipment and systems that their company is interested in using.	A time-controlled task in which learners produce written explanations and accompanying diagrams of actuation systems and steam, refrigeration and air conditioning systems. They should also carry out a comparison of pneumatic and hydraulic systems.

Essential resources

Centres should have access to a range of engineering components, demonstration equipment and engineering and motor vehicle workshops.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Specialist Units* (Routledge, 2010) ISBN 9780080965772

Neale M J – *Lubrication and Reliability Handbook* (Newnes, 2000) ISBN 9780470015247

Unit 10: Organisational Efficiency and Improvement

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning: 60

Unit introduction

In this unit learners will gain an understanding of continuous improvement within their sector and identify areas within production where lean working could be used to aid the company. They will learn about quality control methods used in industry and understand the key factors required to remain competitive in the market.

Learners will also understand the importance of human resource management in terms of building successful teams and the effect this can have on recruitment and retention of employees.

Note that the use of e.g. in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an e.g. needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand production activities
2 Understand application of quality control and quality assurance
3 Understand organisational improvement techniques and competitiveness
4 Understand personal rights and responsibilities within an organisation.

Unit content

1 Understand production activities

Types of production: e.g. mass; flow; automated; batch; one-off

Considerations: market requirements; design of product; plant and equipment availability; plant and equipment layout; personnel; production control; quality control; cost

Methods and application of Cellular and Just in Time (JIT) production: relation to modern production requirements; application of Push and Pull types of production to meet company and customer needs and expectations

Stages of production planning: scheduling, loading, dispatching (co-ordination of pre-production activities); requirements: e.g. engineering drawings, technical data, personnel, machinery/tools, components, materials, consumables

Process charts: e.g. flow charts/diagrams, Gantt charts; symbols used in process charts

2 Understand application of quality control and quality assurance

Quality control and assurance: meaning of 'quality control' and 'quality assurance'; fitness for purpose e.g. meeting customer expectations; purchasing; production planning and procedures for quality assurance; manufacture (process control); final inspection and dispatch; Statistical Process Control (SPC): e.g. measuring quality/performance, document control as an integral part of quality assurance, records of the correct operation; types and the purpose of sampling, e.g. spot check, random sampling, process sampling, batch sampling; mean time between failures (MTBF) in the context of sample size and frequency

Inspection: checking every stage for deviation from design specification; adjustments that need to be made; stages of inspection e.g. goods inward, during production (process control), final inspection; role of the inspector in checking compliance with quality standard and procedures; quarantine area to store defective work

BS EN ISO 9001: internationally recognised quality assurance standard; role of the quality manual and process/procedures manual; internal/external audits

Quality manager: relationship with other managers/departments within the company; considerations to be made when developing a quality plan e.g. quality requirements (customer expectations), allocation of responsibilities (at all levels), the setting up of systems to measure quality and report progress, identification and calibration of quality equipment, ability to take corrective actions where necessary

Total Quality Management (TQM): main principles and goals; advantages of adopting TQM, e.g. competitiveness within the market, enabling growth and longevity, reducing stress, building teams, partnerships and co-operation

3 Understand organisational improvement techniques and competitiveness

Business Improvement Techniques (BIT): principles of lean manufacture e.g. removal of waste of all kinds (time, motion, inventory, poor cost of quality etc.), stimulating productivity and quality; use of value-added processes, Kaizen as a philosophy that encompasses continuous improvement; just in time (stockless production or lean production) e.g. manufacturing to order not to stock; Kanban inventory control

Productivity: meaning of the term 'production'; benefits to the company of increasing productivity; company e.g. multinationals, nationals and regional, SMEs and sole traders; managing the production process e.g. layout of the production area, batch production, synchronisation, lead-time

Continuous improvement: meaning of 'continuous improvement'; continuous improvement cycle (plan, do, check, and action); benefits gained; 'flexible working' and 'multi-skilling'; importance in the national and global marketplaces e.g. multinationals, nationals. SMEs and sole traders

Teamwork: roles within a team e.g. leaders, doers, thinkers, carers; balance in a team; what individuals bring to a team; team building; communication within the team

4 Understand personal rights and responsibilities within an organisation

Organisational documentation and employment legislation: documentation e.g. contracts of employment, staff handbook; personnel records, grievance procedures; appraisals; disciplinary procedures; legislation e.g. Employment Rights Act, Working Time Regulations, Health and Safety at Work Act, Data Protection Act, Equal Opportunities Act, Human Rights Act, Equalities Act

Development and progression opportunities: company training programmes; apprenticeships; organisational training opportunities; promotion; transfer; higher education; professional qualifications

Roles of representative bodies: e.g. trade unions, professional bodies, employers' organisations (EEF); industry training support

Investors in People (IiP) national standard: four key principles - commitment, planning, action and evaluation; how organisations acquire IiP status

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the different types of production	M1 compare the advantages and disadvantages of different types of production	D1 justify the selection of a production type for a given process
P2 describe the requirements that need to be considered when selecting a type of production		
P3 describe the different stages of production planning		
P4 explain how to apply typical process charts to production planning		
P5 explain the meaning of the terms 'quality control' and 'quality assurance'	M2 explain the importance of using a structured approach for quality control and quality assurance	D2 evaluate a quality management process and make suggestions for improvement
P6 describe the role and stages of inspection activities		

P7 explain the application and content of the BS EN ISO 9000 series of standards		
P8 explain the role and responsibilities of the quality manager		
P9 describe the requirements of quality planning		
P10 describe the principles of Total Quality Management (TQM)		
P11 explain the meaning of the terms Lean Manufacture, Kaizen, Just in Time and Kanban and their overall advantages	M3 explain the consequences for an organisation of not maintaining continuous improvement standards	D3 evaluate a production process and identify where improvements can be made to increase productivity and organisational competitiveness.
P12 explain the importance of improving organisational productivity		
P13 describe the need for continuous improvement to ensure organisational competitiveness		
P14 describe the key requirements for managing the production process		
P15 explain the importance of teamwork and the individual's contribution to effective teamwork		
P16 explain the key features of employment legislation in relation to personnel rights and responsibilities	M4 explain the effects of not adhering to employment legislation in relation to personal rights and responsibilities.	

P17 describe the personnel opportunities for development and progression that are available within the workplace		
P18 describe the role of the representative bodies in the engineering sector that support personnel and organisations		
P19 explain the implications that 'Investors in People' has on an organisation and its personnel.		

Essential guidance for tutors

Assessment

To achieve a pass grade, all the pass criteria must be met. Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1, P2, P3 and P4 could be achieved by means of a written task based upon a given product that needs to be manufactured. For P2 the learner should identify the customer requirements for the given product and describe how each will impact on the selection of a specific production method. For P1 the learner would then identify a range of production processes that could be used to manufacture the product and explain the underlying principles behind them. For P3 the learner would identify the key stages in production planning to produce their production plan for the given product. For P4 the learner can add in the need and importance of process charts within the plan to identify key stages in the production. This task can also allow the learner to achieve M1 through a thorough analysis of the company. Alternatively a case study into quality management of a sample company could be used. At least two possible production types should be compared. D1 can be achieved through justifying their choice of production type in detail.

Achievement of P5, P7, P9 and P10 could utilise a written task asking the learner to identify the terms and roles suitable for accurate quality control procedures and how this can be built into TQM. This could be linked into a case study, based around a company visit if possible. Learners would have to identify the areas where standards such as ISO9001 are vital in industry and how the companies involved identify the relevant roles for P6 and P8 respectively. As part of this written task the learner can also draw evidence of explaining the importance of structure in the quality procedures to gain M2.

This case study or visit should then allow the learner to identify and evaluate the QA procedures in operation and allow them to suggest improvements for D2.

P11 and P12 can be achieved through a written analysis of the different types of production processes and their advantages in improving productivity. This would then lead into a description of the importance of continuous improvement for P13 and also allow the learner the opportunity for detailed discussion to achieve M3 at the same time. The learner should describe a given production process and the importance of the management structures present for P14 and then explain the impact effective team building and team working has on productivity for P15. The learner can then suggest improvements to this in detail which would give the opportunity to achieve D3.

The achievement of P16 should be tied to an analysis of the learners own workplace's human resources department to produce an explanation of the key features and also allow the opportunity to discuss why it is important for companies to follow the law with some examples of the effects for M4. This could be linked to the importance of representation from bodies such as workers' unions for P18.

P17 and P19 can be achieved through research into why companies should continually develop their staff and the effect that Investors in People has on encouraging employment and development.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4 M1, D1	Production Processes and Planning	A company decides to manufacture a product. The learner should analyse the possible types to produce it and identify the most suitable, justifying their selection.	Written task
P5, P6, P7, P8, P9, P10 M2, D2	Investigation into Quality Management	Learners will analyse existing quality management procedures in a company (or their own company if suitable) and use the data found to suggest improvements.	Case study
P11, P12, P13, P14, P15 M3, D3	Continuously Improving Productivity	Learners identify the most common production methods used by companies (and their own company if appropriate) and analyse the impact that these processes have had on productivity.	Written task, case study

Criteria covered	Assignment title	Scenario	Assessment method
P16, P18, M4	Employers' Rights and Employment Law	Learners analyse their workplaces employment contracts and processes alongside existing cases brought against companies to analyse the importance and effect of the law and union's role in defending workers' rights.	Written task, case study
P17, P19	Investment in People	The learner will identify the importance of investment in the workforce, how companies obtain IiP and what effect that has on employment.	Written task

Essential resources

Case study into quality management of a sample company for learners with unsuitable employers to study their own company.

Evidence from previous employment law cases to allow learners to identify the importance of a company abiding by the law.

Indicative reading for learners

Textbooks

Waldock B – Being Agile in Business (Pearson Education Ltd. 2015) ISBN-13: 9781292083704

Hutchinson S – Performance Management: Theory and Practice, (CIPD, 2013)

ISBN 9781843983057

Mullins LJ – Management and Organisational Behaviour, 10th Edition (FT Publishing

International, 2013) ISBN 9780273792642

Journals

Business Review Magazine (Phillip Allan Publishers – see www.phillipallan.co.uk)
The Economist (The Economist Newspaper Group Inc)

Websites

www.bbc.co.uk/business BBC News website

www.nln.ac.uk National Learning Networkwww.thetimes100.co.uk Free materials and case studies

Unit 11: Electro-pneumatic and Hydraulic Systems and Devices

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning: 60

Unit introduction

An understanding of how fluid power systems are used to control the operation of machinery and equipment is important for anyone thinking of taking up a career in engineering.

Pneumatic (pressurised air or gas) systems are widely used in manufacturing engineering to operate equipment such as packaging machines, automated assembly machines, clamping and lifting devices. There are many other everyday applications where air operated equipment is found, for example for opening doors on buses. Hydraulic (pressurised liquid) systems are used where greater amounts of power are involved, a good example of this being the linear actuators that move the arms on excavators and other types of earthmoving equipment.

This unit will give learners a broad understanding of the design and safe operation of pressurised fluid systems that use electrical control devices to make them work. This will include being able to read and produce simple fluid power circuit diagrams, understanding the principles of maintenance, and the use of test routines to identify faults in these systems.

Learners will investigate the impact that current legislation has on the design and safe operation of fluid power circuits, so that when carrying out practical work they are able to work safely. High pressure systems and devices, particularly air-based ones, have hidden dangers. Because hydraulic oil is carcinogenic learners will be made aware of the regulations covering the handling and disposal/recycling of this substance.

This is then followed by a look at a selection of the components used in fluid power systems and how they can be represented using universally recognised circuit diagram symbols. The components studied will include those used to generate a supply of high pressure air or hydraulic fluid, prime movers such as linear actuators (cylinders) and control devices such as valves and sensors.

Learners will be introduced to some of the calculations that need to be carried out before designing and setting up a system. These include some basic pressure and volume calculations involving gases, determination of the correct size of cylinder to produce a specified extending force, and calculation of fluid flow rates needed to keep a system operating effectively. Learners will then investigate how components can be linked together to form systems for a specific purpose.

The final section of the unit looks at how fluid power systems are maintained in service and what happens if they develop faults. The emphasis here is on applying safe working practices, using predetermined systematic schedules and keeping accurate records for future reference.

Note that the use of 'e.g' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know about the legislation, regulations and safety precautions that apply when working with fluid power systems

2 Know the construction and operation of fluid power devices and how they are represented as symbols in circuit diagrams

3 Be able to apply fluid power principles in the design of circuits

4 Be able to carry out maintenance, inspection, testing and fault-finding on fluid power systems.

Unit content

- 1 **Know about the legislation, regulations and safety precautions that apply when working with fluid power systems**

  Legislation and regulations: legislation e.g. Health and Safety at Work Act 1974, Employment Act 2002, Factories Act 1961, Fire Precautions Act 1971, Deposit of Poisonous Waste Act 1972, European Conformity (CE marking); regulations e.g. Employment Equality (Age) Regulations 2006, Management of Health and Safety at Work Regulations 1999, Provision and Use of Work Equipment Regulations 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995, Workplace (Health, Safety and Welfare) Regulations 1992, Health and Safety (First Aid) Regulations 1981, Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009, Simple Pressure Vessels (Safety) Regulations 1991 (SI 1994/3098), The Simple Pressure Vessels Directive (Directive 87/404/EEC) (SPVD); Supply of Machinery (Safety) (Amendment) Regulations 2005 (SI 2005/831)

  Safety precautions: risk assessment of fluid power systems; assembling and testing electro-pneumatic and hydraulic systems and devices e.g. isolation of services (such as electrical, air, oil), escape of fluids at high pressure which may cause contact injury, hydraulic oil contact with the skin, sudden movement of linear actuators causing entrapment injuries; personal protective equipment (PPE) e.g. safety glasses, gloves, overalls, footwear

- 2 **Know the construction and operation of fluid power devices and how they are represented as symbols in circuit diagrams**

  Fluid power devices: fluid conditioning e.g. supply tank, filter, pump, cooler, compressor, dryer, receiver, accumulator; fluid supply e.g. pipework, fittings, seals, drainage points; electrical supply systems e.g. mains, low voltage regulated power supply units, AC, DC; fluid control valves e.g. directional (manual and solenoid), pilot, 4 port, 5 port, pressure reducing, non-return, flow rate; actuators linear, rotary; motors e.g. electric, air, hydraulic; position sensors e.g. reed switch, pressure switch, inductive, microswitch; system control e.g. programmable logic controller (PLC), electro mechanical

  Symbols: relevant and current standards e.g. BS3939, BS ISO 1219-1:2012, European Fluid Power Committee (CETOP); symbols for common components e.g. fluid conditioning, fluid supply, electrical supply, control valves, actuators, motors, sensors, control

  Circuit diagrams: diagrams e.g. pneumatic, hydraulic, block diagrams, system layout, displacement step diagrams; reference material e.g. component and equipment data sheets, BS ISO 1219-1:2012, software (such as FluidSIM or Automation Studio)

- 3 **Be able to apply fluid power principles in the design of circuits**

  Fluid power principles: properties and behaviour of air and hydraulic fluids; gas laws e.g. Boyle's, Charles', Gay-Lussac's, general gas, dew point; fluid flow e.g. Bernoulli's principle, volumetric rate, receiver volume, actuator flow requirements; fluid pressure e.g. units of measurement, Pascal's law, inlet and outlet pressure, pressure drop, actuator efficiency, clamping force; formulae ($P_1V_1T_2 = P_2V_2T_1$, displaced volume = piston area x stroke, volumetric flow rate = displaced volume/time, absolute pressure = gauge + atmospheric pressure, force = pressure x area, actuator force = pressure x area x efficiency)

  Circuits: pneumatic e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell, position and clamp an object using a two-cylinder arrangement, rotary actuator with reversing action; hydraulic e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell and regeneration, hydraulic motor with reversing action

- 4 **Be able to carry out maintenance, inspection, testing and fault-finding on fluid power systems**

  Maintenance: routines e.g. frequency of maintenance, manuals and reference documentation, keeping of accurate records using paper- or software-based systems; components (electro-pneumatic, hydraulic); systems e.g. electro-pneumatic, electro-hydraulic

  Inspection: functional e.g. at component level, as a system, performance against specification; keeping of accurate records; report e.g. component drawing, system circuit diagram, digital images, inspection checklist, record of visual observations made against checklist, conclusions, recommendations

  Testing: performance e.g. against specification, reliability; keeping of accurate records; report e.g. system circuit diagram, system specification, test schedule, list of test equipment, record test results, record visual observations, compare test results with system specification, recommendations for future actions

  Fault finding: identify faults in fluid power systems e.g. manual diagnosis, visual examination, unit substitution, input to output, injection and sampling, half-split technique, six-point technique, self-diagnostic techniques using programmable electronic equipment, effect of malfunctions; fault-finding aids e.g. functional charts, diagrams, flow charts, troubleshooting charts, component data sheets, operation and maintenance manuals, specialised equipment; record faults e.g. paper based, software based, analyse data; report e.g. system circuit diagram, record test results, record visual observations, compare test results with system specification, record faults and cross reference to circuit diagram, identify type of fault, strategy for rectification of fault

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 list the aspects of health and safety legislation and regulations that apply when working with given fluid power equipment and systems		
P2 describe the safety precautions that apply when working with fluid power equipment and systems		
P3 describe, with the aid of suitable diagrams, the construction and operation of a given electro-pneumatic device and a given electrohydraulic device	M1 compare the construction and operation of a pneumatic system with that of a hydraulic system	D1 assess the relevance of current standards, such as CETOP, to the construction and operation of fluid power devices
P4 use standards to identify electro-pneumatic and hydraulic components shown as symbols in given circuit diagrams and reference materials		

P5 carry out calculations that relate to the fluid power principles used in the design of circuits		
P6 produce a circuit diagram to meet a given electro - pneumatic system specification		
P7 produce a circuit diagram to meet a given hydraulic system specification		
P8 use routines and carry out maintenance on given electro-pneumatic and hydraulic components and a given electro-pneumatic or electro-hydraulic system	M2 explain the routines used when carrying out maintenance on a given electro-pneumatic or electro-hydraulic system	
P9 carry out inspection, testing and fault-finding on a given electro-pneumatic or electrohydraulic system in line with checklists.	M3 produce a report of showing findings.	D2 evaluate the use of self-diagnostic techniques to monitor the performance of fluid power systems used in industry.

Essential guidance for tutors

Assessment

It may be appropriate to structure the assessment of this unit as five assignments, using four to cover the pass and merit criteria and the fifth one the two distinction criteria.

The first assignment could cover P1 and P2 and should be structured so that learners remain focused on the content of learning outcome 1. Learners are expected to use their own words when referring to legislation and, whilst much of their research will be done using the internet, it is important that what they present is not just a simple cut and paste exercise. Evidence to support knowledge of safety precautions could be generated by giving learners a list of situations/scenarios and then asking them to detail what needs to be done to work safely. This leads into risk assessment and learners could be asked to carry out an assessment for equipment which they will be using later in the unit.

Grading criteria P3, P4, M1 and D1 complement each other and could be assessed through a second assignment which covers the whole of the content for learning outcome 2. P3 asks for information about the construction and operation of equipment and, provided that any written explanation is supported by diagrams there is no requirement for learners to present fully detailed drawings of the devices considered.

To meet the requirements of P4 learners could be given a suitable set of circuit diagrams and manufacturers' reference material for the equipment described for P3. This would determine the amount of components and symbols needed to meet the requirement of P4. Examples of such devices are found in the unit content and delivery guidance. M1 encompasses P3 and P4 and requires a comparison of the construction and operation of the two systems. This comparison can be extended to assess the relevance of standards such as ISO and CETOP to the construction and operation of fluid power devices.

P5, P6 and P7 are linked and could be assessed using a third assignment which will involve calculation and the production of circuit diagrams which meet given design specifications. These can be hand drawn but it is better if learners use a software package, so that simulation can be carried out to ensure correct operation of the circuits. This could be evidenced in the form of screen prints consolidated by a witness statement or observation record.

Grading criteria P8, P9, M2 and D2 could be assessed using a fourth assignment. Evidence of learner competence when carrying out practical tasks will need to be recorded using witness statements, observation records and digital images.

The tasks set to generate evidence for P8 should involve the use of a small range of components and just one fluid power system (i.e. pneumatic or hydraulic). Similarly, when producing evidence for P9 it is only necessary to work with one type of system. Both criteria require learners to keep accurate records and use relevant documentation in addition to carrying out the practical tasks. Learners who built the circuits that they designed to achieve P6 and P7 could work on these when gathering evidence for P8 and P9.

M2 and M3 build on P8 and P9 requiring an explanation and a report showing findings. Finally, D2 requires an evaluation of self-diagnostic techniques to monitor performance. This could include, for example, electronic programmable equipment to carry out the monitoring and an evaluation of its effectiveness.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Legislation and Safety Precautions	Learners to carry out a risk assessment for fluid power equipment in an engineering situation.	A written assignment in which learners detail the legislation and safety precautions that apply to a piece of fluid power equipment that they are going to use.
P3, P4, M1, D1	Construction and Operation of Fluid Power Devices	Use and interpret circuit diagrams to identify and describe the operation of fluid power devices and components.	A written assignment with tasks requiring learners use diagrams to describe fluid power devices and identify components.
P5, P6, P7	Fluid Power Principles and Circuits	Learners have been asked to produce circuit diagrams to meet the requirements of a customer specification in an engineering situation.	A practical assignment requiring learners to produce two circuit diagrams and carry out calculations.
P8, P9, M2, M3, D1, D2	Carrying Out Fluid Power Maintenance, Inspection, Testing and Fault-Finding	Learners have been asked by their supervisor to carry this out on fluid power systems.	A practical assignment supported by a logbook/report of activities carried out plus observation records.

Essential resources

To meet the needs of this unit it is essential that centres have access to the following:

- industrial-standard electro-pneumatic and hydraulic equipment and systems
- fluid power circuit design software e.g. FluidSIM or Automation Studio
- test equipment and measuring instruments
- relevant British and international standards
- health and safety publications.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Specialist Units* (Routledge, 2010) ISBN 9780080965772

Kay M – *Practical Hydraulics* (CRC Press, 2007) ISBN 9780415351157

Parr A – *Hydraulics and Pneumatics* (Jaico Publishing, 2005) ISBN 9788172241896

Turner I – *Engineering Applications of Pneumatics and Hydraulics* (Routledge, 1995) ISBN 9780340625262

Zhang Q – *Basics of Hydraulic Systems* (CRC Press, 2008) ISBN 9781420070989

Parr A – *Hydraulics and Pneumatics: A Technician's and Engineer's Guide* (Butterworth-Heinemann, 2011) ISBN 9780080966748

Chapple PJ – *Principles of Hydraulic System Design* (Coxmoor Publishing Co, 2008) ISBN 9781901892154

Unit 12: Engineering Drawing for Technicians

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

It is important that when a product has been designed it is manufactured correctly and to specification. To achieve this it is crucial that the people making the product in a workshop are provided with well-presented engineering drawings, produced to international standards and conventions. This avoids errors of interpretation which can lead to the scrapping of expensive parts.

An understanding of how graphical methods can be used to communicate information about engineering products is an important step for anyone thinking of taking up a career in engineering. This unit gives learners an introduction to the principles of technical drawings and their applications using hand drawing and computer-aided drafting (CAD) techniques.

Learners will start by carrying out freehand sketching of simple engineering products using pictorial methods that generate three-dimensional images. A range of standard components, such as fixing devices, will be sketched together with other solid and hollow items. Learners are then introduced to a more formalised drawing technique that conforms to British Standards and will put this into practice through a number of drawing exercises. A consistent presentation style will be used as learners draw single part components and simple engineering assemblies.

These drawings will contain all the information needed to manufacture or assemble the product, including information such as dimensions, manufacturing notes and parts lists. The use of conventions to represent standard items will be investigated, such as screw threads and springs in mechanical type drawings or circuit symbols such as solenoids and resistors in electrical/electronic type drawings.

Having learned the principles of engineering drawing, learners will then move on to using a two-dimensional (2D) CAD system for the production of drawings using basic set-up, drawing and editing commands. The first task is to produce a drawing template which can be saved to file, as this reinforces the concept of standardisation and consistency of presentation. This is followed by drawing exercises of single-part components, a simple multi-part assembly and circuit diagrams.

Overall, the unit will develop learners' ability to create technical drawings and allow them to compare the use of manual and computer aided methods of producing engineering drawings.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to sketch engineering components

2 Be able to interpret engineering drawings that comply with drawing standards

3 Be able to produce engineering drawings

4 Be able to produce engineering drawings using a computer aided drafting (CAD) system.

Unit content

- 1 **Be able to sketch engineering components**

  Sketches: regular solids e.g. cube, rectangular block, 900 angle bracket; hollow objects e.g. circular tube, square section tube; standard components e.g. nuts, bolts, screws, pulleys; engineering components e.g. pulley support bracket, machine vice

  Sketching techniques: sketching equipment e.g. paper (plain, squared, isometric), pencil, eraser; pictorial e.g. oblique drawing (cavalier and cabinet), isometric; orthographic e.g. single and linked views; sketching in good proportion; dimensions e.g. overall sizes, detail

  Benefits and limitations of using pictorial techniques: benefits e.g. speed of production, visual impact; limitations e.g. lengths and shapes not true, not produced to a recognised standard, dimensions difficult to read; consequences of interpretation errors e.g. incorrect manufacture, incorrect assembly, cost to scrap

- 2 **Be able to interpret engineering drawings that comply with drawing standards**

  Interpret: obtaining information from engineering drawings e.g. component features, dimensions and tolerances, surface finish, manufacturing detail, assembly instructions, parts list, circuit operation

  Drawing standards: British Standards e.g. BS8888, BS3939, BS2917, PP7307; company-standardised layouts e.g. drawing number, title and issue number, projection symbols (first angle, third angle), scale, units, general tolerances, name of person responsible for producing drawing; line types e.g. centre, construction, outline, hidden, leader, dimension; lettering e.g. titles, notes; orthographic projection e.g. first angle, third angle; views e.g. elevation, plan, end, section, auxiliary; representation of common features e.g. screw threads, springs, splines, repeated items; section views e.g. hatching style, webs, nuts, bolts and pins, solid shafts; symbols and abbreviations e.g. A/F, CHAM, Φ, R, PCD, M; circuit symbols e.g. electrical, electronic, hydraulic, pneumatic

- 3 **Be able to produce engineering drawings**

  Detail drawings of single-piece engineering components: projection method; scale; title block; line work; views; sections; dimensions; tolerances; surface finish; notes

  Assembly drawings: line work e.g. centre lines, construction, outline, cutting plane, sectional view, hatching; representation of standard components e.g. nuts, bolts, screws, keys; parts referencing e.g. number referencing, parts list; notes e.g. assembly instructions, installation features, operating instructions

  Circuit diagrams: circuits e.g. electrical, electronic, hydraulic, pneumatic; components e.g. transformers, rectifiers, solenoids, resistors, capacitors, diodes, valves, pumps, actuators, cylinders, receivers, compressors

- 4 **Be able to produce engineering drawings using a computer aided drafting (CAD) system**

  Prepare a template: standardised drawing sheet e.g. border, title block, company logo; save to file

  CAD systems: computer systems e.g. personal computer, networks; output devices e.g. printer, plotter; storage e.g. server, hard disc, CD, pen drive; 2D CAD software packages e.g. AutoCAD, Microstation, Cattia, Pro/Engineer, Pro/Desktop

  Produce engineering drawings: set-up commands e.g. extents, grid, snap, layer; drawing commands e.g. coordinate entry, line, arc, circle, snap, polygon, hatch, text, dimension; editing commands e.g. copy, move, erase, rotate, mirror, trim, extend, chamfer, fillet

  Store and present engineering drawings: save work as an electronic file e.g. hard drive, server, pen drive, CD; produce paper copies e.g. print, plot, scale to fit

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 create sketches of engineering components using a range of techniques	M1 assess the suitability of the different techniques for the sketches	
P2 describe the benefits and limitations of using pictorial techniques to represent a given engineering component		
P3 interpret the main features of a given engineering drawing which complies with drawing standards	M2 explain in the importance of working to recognised standards when producing engineering drawings	
P4 produce detailed drawings of three given single-piece components that comply with drawing standards	M3 explain how the sketches comply with drawing standards	
P5 produce an assembly drawing of a product containing three parts that complies with drawing standards		

P6 produce a circuit diagram that complies with drawing standards, with at least five different components which use standard symbols	M4 explain in how a given engineering drawing would be used and the reasons it is suitable for its intended audience	D1 evaluate the use of different methods of producing engineering drawings including manual and computer aided methods
P7 prepare a template drawing of a standardised A3 sheet using a CAD system and save to file	M5 explain the hardware components of a typical industry standard CAD system.	D2 evaluate the functionality of a CAD software package.
P8 produce, store and present 2D CAD drawings of a given single-piece component and an assembly drawing of a product containing three parts.		

Essential guidance for tutors

Assessment

Assessment of this unit could be through the use of five assignments. To achieve a pass learners are expected to show competence in a number of graphical techniques and to be able to apply these to the production of engineering drawings which meet recognised standards.

The first assignment, to cover P1, P2 and M1, could consist of a small portfolio of sketches and written descriptions. Items drawn must include regular solids and hollow objects, standard and engineering components. The techniques used must be valid and involve sketching equipment, pictorial and orthographic representation and sketching in good proportion with the addition of some dimensions (as specified in the unit content). An assessment of these techniques will meet the requirement for M1.

The second assignment, to cover P3 and M2, will need to be carefully structured and should be based on a drawing of a component or assembly rather than a circuit diagram so that the unit content can be properly covered. M2 builds upon the evidence presented for P3 and these two criteria could be assessed using a single assignment. The wider issues of standardisation and manufacturing for the global market place should be addressed with learners supporting their explanations with case study evidence.

The third assignment could cover P4, P5 and M3 with the three single-piece components in P4 being used for the assembly drawing in P5. This would then make the assignment more realistic in terms of what happens in industry. M3 would require an explanation of how the sketches in P4 comply with drawing standards.

The fourth assignment could cover P6, M4 and D1 with learners being given a choice of the type of circuit they produce depending on their interest (i.e. from electrical, electronic, hydraulic and pneumatic). The circuit can be drawn by hand but using CAD may be the preferred method if a library of components is available. M4 requires an explanation of the use of engineering drawings to communicate information effectively. D1 could be carried out as a separate task, requiring an evaluation of the various drawing techniques used by the learner and link directly with the criteria P1, P5, P6 and P8. To add depth to their evidence, learners could be asked to look more widely at what is used in industry – particularly the use of 3D CAD systems which generate solid models. This would then bring them full circle back to the start of the unit, where they were producing pictorial sketches.

P7, P8, M5 and D2 can be covered by a fifth assignment, which could ask for increased competence in the application of standards when producing drawings. To help authenticate learners' work, additional evidence could be in the form of witness statements, tutor observation records and 'screen dumps' which show the range of commands used during the development of the drawings. M5 and D2 could form a separate task as part of this assignment, requiring an explanation of CAD hardware and an evaluation of CAD software functionality.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Producing Engineering Sketches	Learners have been asked to produce sketches of a range of different objects.	A practical assignment requiring learners to produce a portfolio of engineering sketches with accompanying written descriptions.
P3, M2	Interpreting and Using Drawing Standards	Learners have to read and interpret an engineering drawing in order to report the key features of the component, circuit or assembly to a colleague.	A written assignment for which learners need to produce a short report detailing the main features of a given engineering drawing that complies with drawing standards. A further task would require them to explain the importance engineering standards.
P4, P5, M3	Producing Engineering Drawings	Learners need to produce an engineering drawing of three components and an assembly drawing for use by the manufacturing department of their company.	A practical assignment in which learners produce component and assembly drawings.
P6, M4, D1	Producing Circuit Drawings	Learners need to produce a circuit diagram for use by the manufacturing	A practical assignment in which learners produce a circuit diagram.

		department of their company.	

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, M5, D2	Producing Engineering Drawings Using CAD	Learners need to prepare and produce 2D CAD drawings for use by the manufacturing department of their company.	A practical assignment in which learners produce 2D CAD drawings of a component and an assembly.

Essential resources

To meet the needs of this unit it is essential that centres have, or have access to, manual drawing equipment and a CAD system which uses a 2D commercial engineering software package. Centres will also need extracts and illustrations from appropriate drawing standards and conventions.

Indicative reading for learners

Textbooks

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Fane B – *AutoCAD 2014 for Dummies* (John Wiley and Sons, 2013) ISBN 9781118603970

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2009) ISBN 9780750689854

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 13: Computer Aided Drafting in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Computer aided drafting is fast becoming the primary means of communicating design information in many industry sectors, particularly in engineering and manufacturing. Two-dimensional (2D) CAD drawings and three-dimensional (3D) CAD data can be shared with computer numerical control (CNC) machines using computer aided manufacturing (CAM) software. 3D models can be rendered to produce photo-realistic representations, or can be animated to produce moving views of products and components as they would appear in service. Additionally, models can be used to analyse features such as mass, volume and mechanical properties.

This unit will enable learners to produce a variety of CAD drawings, from single-part 2D components to complex 3D models. Advanced techniques, such as using pre-prepared symbols to construct circuit diagrams and assembly drawings, will provide opportunities for learners to develop their skills. Learners will also investigate the use of CAD in industry, the hardware and software required and the links with other software packages. In doing this learners will appreciate the advantages of CAD over more conventional methods of drawing production.

Finally, learners will generate 3D models, make comparison with 2D CAD drawings and evaluate the impact of this technology on manufacturing companies and their customers.

The unit as a whole provides an opportunity to carry out practical CAD activities using a full range of commands and drawing environments. In addition, learners will gain an understanding of the use and impact of CAD on the manufacturing industry.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the national and international standards and conventions that CAD drawings and design need to comply with

2 Understand the advantages of using CAD in comparison with other methods

3 Know about the software and hardware required to produce CAD drawings

4 Be able to produce and interpret CAD drawings

5 Be able to use CAD software to produce 3D drawings and views.

Unit content

- 1 **Know the national and international standards and conventions that CAD drawings and design need to comply with**

  Requirements of current national and international standards and conventions: engineering drawing practice: BS8888:2013, BS5070-3 1988, BS EN 13622:2002, ISO standards

  Features of CAD drawings that need to comply with national and international standards: drawing sheet sizes and layouts, projection - first and third angle types of line, lettering and numbering, dimensioning, section cross hatching

  Standard representations: welding symbols, electrical symbols, pneumatic/hydraulic symbols, mechanical symbols

- **2 Know the advantages of using CAD in comparison with other methods**

  Advantages of CAD: quality; accuracy; time; cost; electronic transfer of information; links with other software e.g. CAD/CAM, rendering software, animation software, finite element analysis (FEA)

  Other methods: manual drafting; model making

- 3 **Know about the software and hardware required to produce CAD drawings**

  Software: operating systems; CAD software packages e.g. AutoCAD, AutoCAD/Inventor, Microstation, Catia, Pro/ENGINEER, Solidworks; minimum system requirements e.g. hard disk space, memory required, processor, video card

  Hardware: keyboard; mouse; other input devices e.g. light pen, digitiser, joystick, thumbwheel; monitor; printer; other output devices e.g. plotter, rapid prototyping; storage e.g. floppy disk, hard disk, memory stick, CD, network

- 4 **Be able to produce and interpret CAD drawings**

  CAD drawings: orthographic projections; circuit diagrams e.g. hydraulic, pneumatic, electronic; exploded/ assembly drawing; standards e.g. BS8888, BS3939, BS2917

  Commands: absolute/relative/polar coordinates; features e.g. linetypes, grids, snaps, circle, text, hatching, dimensioning, layers/levels, colour; viewing e.g. zoom, pan; inserting other drawings e.g. symbols, blocks; modifying e.g. copy, rotate, move, erase, scale, chamfer, fillet

  Interpret: determine properties of drawn objects e.g. list, distance, area, volume

- 5 **Be able to use CAD software to produce 3D drawings and views**

  3D environment: 3D views e.g. top, front, side, isometric

  3D models: 3D techniques e.g. addition and subtraction of material, extrude, revolve, sweep, 3D coordinate entry (x, y, z), wire frame drawing, 2D to 3D (thickness, extrusion); surface models; solid models

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the requirements of national and international standards and conventions relating to engineering drawing practice		
P2 explain which features of CAD drawings that need to comply with national and international standards		
P3 explain the advantages, compared to other methods, of producing drawings electronically using a CAD package	M1 explain the relationship between CAD and other software/hardware used in manufacturing	D1 justify the use of CAD in a manufacturing company
P4 describe the software and hardware that are required to produce CAD drawings		

P5 produce 2D CAD detail drawings of five components that make up an assembly or sub-assembly to given standards, using appropriate commands	M2 explain how the range of commands used to produce CAD drawings can impact drawing production	
P6 produce a circuit diagram containing at least five components to appropriate standards, using appropriate commands		
P7 produce an assembly drawing and exploded view of an assembly or sub-assembly containing at least five parts, using appropriate commands		
P8 interpret the properties of an engineering component or circuit from a given CAD drawing		
P9 construct a 3D CAD drawing as a surface and solid model.	M3 explain how 3D CAD models can be used in the design process.	D2 evaluate the impact of the use of 2D and 3D CAD models on final design requirements.

Essential guidance for tutors

Assessment

An assignment could cover P1 and P2 and should be structured so that learners remain focused on the content of learning outcome 1. Learners are expected to use their own words when referring to the national and international standards and conventions, whilst much of their research will be done using the internet, it is important that what they present is not just a simple cut and paste exercise. Evidence to support knowledge of which features of CAD drawings comply with national and international conventions. CAD drawings could be generated by giving learners which highlight the details required for meeting National and International conventions.

The assessment evidence for P3 and P4 could be produced through a case study or through studying the company in which learners may be employed. Typically, it would take the form of a written report or presentation. To achieve P3, learners must demonstrate an understanding of how CAD is used in comparison with more traditional drawing methods, stating its advantages and explaining how CAD systems can be linked with other software. A description of basic hardware and software requirements to operate a CAD system will be required to achieve P4.

The remaining pass criteria could be evidenced through a series of competence based practical activities. Evidence could be in the form of witness statements, tutor observation records or a portfolio, although it is likely that electronic files will be used for the majority of the assessment. Screen dumps can often be a good source of evidence to show the range of commands used during the development of the drawings. The process evidence for these remaining pass criteria (P5 to P9) could be obtained from further assignments. In the first of these learners would be required to produce five separate CAD drawings of the components which make up an assembly or sub-assembly. The full range of commands must be used and the drawings should be dimensioned to an appropriate standard, enabling P5 to be achieved. These drawings could then be used to produce an assembly and exploded view drawing (P7).

A further assignment would require production of a circuit diagram to achieve P6. This might reflect the learner's occupation or area of interest and should be assembled from symbols previously introduced by the tutor and/or externally sourced. This assignment could also ask learners to interpret and provide a summary of the information contained in a given detail drawing or circuit diagram (P8).

The final assignment would require production of a single 3D model using both surface and solid modelling techniques to enable achievement of P9. This might be a 3D version of one of the part drawings used as evidence for the assembly and exploded view drawing.

To achieve a merit grade, learners will need to look beyond how drawings are produced and evaluate their use and application. This will typically be through looking more closely at the relationship between CAD and other software. Learners should be able to explain how linking CAD to other software/hardware impacts on an organisation (for example improving production, reducing waste, reducing lead times). This will build upon the evidence generated for P3 and enable the M1 merit criterion to be achieved.

An explanation of the range of commands for criterion M2 and how they impact on drawing production in terms of efficiency (for example speed, accuracy, repeatability) links with P5, P6 and P7. Similarly, knowledge for the M3 criterion of how 3D models can be used in the design process links with the 3D activity in P9.

To achieve distinction criterion D1, learners should be able to justify the use of CAD and will need to analyse other factors (for example disadvantages, costs, training requirements). This links with P3 and P4 as well as the M1 and M2 criteria. Learners should be able to evaluate the relative merits of using CAD software. This could be as part of the case study outlined as possible evidence for the P3 criterion.

To achieve the D2 criterion learners will need to evaluate 2D and 3D drawings from a customer perspective. This links directly with the P9 and M3 criteria. Learners will need to compare and contrast the impact on customers of producing drawings using 2D and 3D CAD and how customers might use the information produced.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1 and P2	National and International Standards Report	Learners to research national and international standards and relate to engineering CAD drawing practice.	A report describing national and international standards and an explanation of CAD features that need to comply with these standards.
P3, P4, M1 and D1	CAD Report	Learners to research and compare the use of CAD with other methods and determine the software and hardware required to produce CAD drawings; in addition an investigation of how CAD links to other software and hardware and a justification of the use of CAD in manufacturing.	A report containing written responses about the use of CAD and alternative methods; in addition the software and hardware requirements of a CAD system should be listed and explained. An explanation of how CAD links with other software and hardware should support a justification of the use of CAD in a manufacturing context.
P5, P7 and M2	CAD Portfolio	Learners to create an assembly drawing of at least five parts and detail CAD drawings of the five components; in completing the task learners	A portfolio of five component drawings and an assembly drawing containing the five individual parts; in addition a short report containing written responses

		should be able to explain how they used a range of commands in the CAD software to efficiently produce drawings.	and/or screen dumps explaining how a range of CAD commands were used to efficiently produce the completed drawings.

Essential resources

Centres will need to have access to a suitably equipped IT facility with access to a printer/plotter. Access to software with 2D and 3D capabilities, such as AutoCAD and Inventor is also required. Whilst general graphics packages would not be suitable, any CAD software capable of generating the evidence required for this unit would be acceptable.

Indicative reading for learners

Textbooks

Ambrosius L – *AutoCAD 2009 and AutoCAD LT 2009: All-in-one Desk Reference for Dummies* (John Wiley and Sons, 2008) ISBN 9780470243787

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2009) ISBN 9780750689854

Yarwood A – *Introduction to AutoCAD 2012* (Routledge, 2011) ISBN 9780080969473

Unit 14: Advanced Mechanical Principles and Applications

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

This unit will build on the learner's knowledge of underpinning mechanical principles and the way they affect the design, operation, testing and servicing of machines and mechanisms.

The component parts of a mechanical system are very often subjected to loads and may be used to transmit force. It is essential that they are fit for purpose so that costly breakdowns and accidents are avoided. Design engineers must be able to predict the stresses to which engineering components will be subjected and ensure an appropriate level of safety.

Learning outcomes 1 and 2 will broaden the learner's knowledge of stress analysis to include stress due to bending, stress due to torsion and the effects of two-dimensional and three dimensional loading.

Learners sometimes have difficulty with the concepts of resultant and relative velocity. Learning outcome 3 seeks to clarify how these concepts are determined through the techniques of vector addition and vector subtraction. These are then applied to the operation of plane linkage mechanisms to determine the output characteristics for given input conditions.

The aim of learning outcome 4 is to give an understanding of mechanical oscillations in engineering systems. The concept of simple harmonic motion is introduced and expressions are derived for its parameters. These are then applied to freely vibrating systems such as mass-spring systems and the simple pendulum.

The unit as a whole provides an opportunity for investigative, relevant and active study that will enhance the learner's ability to solve engineering problems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to determine the effects of uniaxial and complex loading on engineering components
2. Be able to determine the stress due to bending in beams and torsion in power transmission shafts
3. Be able to determine relative and resultant velocity in engineering systems
4. Be able to determine the characteristics of simple harmonic motion in engineering systems.

Unit content

- 1 **Be able to determine the effects of uniaxial and complex loading on engineering components**

  Uniaxial loading: expressions for longitudinal and transverse strain; application of Poisson’s ratio; determination of dimensional changes in plain struts and ties

  Complex loading: expressions e.g. strain in x and y directions due to 2D loading, strain in x, y and z directions due to 3D loading; changes e.g. dimensional in rectangular plates, dimensional and volume for cubic elements

- 2 **Be able to determine the stress due to bending in beams and torsion in power transmission shafts**

  Direct stress due to bending: expressions for second moment of area of solid and hollow rectangular and circular beam sections; application of bending equation ($\sigma/y = M \mathrm{I} = E \mathrm{R}$) to determine stress due to bending and radius of curvature at a beam section; determination of factor of safety in operation

  Shear stress due to torsion: expressions for polar second moment of area of solid and hollow circular transmission shaft sections; application of torsion equation ($\tau/\mathrm{r} = T J = \mathrm{G}\,\theta\,\mathrm{l}$) and expression for power transmitted (*Power* = $T\omega$) to determine induced shear stress and angle of twist; determination of factor of safety in operation

- 3 **Be able to determine relative and resultant velocity in engineering systems**

  Resultant and relative velocity: vector addition of velocities; resultant velocity of a body with simultaneous velocities in different directions; vector subtraction of velocities; relative velocity between objects moving simultaneously in different directions; construction of space diagrams and velocity vector diagrams

  Plane mechanisms: e.g. slider-crank and inversions, four-bar linkage and inversions, slotted link quick return mechanism, Whitworth quick-return mechanism; construction of diagrams e.g. space diagram, velocity vector diagram, determination of output motion

- 4 **Be able to determine the characteristics of simple harmonic motion in engineering systems**

  Simple harmonic motion generation: general equations for simple harmonic motion derived from a consideration of uniform circular motion e.g. expressions for circular frequency, displacement with time, velocity with time, velocity with displacement, acceleration with time, acceleration with displacement, periodic time, frequency of vibration; application to mechanical systems where output simple harmonic motion is generated by input uniform circular motion e.g. scotch yoke mechanism; parameters to be determined e.g. frequency of vibration, periodic time, displacement, velocity and acceleration at a given instant

  Vibrating mechanical systems: systems (mass-spring, simple pendulum); expressions for circular frequency in terms of system parameters; application of general equations for simple harmonic motion e.g. natural frequency of vibration, periodic time, velocity and acceleration at a given instant

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 determine the dimensional effects of uniaxial loading on a plain structural component and two-dimensional loading on a rectangular plate	M1 determine the dimensional effects and change in volume for a given element of an engineering component when subjected to three-dimensional loading	
P2 determine the maximum stress due to bending, factor of safety in operation and minimum radius of curvature for a simply supported beam carrying a given concentrated load and a uniformly distributed load	M2 compare the effects on a rectangular section beam's load-carrying capacity of increasing the breadth and increasing the depth by given amounts	D1 compare the saving in weight and the reduced torque transmission capacity for a hollow power transmission shaft as its internal diameter is increased
P3 determine the maximum shear stress, factor of safety in operation and angle of twist for a mechanical power transmission shaft when transmitting given power at a given speed		

P4 determine the resultant velocity of an object when moving simultaneously with velocities in two different directions and its velocity relative to a second object moving in the same plane in a third direction	M3 determine the output velocity of a given quick-return mechanism for given input conditions	
P5 determine the output motion of a slider-crank mechanism and a four-bar linkage mechanism for given input conditions		
P6 determine the periodic time and the displacement, velocity and acceleration at a given instant of the simple harmonic motion generated by circular motion of given parameters	M4 evaluate the output motion of the slider in a slider-crank mechanism with uniform input motion of the crank, for compliance with the conditions necessary for it to describe simple harmonic motion.	D2 determine from test data the effective contributory mass of the spring in an oscillating mass-spring system.
P7 determine the circular frequency, the natural frequency of vibration and the maximum velocity and acceleration for a mass-spring system and a simple pendulum with given parameters.		

Essential guidance for tutors

Assessment

Ideally, assessment of this unit will be achieved through applying the mechanical principles covered to relevant engineering settings. This could be achieved through integration with other engineering principles units, practical work that provides learners with opportunities to produce individual evidence for assessment and individual project/assignment tasks. Whichever approach is taken it is important to ensure that the criteria are achieved autonomously. Where centres consider a test/examination is necessary to achieve authentic evidence, they need to ensure that the test items are set in a way to enable the criteria to be met in full. Centres also need to consider how such an assessment will provide opportunities to meet the merit and distinction criteria and how to provide learners with further learning and assessment should they initially fail to achieve in the test/examination.

If learners make an arithmetic error within the solution to a problem, it is for the centre to decide the significance of such an error, assess the work accordingly and provide suitable feedback. For example, if a learner has chosen the correct approach and manipulated the necessary formulae and data correctly but has made and carried through a minor arithmetic error, then the final 'inaccurate' solution to the problem may be deemed to be good enough to meet the criterion. However, if the final solution to the problem is so obviously wrong that it should have prompted further checks for accuracy, then the solution could be deemed to be unacceptable and reassessment considered. The incorrect application of units and/or dimensions is a typical cause of such major errors, which can lead to relatively large scale errors of the magnitude 103 or greater.

Assuming that the unit is delivered in the order of the learning outcomes, a first assignment could provide an opportunity to achieve the pass criterion P1 by means of tasks to determine the dimensional effects of uniaxial and two-dimensional loading. These could be followed by a task to determine the dimensional effects of three-dimensional loading and corresponding change in volume for achievement of the M1, all to be documented in a short report and authentication of the evidence being presented

A second assignment might contain a task to determine the stress and curvature in a loaded beam (P2) and a task to determine the shear stress and angle of twist in a power-transmission shaft for given operating conditions (P3), suitably documented. A third task, to achieve criterion M2, could be to examine the effects of increasing the breadth and depth of a rectangular beam section on its second moment of area and hence also on its load-carrying capacity. A fourth task to achieve D1 might be to compare the saving in weight and the reduction in torque transmission capacity as the internal diameter of a hollow transmission shaft is increased.

P4 and P5 could be assessed through an assignment containing a task to determine resultant and relative velocities in a system of moving bodies and a task to determine the output motion of plain mechanisms for given input conditions. Both a slider-crank and four-bar chain should be considered, whilst a third task to achieve M3 could be to determine the output velocity of a quick-return mechanism. In all three criteria there is an expectation that the response will involve the construction of diagrams to help determine the solution.

A final assignment for P6 and P7 should contain tasks to determine the parameters of simple harmonic motion for a system generated by uniform circular motion, a mass-spring system and a simple pendulum. These could be followed by a task to evaluate the output motion of a slider-crank mechanism for uniform input rotation of the crank to achieve merit criterion M4.

The evaluation should conclude that the motion is not simple harmonic but that it may be approached be lengthening the connecting link. A final task to achieve distinction criterion D2 could involve the gathering and analysis of test data to determine the contributory effect of spring mass on the periodic time of a vibrating mass-spring system. The test data may be given in the absence of practical test facilities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	Uniaxial and Complex Loading	A suitable engineering situation to set problems involving engineering components subjected to uniaxial loading, two-dimensional and three-dimensional loading.	A written report containing an explanation to each step in the sequence of calculations, experiments or simulations and findings.
P2, P3, M2, D1	Bending and Torsion	A suitable engineering situation to set problems on a simply supported beam and problem on a power transmission shaft Evaluation of load-carrying capacity and power-transmission capacity.	A written report containing an introductory explanation to each step in the sequence of calculations and findings. A written evaluation of the load-carrying capacity of a beam and the power-transmission capacity of a shaft.
P4, P5, M3	Resultant and Relative Velocity	A suitable engineering situation to set problems involving resultant and relative velocity of moving bodies and motion in plane mechanisms.	A written report containing an introductory explanation to each step in the sequence of graphics and calculations.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M4, D2	Simple Harmonic Motion	A suitable engineering situation to set problems involving simple harmonic motion in engineering systems. Evaluation of the output motion of the slider-crank mechanism and analysis of test data for a mass-spring system.	A written report containing an explanation to each step in the sequence of calculations and findings. A written evaluation of the output motion of a slider-crank mechanism. Analysis of test data for a mass-spring system to determine the contributory mass of the spring.

Essential resources

Centres should have access to investigation and demonstration equipment, such as simply supported beam apparatus, torsion test apparatus and apparatus for the investigation of simple harmonic motion.

Indicative reading for learners

Textbooks

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Bolton W – *Engineering Science* (Newnes, 2006) ISBN 9780750680837

Darbyshire A – *Mechanical Engineering BTEC National Option Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 15: Engineering Primary Forming Processes

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Almost everything we touch in the world of technology has been created through some technique or process associated with primary forming – the forming of shapes with minimal waste and loss of volume. Without these primary forming processes, the technological world as we know it today would not exist.

Many engineering components are initially formed by moulding, deformation or shaping. Over the years, these processes have been refined to suit the introduction of new materials and the demands of quantity production. In some processes, the shaped component is almost ready for use and requires only a little cleaning and trimming. In others it is produced slightly oversize and, after cleaning and trimming, it is machined accurately to the required dimensions.

The main aim of this unit is to provide a broad understanding of manufacturing processes associated with primary forming. It will give learners a broad understanding of moulding techniques for metals, ceramics and polymers, deformation processes for metals and polymers, and shaping and assembly of composites. The unit will introduce learners to a range of techniques and primary processes but will provide a deeper understanding of the more common processes.

For each technique and process learners will form an appreciation of the fundamental process requirements, the working techniques used and the relevant health and safety considerations. The use of these primary processes sometimes creates a dangerous environment and knowledge of relevant health and safety and related legislation is very important.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand how moulding techniques involving metals, ceramics and polymers are used

2 Understand how deformation processes involving metals and polymers are used

3 Understand how shaping and assembly processes involving composites are used

4 Understand how health and safety issues relate to primary forming processes.

Unit content

- 1 **Understand how moulding techniques involving metals, ceramics and polymers are used**

  Moulding techniques involving metals: casting method e.g. sand, die (gravity, pressure), investment, continuous; metal applicable to process e.g. ferrous (carbon steels, stainless steels, cast iron), non-ferrous (aluminium, copper, brass, zinc, magnesium, nickel, titanium, alloys); form of material supply e.g. pig iron, scrap, ore, ingots, recycled material, metal composition, trace elements, coke, limestone; mould production e.g. patterns, cores, dies, moulding parts (boxes, sand, reinforcements, releasing agents, runners, risers, sprues); component removal and finishing e.g. knock out, ejection, fettling

  Moulding techniques involving ceramics: powder metallurgy (blending, compacting); sintering; secondary operations e.g. infiltration, sizing, coining, machining, impregnation, plating, heat treatment; ceramics applicable to process e.g. metallic carbides, nitrides, oxides

  Moulding techniques involving polymers: techniques e.g. compression, transfer, injection, rotational moulding, blow moulding; polymers applicable to process e.g. thermoplastics, thermosetting plastics, polystyrene, polyethylene, acetal, acrylonitrile butadiene styrene (ABS), nylon, polycarbonate, polypropylene; use of additives e.g. stabilisers, flame retardants, fillers (asbestos, cotton flock, fibres, mica, graphite, wood flour), plasticisers, antistats, colorants, lubricants; mould tools e.g. two plate, three plate, combination/composite, split, unscrewing; moulding parameters e.g. temperature, pressure, speed/timings, distance, flashing, short shot, distortion, burning, colour deviation

- 2 **Understand how deformation processes involving metals and polymers are used**

  Deformation processes involving metals: processes e.g. extrusion (direct, indirect, impact), forging (drop, pressure, upset), rolling (hot, cold), presswork (forming, bending, deep drawing), metal spinning; metals applicable to process e.g. ferrous (carbon steels, stainless steels), non-ferrous (aluminium, copper, brass)

  Deformation processes involving polymers: processes e.g. vacuum forming, extrusion, calendaring; polymers applicable to process e.g. thermoplastics, polycarbonate, polysulphon, acrylic, polyvinyl chloride, ABS, thermoplastic sheet; use of additives e.g. plasticisers, antistats, lubricants, heat stabilisers; features e.g. double curvatures, shapes (male, female), stiffened mouldings, section shape; parameters e.g. temperature, pressure, speed/timings, distance, flashing, short shot, distortion, burning, colour deviation

- 3 **Understand how shaping and assembly processes involving composites are used**

  Composite shaping processes: processes e.g. pre-preg laminating, wet lay-up, moulding; use of fibre (glass, polyethylene, aramid, carbon); use of resin (polyester, vinyl ester, epoxy, phenolic); composite materials applicable to process e.g. wood, Coremat, foam, honeycomb (Nomex, aluminium), syntactic core, expanding core; design features e.g. corners (internal, external), surface (concave, convex, return, vertical), double curvature, nett edges, joggle details; types of reinforcement e.g. roving, braids, tapes, chopped strand, continuous filament, uni-directional, woven, multi-axis

  Composite assembly processes: types e.g. trial, one-off, batch, assembly line; features e.g. tolerances (loose or close fit), fixing (permanent or non-permanent), shape location, joins (joggle, return or overlap); assembly methods e.g. fettling, pinning, clamping, trial fitting, aligning, assembly jigs and sequences; joining methods e.g. thread inserts, fasteners (mechanical, quick release), anchor nuts, rivets; composite components e.g. trim, panels (closing, body), tubes, structural, aerodynamic, core materials, sections, inserts, housings; non-composite components e.g. brackets, fixtures, fittings, trim, tapes, memory foam, films

- 4 **Understand how health and safety issues relate to primary forming processes**

  Health and safety: relevant health and safety legislation and regulations e.g. Control of Substances Hazardous to Heath (COSHH) Regulations 2002, Provision and Use of Work Equipment Regulations (PUWER) 1998, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013 Lifting Operations and Lifting Equipment Regulations 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Control of Major Accidents and Hazards Regulations 2015 (COMAH), Control of Noise at Work Regulations 2005, Health and Safety (First Aid) Regulations 1981, European directives, relevant codes of practice; requirements for the use of guards, screens, ventilation; use of personal protective equipment (PPE); manual lifting and handling techniques

  Reducing risks: e.g. use of risk assessment methods, avoidance of dangerous conditions, appropriate training, good housekeeping, safe use of tools and equipment

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the moulding techniques used to manufacture a metal-based component	M1 compare and contrast the different moulding techniques used to manufacture products from metals, ceramics and polymers	D1 justify the use of a specific moulding technique for the manufacture of a given product
P2 explain the moulding techniques used to manufacture a ceramic-based component		
P3 explain the moulding techniques used to manufacture a polymer-based component		
P4 explain the deformation processes used to manufacture a metal-based component	M2 compare and contrast the different deformation processes used to manufacture products from metals and polymers	D2 justify the use of a deformation process for the manufacture of a given product.
P5 explain the deformation processes used to manufacture a polymer-based component		

P6 explain the shaping processes used to manufacture a composite-based component	M3 explain why a composite shaping process is appropriate for a given manufactured product	
P7 explain the methods used to manufacture a composite-based assembly		
P8 explain the health and safety issues that relate to each of the primary forming processes considered	M4 suggest improvements that could reduce the risk to the health and safety of a primary forming process operator.	
P9 explain methods of reducing risk for each of the primary forming processes considered.		

Essential guidance for tutors

Assessment

A suitable strategy for this unit would be for learners to carry out detailed investigations into the way given or chosen products are manufactured. A range of products will be required and needs to be investigated to ensure learners have opportunities to cover the range of primary forming processes listed and the requirements of the assessment criteria.

Criteria P1, P2, P3, M1 and D1 relate to learning outcome 1 and P4, P5, M2 and D2 relate to learning outcome 2. These could be assessed by the first two assignments. These assignments should give learners an opportunity to demonstrate their understanding of the different moulding techniques and deformation processes. The tasks set should ensure that they explain a moulding technique suitable for each of the materials covered by learning outcome 1 (i.e. metals, ceramics and polymers) and suitable deformation processes for both metals and polymers for learning outcome 2. Tasks set within the assignments could require learners to compare and contrast particular moulding techniques (M1) and deformation processes (M2) for products made from the materials listed in the content for learning outcomes 1 and 2 respectively. For the products selected learners must justify the moulding technique used (D1) and deformation process (D2).

A third assignment could concentrate on composite manufacture (learning outcome 3). A task should be set to explain both a composite shaping process (P6) and a composite assembly process (P7). A further task, or a holistic task, could then ask learners to explain why a particular composite shaping process would be appropriate for a given manufactured product (M3). Care should be taken when selecting a product for this task to ensure that it has all the requirements of the content within the learning outcome, i.e. the use of fibre, resin, design features and types of reinforcement. Likewise, the explanation for P6 should also have these aspects of content covered.

The final assignment should enable learners to achieve P8, P9 and M4. They should be asked to explain the health and safety issues that relate to the processes covered earlier (P8) and to describe risk reduction for one process (P9).

To cover M4 learners could evaluate and suggest improvements to any relevant aspects of legislation or risk within an area of interest to them (for example use of equipment, guards, clothing and handling). The most important aspect of the evidence will be the learners' ability to evaluate the situation and come up with some distinct and valid improvements.

The assessment evidence for this unit is likely to be in the form of a number of written responses in a portfolio that may include information and diagrams. Centres need to take care that the evidence used for assessment is the learner's own work and that where learners make use of other people's work then this is clearly acknowledged and referenced. Centres may find it helpful to guide learners by providing a recommended structure for their descriptions and in particular a format/system for including references.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Moulding Techniques for Metals, Polymers and Ceramics	An activity requiring learners to carry out research based on actual engineering techniques and suitable roles associated with metals, polymers and ceramics.	A portfolio containing written responses and diagrams showing moulding techniques for each material family type. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.
P4, P5, M2, D2	Deformation Processes for Metals and Polymers	An activity to investigate, aligned to a suitable role, the processes associated with the deformation of a range of metals and polymers.	A portfolio containing written responses and diagrams showing deformation processes for metals and polymers. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.
P6, P7, M3	Shaping and Assembling Composite-Based Products	An activity to investigate the shaping and assembly processes associated with composite product manufacture set within a suitable context.	A portfolio containing written responses and diagrams showing composite shaping processes and assembly processes used to manufacture composite based products. Carried out under

			controlled conditions. This activity could be supported by a PowerPoint presentation.
P8, P9, M4	Improvements to Processes and Health and Safety in Primary Forming	An investigative activity based around a suitable role involving the review of the health and safety issues associated with primary forming processes involving metals, polymers and ceramics. Followed by a case study to improve the primary forming process of a manufactured product and making a safer environment for an operator.	A portfolio containing a written commentary about health and safety and risk reduction. This activity could be supported by an evaluation of a process to suggest improvements to the process and its safe operation. Evidence could also be made available by a PowerPoint presentation.

Essential resources

Centres must have access to a range of cast, ceramic-moulded, polymer-moulded and process-deformed components, along with a range of components made from composites, including both shaped and assembled. Ideally, centres would have facilities to practically demonstrate some of the primary processes covered by the unit content, although this is not essential. However, centres that are unable to do so should consider industry visits or, alternatively, video and other presentation resources. Access to relevant health and safety legislation will be required.

Indicative reading for learners

Textbooks

Black B – *Workshop Processes, Practices and Materials* (Routledge, 2015) ISBN 9781138784727

Bolton W – *Materials for Engineering* (CRC Press, 2006) ISBN 9780849387807

Health and Safety Executive – *Health and Safety in Engineering Workshops* (Health and Safety Executive, 2004) ISBN 9780717617173

Timings R L – *Manufacturing Technology* (Prentice Hall, 1998) ISBN 9780582356931

Unit 16: Engineering Secondary and Finishing Techniques

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

For everyday products and components to be manufactured to a required standard, the machines that produce them need to be operated in an efficient and safe manner. During this process, trial components are made to check accuracy and ensure a minimum amount of waste during production. Machine operators will produce better components if they are aware of a range of finishing and secondary processes that can be used. A secondary process is where raw material or a component is taken for further working, usually involving material removal, and is carried out after a primary forming process.

This unit aims to provide learners with a detailed knowledge of the use of secondary processing machines, including traditional machines (for example lathes and drilling machines) and others found in a more specialist workshop (for example spark or wire erosion methods).

The unit gives learners an opportunity to examine a range of secondary processing machines, their design and application. To a lesser extent they will also be able to identify a range of 'non-traditional' techniques, such as electro discharge and broaching.

Learners will investigate heat treatment processes, which are often used to get a product or component into its final state and ready for use. Without these processes parts would fail prematurely or further manipulation would not be possible on certain materials to create a final component. Learners will also understand assembly methods, including automated techniques that can be associated with computer-aided manufacture and other modern approaches, such as flexible manufacturing systems.

Finally, learners will understand how finishing techniques are used in engineering to add either function or aesthetics to a part component or product. Anodising and plating methods will be discussed, as well as hot processes used to obtain a required finish (such as powder coating or hot dipping) and the associated aspects of health and safety.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand how a range of secondary machining techniques are used
2 Know how a range of non-traditional techniques are used
3 Know how heat treatment processes and assembly techniques are used
4 Know how finishing techniques are used.

Unit content

1 Understand how a range of secondary machining techniques are used

Turning: machine e.g. centre lathe, turret; features of the workpiece e.g. flat faces, diameters (such as parallel, stepped, tapered), holes (such as drilled, bored, reamed), profile forms, threads (such as internal, external), eccentric features, parting off, chamfers, knurls or special finishes, grooves, undercuts

Milling: machine e.g. horizontal, vertical, universal, planer/gantry; up-cut; down-cut; features of the workpiece e.g. faces (such as flat, square, parallel, angular), steps/shoulders, slots (such as open ended, enclosed/recesses, tee), holes (such as drilled, bored), profile forms (such as vee, concave, convex, gear), serrations, indexed or rotated forms, special forms

Boring: machine e.g. horizontal, vertical; features of the workpiece e.g. bored holes (such as through workpiece, to a depth, tapered), holes (such as drilled to depth, drilled through workpiece, reamed, threaded), external diameters, grooves/recesses, chamfers/radii, faces (such as flat, square, parallel, angular, milled), slots, forms (such as indexed, rotated), external tapers

Grinding: machine e.g. surface (such as horizontal, vertical), cylindrical (such as external, internal), centreless, universal, thread, profile; features of the workpiece e.g. faces (such as flat, vertical, parallel, square to each other, shoulders and faces), slots, diameters (such as parallel, tapered), bores (such as counterbores, tapered, parallel), profiles forms, thread forms (such as vee, right hand, single start, multistart, internal, external), angular faces

Presswork: machines e.g. single action, multiple action; features of the workpiece e.g. blanking, notching, piercing, joggling, cropping/shearing, bending/forming, coiling/rolling, planishing/flattening, first draw, second draw, compound operations, cupping, embossing, coining

Health and safety: appropriate legislation and regulations e.g. Health and Safety at Work Act 1974, Fire Precautions Act 1971, manual handling, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013, Provision and Use of Work Equipment Regulations (PUWER) 1998, Health and Safety (First Aid) Regulations 1981; use of personal protective equipment (PPE)

Materials: e.g. ferrous, non-ferrous, non-metallic, stainless, special alloys, deep drawing steels

Kinematics: machine tool design; generation and forming of shapes; six degrees of freedom

2 Know how a range of non-traditional techniques are used

Electro discharge: machines e.g. spark erosion, wire erosion; features of the workpiece e.g. holes, faces (such as flat, square, parallel, angular), forms (such as concave, convex, profile, square/rectangular), other features (such as threads, engraving, cavities, radii/arcs, slots)

Broaching: machines e.g. horizontal, vertical; features of the workpiece e.g. keyways, holes (such as flat sided, square, hexagonal, octagonal), splines, serrations, other special forms

Honing and lapping: machines e.g. honing (such as horizontal, vertical), lapping (such as rotary disc, reciprocating); features of the workpiece e.g. holes (such as through, blind, tapered), faces (such as flat, parallel, angular)

3 Know how heat treatment processes and assembly techniques are used

Heat treatment processes for ferrous metals: surface hardening; other processes e.g. hardening, tempering, annealing, normalising; appropriate health and safety requirements e.g. Health and Safety at Work Act 1974, requirements relating to chemicals and materials handling (such as Control of Substances Hazardous to Health (COSHH) Regulations 2002, safe disposal of waste materials and components (fluids, hardening materials), manual handling, safe use of electrical and pressurised equipment, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013, Provision and Use of Work Equipment Regulations (PUWER) 1998)

Assembly techniques: manual e.g. screwed fasteners, locking devices, keys, dowels, circlips; automated e.g. part feeding devices, transfer and indexing, orientation devices

4 Know how finishing techniques are used

Hot processes: e.g. hot dip treatment (such as molten wax, molten tin to steel, molten zinc to steel, organic coatings), powder coating (such as fluidised bed thermoplastic coating powder, fluidised bed thermosetting powder, electrostatic grade thermoplastic powder, electrostatic grade thermosetting powder)

Anodising: e.g. sulphuric acid, chromic acid, hard anodising

Plating methods: e.g. electroplating (such as copper, gold, silver, cadmium, platinum), electroless nickel, mechanical (such as mechanical zinc, mechanical tin-zinc, mechanical aluminium-zinc), alloy (such as brass, nickel-iron, tin-lead, zinc-nickel, zinc-iron, zinc-cobalt), zinc (such as cyanide zinc, alkaline zinc, acid zinc), nickel and chromium, hard chromium; substrates e.g. mild steel, stainless steel, brass, copper, zinc based, aluminium

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain how five different secondary machining techniques are used safely on a range of materials	M1 compare and contrast why different secondary machining techniques are used when manufacturing products	D1 evaluate the effective use of an appropriate secondary machining technique
P2 explain kinematics in secondary machining techniques		
P3 identify appropriate non-traditional techniques for six given products		
P4 describe an appropriate non-traditional technique for a given product		
P5 explain surface hardening and another heat treatment process for ferrous metals	M2 compare and contrast why different heat treatment processes are used when manufacturing products from ferrous metals	
P6 describe two different manual and an automated assembly technique		
P7 describe a hot process, anodising and plating		

method when used for finishing on different components		
P8 explain the appropriate heat treatment processes, secondary, finishing and assembly techniques needed to manufacture four given components.	M3 from given restrictions and information justify alternative assembly and finishing techniques.	D2 evaluate a given secondary machining technique and heat treatment process for health and safety risk and impact on the environment.

Essential guidance for tutors

Assessment

It is important that the assessment strategies used are designed to suit the needs of learners. Good assessment strategies are most likely to be supported by proper presentation of appropriate evidence. A portfolio or file of evidence should not contain course notes, research etc. unless it is to become part of the required evidence and assessment.

Work done through the use of case-study material can be used to generate evidence for the portfolio, particularly if industrial visits are well embedded in delivery. It is likely that a range of products will need to be investigated to ensure learners have opportunities to cover the required range of secondary machining techniques and heat treatment processes, together with finishing and assembly techniques.

To achieve a pass, learners need to demonstrate understanding and knowledge of the different processes and techniques, explain or describe their characteristics and how they are used. While learners need to explain what is meant by kinematics in relation to secondary techniques, they only need to show enough knowledge to describe one non-traditional technique. However, they must be able to select appropriate non-traditional techniques for six different products. Learners also need to describe both surface hardening and one of the other processes, such as annealing, and both types of assembly techniques (manual and automated). They should also be able to describe all three types of finishing techniques as listed in the unit content.

This unit could be assessed through three assignments. The first assignment could be a series of written tasks to cover P1, P2, P3 and P4. The task for P1 should have enough detail for learners to cover turning, milling, boring, grinding and presswork. The types of machine they consider from each of these could be left to the learner, as they may have a preference from their place of work. Alternatively, a specific machine type could be given to different learners across the range. This would help centres authenticate each learner's response.

The tasks should also ensure that learners consider the health and safety requirements and cover at least three of the material types listed in the content.

The six products given for P3 must cover the three non-traditional techniques ranged – electro discharge, broaching and honing/lapping. The products should have sensible characteristics, such as type of material, quantity, size, accuracy (tolerances) and surface texture requirements to clearly direct learners towards the correct non-traditional technique. The written task for P4 could be about one of the machines from these techniques. Again, some learners may have preferences based on their workplace. This assignment could also include further written tasks to cover both M1 and D1.

The second assignment could have tasks to explain heat treatment processes (P5) and assembly techniques (P6). Surface treatment must be covered but freedom can be given as to which other process is described. The task should also ask learners about the health and safety requirements. The task addressing P6 must cover two manual and one automated technique.

A further task could be developed to cover M2, which would give learners an opportunity to cover more of the range of heat treatment processes. A comparison between hardening, tempering and annealing would be sensible. Another task in the assignment could cover P7 ensuring that all finishing techniques are covered.

Another task should be given to allow learners to justify alternative assembly and finishing techniques (M3). In doing so, a range of restrictions and information should be given to ensure learners are able to come up with some sensible alternatives. An example is when the modification of an assembled component allows an automatic feeding device to be used, assuming the batch quantity information indicates it would be viable, or a material amendment needs a change of finishing technique.

The third assignment could have a task requiring learners to explain appropriate processes and techniques as listed in P8 for four different components. These components need to be fairly complex to include a requirement for a heat treatment process, a secondary, a finishing and an assembly technique. These requirements must not be given but be suggested by the component characteristics and specification. This can be done by a set of drawings/specifications or by actual products, with a set of notes that would ensure the learners are able to identify the appropriate process and techniques. A final written task could be included to give an opportunity to cover D2.

To achieve a merit, learners need to be able to compare and explain how different machining techniques are used (M1) and how different heat treatment processes are used in manufacturing (M2). They will need to suggest alternative assembly and finishing techniques when given specific restrictions and information (M3).

To achieve a distinction, learners need to confidently evaluate the effective use of secondary machining techniques (D1) for certain circumstances. Learners should show skills in evaluating a given secondary machining technique and a given heat treatment process for health and safety risk and impact on environmental issues (D2).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P1, P2, P3, P4, M1 and D1	Secondary and Non-Traditional Machining Techniques	An activity requiring learners to carry out research based on actual secondary and non-traditional machining techniques associated with a range of materials.	A portfolio containing written responses and diagrams showing the five different secondary machining and non-traditional techniques for a range of material types, possibly supported by a PowerPoint presentation. Alternatively a case study could be used and presented as a portfolio.
P5, P6, P7, M2	Heat Treatment Processes, Assembly and Finishing Techniques	An activity to investigate the processes associated with the heat treatment of ferrous metals, and the use of hot processes and finishing techniques.	A portfolio containing written responses and diagrams showing heat treatment processes for ferrous metals and descriptions of assembly techniques, hot processes, anodising and a plating method. This activity could be supported by a PowerPoint presentation.
P8, M3 and D2	Secondary Processes and Finishing Techniques Associated with	An activity to investigate the heat treatment processes, secondary,	A portfolio containing written responses to show the processes and techniques used

	Manufacturing Products	finishing and assembly techniques associated with product manufacture.	to manufacture four given components, possibly supported by a PowerPoint presentation. Alternatively, a case study could be used and presented as a portfolio.

Essential resources

Centres should have access to as large a range of the machinery and processes outlined in the unit content as possible.

Indicative reading for learners

Textbooks

Health and Safety Executive – Health and Safety in Engineering Workshops (Health and Safety Executive, 2004) ISBN 0717617173

Timings R L – Manufacturing Technology (Prentice Hall, 1998) ISBN 0582356938

Unit 17: Fabrication Processes and Technology

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Fabrication processes and technology are used in the production of metal structures in a wide range of manufacturing industries. The fabrication of metal structures involves four essential stages: measuring and marking out, preparation of the material for fabrication, forming processes and the assembly of the materials.

This unit gives learners with no previous fabrication experience an understanding of the processes and technologies used throughout the fabrication industry, whilst learning to work in a safe environment. The unit is appropriate for work-based learners or for those who are being prepared for employment in an industrial environment where fabrication is an integral part of the manufacturing process.

Learners will work with ferrous or non-ferrous metals in the form of sheet, plate and sectional materials to construct a fabricated structure. They will learn how to use a range of industrial hand tools and machinery to complete fabrication tasks. The unit will give learners the ability to identify the correct processes and equipment to use, and the tools and equipment appropriate to each stage of the fabrication process.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand health and safety legislation, regulations and safe working practices for fabrication activities

2 Know the processes used to mark out and prepare materials to produce fabricated structures

3 Know how materials are formed and assembled to produce fabricated structures

4 Be able to interpret the specification of a fabricated structure and plan and carry out its manufacture.

Unit content

- 1 **Understand health and safety legislation, regulations and safe working practices for fabrication activities**

  Legislation and regulations: applicable to fabrication activities e.g. Health and Safety at Work Act 1974, Employment Act 2002, Factories Act 1961, Fire Precautions Act 1971; regulations e.g. Management of Health and Safety at Work Regulations 1999, Provision and Use of Work Equipment Regulations 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013, Working Time Regulations 1998, Workplace (Health, Safety and Welfare) Regulations 1992, Health and Safety (First Aid) Regulations 1981

  Safe working practices: safety in the workshop and on site; fire prevention; accident prevention and reporting; risk assessment; manual handling; checking conditions e.g. gas leaks, voltage and amperage, correct fuses, leads, guarding of machinery and power tools; action to be taken when machinery and equipment are dangerous or in poor condition; personal protective equipment (PPE); ventilation and extraction; closing down e.g. equipment safety, storing equipment, safe disposal of waste materials, use of compressed air

- 2 **Know the processes used to mark out and prepare materials to produce fabricated structures**

  Marking out: measuring and marking out equipment e.g. rule, protractor, tee square, set square, tape measure, compass, dividers, trammel, templates, marker pen, scriber, chalk line, laser level; detailed drawing e.g. dimensions, tolerances; reference points e.g. datum line, centre line datum; setting out e.g. radial line, triangulation, projection, true lengths; calculations e.g. bend allowance, allowance for springback, intersection points, overlap; calibration of equipment

  Fabricated structures: examples from local industry; made in a centre’s workshop e.g. equipment storage systems (i.e. tool rack, tool box), work bench, car maintenance equipment (i.e. axle stand, ramp, crawler board), ventilation ducting (i.e. collector hood, reducing section, tee connector)

  Preparing materials: obtaining materials e.g. sheet, bar, plate, section; standard bought out condition e.g. hot-rolled, cold rolled, standard dimensions, profiles, thickness; metallic materials e.g. ferrous, non-ferrous; cutting to size and shape e.g. flame, plasma, powder, water jet, laser, band saw, hacksaw, reciprocating saw; shearing e.g. hand, bench, rotary, reciprocating; guillotining e.g. bench, power; nibbling e.g. hand, power; presswork e.g. piercing, blanking, punching; material removal e.g. chiselling, drilling, trepanning, filing, grinding; automated methods e.g. numerical control (NC), computer numerical control (CNC), direct numerical control (DNC), mechanical copying using templates

- 3 **Know how materials are formed and assembled to produce fabricated structures**

  Forming: principles e.g. spring back, bend allowance; forming by hand e.g. hammer and former, fly press, bench mounted bending machine; forming by machine e.g. folding machine, press brake; rolling tools (e.g. rolling rolls, pyramid rolls, slip rolls, cone rolls), angle ring-bending; swaging; deep drawing and pressing; web stiffeners; edge preparation; pipe bending; use of templates and patterns; automated methods e.g. numerical control (NC), computer numerical control (CNC), direct numerical control (DNC)

  Fabricated structures: examples from local industry; made in a centre's workshop e.g. equipment storage (i.e. tool rack, tool box), work bench, car maintenance equipment (i.e. axle stand, ramp, crawler board), ventilation ducting (i.e. collector hood, reducing section, tee connector)

  Assembly: trial assembly or 'physical mock up' e.g. offering up, alignment, clamping, dimensional checks, adjustment, modification; workshop clamps e.g. mitre joint, toggle, G clamp, rivet clamps/skin pins, magnetic clamping devices; joining methods e.g. spot welding, continuous welding, laser welding, brazing, soldering, structural adhesives, riveting; mechanical fixings e.g. nuts, bolts, screws, clamps, pipe connectors; web stiffeners; inspect and check against specification

- 4 **Be able to interpret the specification of a fabricated structure and plan and carry out its manufacture**

  Structure specification: engineering drawing e.g. assembly, detailed, development; material e.g. steel, aluminium; material supply forms e.g. plate of appropriate thickness, hollow section, solid section, pipe, tube; reference points e.g. edge datum, centre line datum; dimensions e.g. overall, reference, installation, tolerance; permanent and non-permanent assembly methods e.g. thermal, adhesive, riveting, mechanical fixings; finish e.g. paint, polymer coat, electro-plate, polish; quantity e.g. one off, small batch, large volume

  Plan and manufacture: calculations e.g. bend allowance, allowance for springback, intersection points, quantity of material required, minimisation of waste material; select suitable equipment e.g. marking out, preparation, templates, patterns, forming and assembly; mark out; produce manufacturing aids e.g. formers, jigs, templates; prepare and form individual parts of the assembly e.g. cutting to size, edge preparation, piercing, bending; assemble the fabrication and join parts together e.g. trial assembly or 'physical mock up', modification, weld, braze, rivet, fixings; meet the required accuracy as specified e.g. dimensions, tolerances, finish, visual appearance, joint quality; inspect and check against specification

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the key features of the health and safety legislation, regulations and safe working practices applicable in a fabrication workshop	M1 explain the effect, including aspects of safety and quality, of using incorrect equipment and processes to produce a fabricated structure	
P2 describe the process of marking out when producing fabricated structures	M2 explain the factors that influence the assembly methods used in the production of a fabricated structure	D1 justify the methods used to prepare materials when producing a fabricated structure
P3 describe the process of materials preparation when producing fabricated structures		
P4 describe how materials are formed before they are assembled into a fabricated structure		
P5 describe the assembly process for a given fabricated structure		
P6 interpret the specification of a fabricated structure to plan its manufacture.	M3 produce a fabricated structure to specification.	D2 evaluate the quality of manufacture against that specified for a fabricated structure.

Essential guidance for tutors

Assessment

Assessment of this unit could be achieved through the use of four assignments.

The first assignment could cover P1, with learners being asked to produce a written report. Evidence presented for P1 must be specific to fabrication processes and learners will need to be given clear guidelines about what to present. There is a huge amount of generic material which learners will have access to. Care should be taken to ensure that what they present is referenced properly and not directly copied from the internet or any other source. Grading criteria P1 and M1 complement each other and it may be that centres wish to cover them both in the first assignment. However, learners might do better if M1 is assessed later once they have a better understanding of the problems associated with using the wrong equipment and processes. If this is the case then M1 could be assessed through the assignment which addresses grading criterion P5.

P2, P3 M2 and D1 can be assessed through a second assignment. Evidence could be in the form of a written report supported by drawings, diagrams and photographic images of formative practical work carried out by learners as they investigated the various marking out and materials preparation techniques. Records of responses to oral questioning by the tutor may also be appropriate. Learners' evidence should also demonstrate further understanding of what influences the use of assembly methods for M2. D1 requires learners to demonstrate an understanding of the techniques used to prepare materials for fabrication by justifying the use of a selected method.

A third assignment could cover P4 and P5(and M1 if not already covered in the first assignment). This should follow a similar format as assignment 2, with much of the evidence being based on the practical investigations carried out by learners on forming and assembly techniques. If M1 is covered in this assignment learners' reports/evidence will also need to evidence their understanding of the consequences of using incorrect equipment and processes.

In P6 and M3 learners will use a given specification to plan and produce a fabricated structure. Care should be taken when designing the assignment brief for P6 and M3 to make sure that it does not just become a test of the learners' practical skills. Due to the time constraints of delivering the unit, it is not reasonable to expect learners to carry out joining processes that require a higher level of skill at an expert level.

There is scope to assess learning outcome 4 as a group activity so that learners can appreciate working as a team to produce a larger fabrication. Each learner could be given a part to work on, although care needs to be taken to ensure that the evidence presented by each learner addresses the whole of the unit content and can be substantiated. Digital annotated photographic images together with witness statements and observation records should be used to consolidate learner evidence of practical competence.

To achieve D2 learners could evaluate the quality of the fabricated structure produced in M3 and report on the quality of the structure compared to that set out in the given specification. This offers an opportunity for learners to evaluate the preparation, forming and assembly techniques they have used and identify where they can develop skills and techniques to improve quality.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P1, M1	Health and Safety for Fabrication Activities	An activity-based assignment that requires learners to research and identify health and safety legislation and safe working practices in fabrication activities.	A report that outlines legislation and safe working practices applicable to fabrication activities. The report should identify and clearly reference all research materials.
P2, P3, M2, D1	Marking Out and Preparing Fabrication Materials	A written assignment that evidences and further investigates the formative practical tasks that have been carried out in a fabrication workshop.	A written report will form a summative assessment that contains drawings, diagrams and photographs to evidence the range of marking out and preparation processes. Learners will justify the methods they have used to prepare materials in a fabrication workshop.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5	Forming and Assembling Fabrication Materials	A written assignment that evidences the practical investigations that the learner has carried out in a fabrication workshop.	Summative assessment will require a written report that contains evidence of the range of forming and assembly processes used in a fabrication workshop. The report will be supported with diagrams and photographs of their work. The report will examine the possible effects of using incorrect tools and processes. It will also include learners' interpretation of why particular assembly processes have been used.
P6, M3, D2	Manufacturing From a Specification	A practical assignment that requires the learner to plan and make a fabricated structure from a given specification.	The learner will interpret information from a given specification and produce a plan of the processes and fabrication techniques to be used. Having planned the work, and agreed the plan with the tutor, the learner will produce the fabricated structure given in the specification.

			Learners will produce a report which evaluates the quality of their work against the original specification.

Essential resources

Learners will need access to workshop facilities equipped with a range of marking out, forming and assembly tools and equipment, along with a variety of fabrication materials. Access to current health and safety legislation and regulations would also be useful for learning outcome 1.

Indicative reading for learners

Textbooks

Kenyon W – *Basic Welding and Fabrication* (Longman, 1987) ISBN 9780582005365

Robinson A – *The Repair of Vehicle Bodies* (Routledge, 2013) ISBN 9780415534451

Smith B D – *Welding Practice* (Butterworth-Heinemann, 1995) ISBN 9780340614068

Timings R L – *Fabrication and Welding Engineering* (Routledge, 2008) ISBN 9780750666916

Wakeford R E – Sheet Metal Work (Special Interest Model Books, 1987) ISBN 9780852428498

Unit 18: Welding Technology

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning: 60

Unit introduction

A diverse range of welding processes is used within the manufacturing engineering industry, including manual, mechanised and machine-based techniques. The selection and application of these joining processes is vital in terms of the weld quality, and the economic viability of the finished product.

The learner will appreciate the need to produce high-quality welded joints in components based on the selection of the most appropriate process. To enable learners to make an informed choice they will be required to select joining processes to satisfy a given application. The unit is appropriate for work-based learners where their industrial environment utilises welding as an integral part of the manufacturing process. It is also suited to learners who are being prepared for employment in the welding industry.

Learners will perform a range of formative practical tasks that will include planning and preparing for work and ensuring that health and safety legislation and safe working practices are understood and followed at all times. Learners will select and check the condition of appropriate equipment, which is particularly important considering that learners could be working with electric currents, combustible gas mixtures or parts rotating at high speed.

Continuous formative assessment allows learners to develop their practical skills and knowledge which lead to summative assessments. Assignments will require them to report and record the development of their skills in the preparation and production of welded joints. Learners will inspect their work with reference to relevant quality standards, ensuring that they are capable of producing welded joints and are able to recognise defects.

Note that the use of 'e.g' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand health and safety legislation, regulations and safe working practices in the welding industry

2 Be able to prepare for welding operations

3 Be able to produce welded joints to a quality standard

4 Understand how quality inspection processes are applied to welded joints in components.

Unit content

- 1 **Understand health and safety legislation, regulations and safe working practices in the welding industry**

  Legislation and regulations: legislation e.g. Health and Safety at Work Act 1974, Employment Act 2002, Factories Act 1961, regulations e.g. The Fire Precautions (Workplace) Regulations 1997, Management of Health and Safety at Work Regulations 1999, Provision and Use of Work Equipment Regulations (PUWER)1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations (LOLER)1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2015, Working Time Regulations 1998, The Workplace (Health, Safety and Welfare) Regulations 1992, Health and Safety (First Aid) Regulations 1981, Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2007, Simple Pressure Vessels (Safety) Regulations 1994

  Safe working practices: fire prevention; accident prevention and reporting; risk assessment; manual handling e.g. materials, safe handling of gas cylinders; checking conditions e.g. gas leaks, voltage and amperage, correct fuses, circuit breakers, leads, earthing of equipment; personal protective equipment (PPE); ventilation and extraction; closing down e.g. equipment safety, storing equipment, safe disposal of waste materials; emergency procedures e.g. within the learning environment and the workplace; hazards associated with welding e.g. burns, electric shock, radiation

- 2 **Be able to prepare for welding operations**

  Information sources: safety instructions; job instructions; engineering drawings; quality control documentation e.g. weld procedure specification (WPS), record and reporting sheets

  Tools and equipment: check equipment availability; function and condition relevant to the welding process e.g. cables, hoses, torches and electrode holders, gas pressure regulators, flow meters; working environment e.g. workshop, site work, conditions for machinery and plant; assembling welding equipment e.g. cables, weld return clamps, electrode holders, gas cylinders, regulators, valves, safety devices

  Welding parameters: setting and adjusting e.g.:

  - for manual processes: gas pressure, flow rates, voltage, current (either alternating (AC) or direct (DC)), according to electrode or filler size
  - for mechanised processes: safety devices, welding speed, other parameters (electrical parameters, flux dispensing and recovery mechanisms, wire feed rate, filler diameter, gas shielding system, mechanical functions (handling, loading, workholding, transfer))
  - for resistance welding machines: welding current, welding and squeeze times, electrode pressure cycle, electrode size, welding speed (seam), weld pitch (spot), mechanical functions, electrode diameter and condition
  - for laser welding machines: electrical parameters, welding speed, weld alignment and characteristics, beam tracking, beam characteristics (focal

spot), gas shielding, mechanical mechanisms for workholding, traversing and transfer

- for friction welding machines: friction and forge cycle time, friction and forge loads (forces), rotational speed or other friction conditions (orbital, frictional burn-off characteristics, forge displacement, braking effort), weld appearance (correct upset)

Welding processes: manual e.g. manual metal-arc (MMA), metal inert gas (MIG), metal active gas (MAG), metal-arc gas shielded, flux cored wire, tungsten inert gas (TIG), plasma-arc, gas welding; mechanised e.g. MIG/MAG, cored wire, TIG, plasma-arc, submerged arc; machine based e.g. resistance welding machines (spot, seam, projection), laser welding machines, friction welding machines

Consumables: appropriate to process e.g. electrode (rutile, basic, nickel alloy, cellulosic, stainless steel, other electrodes), filler wire, gases (oxygen, acetylene, shielding gases), inert and active gases, flux/agglomerated flux, forms of supply, care when handling flux; safe storage of consumables

- 3 **Be able to produce welded joints to a quality standard**

Safety: fire prevention; accident prevention and reporting; using risk assessment; manual handling; equipment maintenance; checking conditions e.g. gas leaks, voltage and amperage, fuses, circuit breakers, leads; wearing PPE; fumes; using ventilation and extraction; closing down equipment safely after use

Joints/components: e.g.

- for manual processes: butt, fillet, autogenous weld (without filler wire)
- for mechanised processes: two different joint configurations, two different material groups
- for resistance welding machines: two different material thicknesses, two different joint configurations
- for laser and friction welding machines: two different components, two different material groups

Welding positions: to a relevant standard e.g. British Standard (BS) EN 287 flat (PA), horizontal vertical (PB), horizontal (PC), vertical upwards (PF), vertical downwards (PG), overhead (PE), inclined tube/pipe (H-L045 or J-L045); welding technique e.g. torch angle, filler angle

Material: forms e.g. plate (thickness appropriate to process, up to 6 mm for resistance welding), section, pipe/tube, sheet (<3 mm), other forms; types e.g. carbon steel, stainless steel, aluminium

Quality standard: minimum weld quality standard equivalent to the level given in the relevant standard e.g. European/International Standard BS EN ISO 5817, BS EN ISO 10042, BS EN ISO 13919-2; meet the required accuracy as specified e.g. dimensions, tolerances, weld quality, spot and projection welds are correctly located

- 4 **Understand how quality inspection processes are applied to welded joints in components**

  Quality standard: safety in the use of test equipment and chemicals; minimum weld quality standard equivalent to the level given in the relevant standard e.g. European and International Standard BS EN ISO 5817, BS EN ISO 10042, BS EN ISO 13919-2, BS EN 12062; meet the required accuracy as specified e.g. dimensions, tolerances, weld quality, spot and projection welds are correctly located

  Testing: non-destructive inspection e.g. dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), pressure tests (hydraulic, pneumatic), fluorescent particle, magnetic particle; destructive e.g. macroscopic examination, nick break (fracture) tests, bend tests visual inspection; weld gauges e.g. fillet, leg length, undercut and hi-lo gauges

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain aspects of health and safety legislation, regulations and safe working practices applicable to welding		
P2 use information sources to select a welding process for a given application, and suggest suitable parameters for the welding process	M1 analyse the effect of using incorrect welding parameters for a selected welding process including the effects on quality when producing welded components	D1 justify the selection of a welding process for a given application when producing welded components
P3 produce a list of consumables that are required for a selected welding process		
P4 plan the tools and equipment needed to produce welded components safely using a selected welding process	M2 explain the safety issues associated with the selected welding process	D2 discuss quality standards associated with the selected welling proves.

P5 use appropriate welding positions and materials to produce two welded joints safely with a manual or mechanised welding process	M3 discuss the advantages and disadvantages of two welding processes considering consumables, equipment, technique and quality for a given welding application	
P6 produce two welded joints/components to a quality standard using a manual or mechanised welding process		
P7 use appropriate welding positions and materials to produce two welded joints safely with a machine-based welding process		
P8 produce two welded joints/components to a quality standard using a machine-based welding process		
P9 explain the results of a destructive and non-destructive test on a given joint/component when welded to a quality standard.	M4 explain the benefits and limitations of using a non-destructive inspection methods on welded components.	

Essential guidance for tutors

Assessment

Assessment of this unit could be through the use of four assignments.

The first assignment could cover P1 where learners are asked to produce a written report. Evidence for P1 must be specific to welding and the processes used within the industry. Learners will need clear guidelines in respect of what they should present. There is a large amount of generic material that learners will need to access. Care should be taken to ensure that what is presented is properly referenced and not directly copied from the internet or any other source.

A second assignment covering P2, M1 and D1 could be used to demonstrate the information sources to select a welding process. The practical experience will influence learners' ability to answer this task. M1 and D1 can be achieved by analysing the effect of incorrect welding parameters and justifying a selected process for a given welding application. Learners will need to demonstrate their knowledge of both joining processes and the properties of engineering materials.

A third assignment covering P3, P4, M2 and D2 could be used to demonstrate the preparatory requirements for a selected welding process. Evidence could be presented in the form of a written report or by an oral presentation, supported by diagrams and photographs of formative practical work. Learners will need to select and describe a welding process for a given application. The expectation within this task is that all areas of the process will be described and the stated quality standards will be taken into account. M2 and D2 could be achieved with reference to safety and quality standards, as shown in the content, associated with the welding process.

Criteria P5, P6, P7, P8 and M3 could be assessed through a fourth practical assignment. The evidence for the practical investigations will be in a written report format, or may be assessed as part of a logbook or portfolio that records the types of joint, materials and positions used, and the consumables required for the process. This may be supported by witness statements or observation records used to show the evidence required. This will provide evidence of the joints produced using either a manual or mechanised welding process. The choice of whether a manual or mechanised process should be used is left to the centre and may be decided by the pathway that learners are following in their workplace. More freedom of choice may exist with centre-based learners but attention should be given to likely local employment opportunities. Criteria P7 and P8 require joints to be welded using machine-based processes which should be assessed in a similar format to P5 and P6. Care must be taken to consult the content section of the unit to ensure that the range of welding positions, joints, materials and consumables appropriate to the joining process being assessed for the manual, mechanised and machine-based welding processes. M3 can be achieved by the learner comparing two processes, which could be the processes used in P6 and P8, and demonstrating further knowledge of the processes. Care will be required when selecting the given application to ensure learners have opportunities to carry out this comparison. Although it is not compulsory to have a manual and mechanised process, this is where opportunities may be maximised during a comparison.

A fifth assignment could be used in assessing P9 and M4 where the learner uses a report to explain the results of quality standards used for the joints produced in P6 and P8. Learners should include their findings, and refer to the standards, accuracy, destructive and non-destructive tests used. Reference should be made to the original guidelines for the given application and any quality standards that are indicated. This will enable them to explain the benefits and limitations of non-destructive inspection methods (M4).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1	Safe Working Practices When Welding	Learners need to produce an information report on health and safety requirements and safe working practices applicable to the welding industry.	A written report that explains the legislation and safe working practices used in the welding industry with clear referencing to appropriate sources of information.
P2, M1, D1	Using Information	Learners have to select a suitable process and welding parameters and identify consumables	A written report could be used to assess the pass criteria using diagrams and photographs of relevant information. Further analysis and justification would assess M1 and D1. It may be considered that an oral presentation, supported with appropriate graphics, may be more suitable in the assessment of all criteria in this assignment. The tutor should consider the method of maintaining evidence of the presentation.
P3, P4, M2, D2	Preparing for Work	Plan the consumables, tools and equipment needed for a given welding application (e.g. a number of welded joints to form a simple component).	A written report supported by a logbook or portfolio that records the range of consumables, tools and equipment.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, P8, M3	Producing Quality Welded Joints	Learners need to produce welded joints to a required quality standard.	A written report supported by a logbook or portfolio that records the range of joints, materials and welding positions used. Evidence of the weld quality may include photographs, diagrams, witness statements, and quality reports. The report should identify the quality standards used and compliance to that standard. A comparison of two welding processes clearly identifying the processes and the advantages and disadvantages of each process for a given application should be included.
P9, M4	Inspecting Welded Joints	Learners test welded joints that they have previously made in a material or component.	A practical activity evidenced by a report that discusses the quality inspection processes used for the joints produced in P6 and P8 and the results. The report can further investigate the benefits and limitations of using non-destructive testing techniques on welded components.

Essential resources

Centres delivering this unit will need access to appropriate welding equipment, consumables and materials as outlined in the unit. Centres must also have access to appropriate destructive and non-destructive test equipment.

Indicative reading for learners

Textbooks

Davies A – *The Science and Practice of Welding, Volume 1* (Cambridge University Press, 1993) ISBN 9780521435659

Davies A – *The Science and Practice of Welding, Volume 2* (Cambridge University Press, 1993) ISBN 9780521435666

Raj B, Shankar V and Bhaduri A – *Welding Technology for Engineers* (Alpha Science International Ltd, 2006) ISBN 9781842651940

Smith B – *Welding Practice* (Routledge, 1995) ISBN 9780340614068

Timings R – *Fabrication and Welding Engineering* (Routledge, 2008) ISBN 9780750666916

Weman K – *Welding Processes Handbook* (CRC Press, 2003) ISBN 9780849317736

Zhang H – *Resistance Welding* (CRC Press, 2012) ISBN 9781439853719

Unit 19: Selecting and Using Programmable Controllers

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

The automation of machines, process control and conveyor lines has resulted in the ever-increasing consistency of quality, speed and cost savings within complex processes. Consumers have come to expect high standards of quality in the manufactured goods they use, but to an engineer these are the challenges that make the profession interesting.

This unit will consider programmable logic controllers (PLCs), control devices which aid the automation of these processes. The capabilities of PLCs have developed over the years, with performance, reliability and operational resilience being key attributes to their continued success. In order to achieve automated monitoring and control, these devices can be used on their own or in conjunction with others through communication systems/links, which are themselves becoming more versatile.

The unit will introduce learners to the use and applications of PLCs, the hardware and software that makes up a PLC and the interaction needed between the component parts. Learners will develop their ability to use programming techniques to produce programs for modern PLCs. They will also gain an understanding of the different types of communication media used to link larger numbers of PLCs together, the networking architecture used and the associated standards and protocols.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand the selection, hardware and software requirements of a programmable controller
2. Be able to use programming techniques to produce a program for a modern programmable controller
3. Understand complex programmable controller applications
4. Understand data communications media and networks used with modern programmable controllers.

Unit content

1 Understand the selection, hardware and software requirements of a programmable controller

Programmable controller selection: types (unitary, modular, rack-mounted); criteria e.g. cost, versatility and scanning time; internal architecture e.g. central processing unit (CPU), arithmetic and logic unit (ALU), flags, registers, memory and types (volatile, non-volatile); scan cycle (self-test, input/logic/output scans)

System hardware and software requirements: manufacturers' specification of input/output (I/O) units (digital and analogue); power supply; use of operating system; configuration of inputs and outputs; number systems e.g. binary, octal, hexadecimal, binary-coded decimal (BCD); input/output devices; mechanical switch relays (electromechanical and solid state); transducers e.g. temperature, pressure, flow, smart sensors, simple motors and drives

2 Be able to use programming techniques to produce a program for a modern programmable controller

Programming techniques: e.g. ladder and logic diagrams, statement listing, functional diagrams, graphical programming languages, mimic diagrams, sequential function charts (SFCs)

Produce, store and present program: human computer interface (HCI) e.g. handheld input pad, personal computer, text, graphical touch screens; use of system software to write, edit, delete, save, restore, create reports, load/unload, search; use of fault diagnostic indicators; print copies of program; storage e.g. scanning, memory organisation, continuous updating, back-up copies, supervisor control and data acquisition (SCADA)

Instruction types: production of program using relay, bit, branch, timer/counter, comparison, logical, arithmetic instructions; proportional integral derivative (PID) controller loops

3 Understand complex programmable controller applications

Program documentation: hardware considerations (environmental, operational, maintainability); instruction types; documentation for testing e.g. software debug instructions, diagnostic indicators, data monitors, search, force facilities; complex engineering applications e.g. machine, process control, conveyor

Health and safety with programmable controller: safe working practices for personnel and with equipment e.g. tools and equipment risk assessment, job safety analysis (JSA), housekeeping practices for work areas, personal protective equipment (PPE), restriction of non-participants from areas; health and safety standards (local, national, international) e.g. local safety agreements between employees and employers, Health and Safety Executive (HSE), Health and Safety at Work Act 1974, regulations for the use of display screens; avoiding haphazard operations e.g. risk management, planning considerations, testing (usability, unit, component, acceptance), 'what If' scenarios, commissioning

4 Understand data communications media and networks used with modern programmable controllers

Communication media: selection criteria, description of features, frequency ranges, technology e.g. analogue, digital, wireless; cable e.g. twisted pairs, coaxial, fibre-optic, shielded/unshielded, categories, operational lengths; connector e.g. Bayonet-Neill-Concelman (BNC), registered jack (RJ-45), straight tip (ST), universal serial bus (USB) type A and type B; opto-isolator e.g. photodiode, phototransistor, thyristors, triacs

Network: network architecture (fieldbus, distributed intelligence, 'open' communications networks); network standards/protocols e.g. International Organisation for Standardisation (ISO), Institute of Electrical and Electronic Engineers (IEEE), Manufacturing Automation Protocol (MAP), Electronics Industry Association (EIA-485), Factory Instrumentation Protocol (FIP)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the selection criteria and a practical application for a unitary, a modular and a rack-mounted programmable controller	M1 explain the benefits and limitations of a programmable controller for a specific application	
P2 explain the system hardware and software requirements for a programmable controller application		
P3 use a programming technique to produce, store and present a program that demonstrates the full range of instruction types	M2 explain the programming technique used and list the instruction types	D1 justify the choice of a specific programming technique and the methods used to produce, store and present the program
P4 explain the program documentation that has been used for a complex engineering application		
P5 describe the importance of health and safety when working with programmable controlled equipment		

P6 explain how one example of each of the three types of communication media would be selected for a specific programmable controller application	M3 compare two different networks used for a modern programmable controller system.	D2 compare the current capabilities and limitations of a programmable controller and identify possible areas of future development.
P7 describe a network and relevant standards and protocols used for a modern programmable controller system.		

Essential guidance for tutors

Assessment

PLCs involve a complex mixture of computer technology, communication interfaces and software programming techniques.

The assessment strategy for this unit should consist of a mix of written technical reports and hands-on practical work. Annotated photographic evidence could also be a valuable tool to capture 'on-site' information and support learners' written work.

Where the grading criteria refer to an 'application' this is intended to mean a real-world situation wherever possible. Although a different application could be used for different criteria it would be reasonable to use the same or closely related applications throughout.

P1 and P2 are closely linked. P1 requires learners to describe the selection criteria and a practical application for a unitary, a modular and a rack-mounted programmable controller. In doing so, learners need to demonstrate their ability to recognise the different approaches to PLC operational activities. In describing the selection criteria learners should consider things such as cost, versatility and scanning time, together with relevant descriptions of the internal architecture (e.g. central processing unit (CPU), arithmetic and logic unit (ALU) etc.) and a practical application of each.

For P2, a comprehensive range of hardware and software requirements should be considered. For example, the power supply available may have quite different consequences for an application involving a field monitoring system as opposed to an installation in a factory. The amount of coverage of content for this criterion will be determined by the actual programmable controller application considered but it is expected that the learner should have at least four or five system hardware and software requirements indicated and explained.

P3 requires learners to use a programming method to produce, store and present a program that demonstrates the full range of instruction types. Learners are not expected to be fully competent programmers but their programs should be printed out, annotated where appropriate and stored.

The explanation required for P4 needs to cover all the related unit content including hardware considerations, instruction types and documentation for testing. A 'complex engineering application' in this context is intended to mean some form of machine, a manufacturing process control operation or a conveyor system based on a real-life situation. Learners will need to provide some details of the complex application and go on to explain the documentation, for example the program instructions, testing documentation and forced facilities etc associated with it. Ideally this would be a work-based application, although learners could be provided with a case study of a complex application.

P5 requires learners to describe the importance of health and safety when working with programmable controlled equipment. A range of 'what if' scenarios for various applications could be used to cover the full requirements of the unit content.

P6 requires learners to explain how one example of each of the three types of communication media (cable, connector, opto-isolator) would be selected for a specific programmable controller application. The key point here is for learners to recognise the media, understand how each one is selected, describe the main features and consider aspects such as frequency ranges and the technology to which they are being applied.

For P7, there is a possibility that the description of a network and relevant standards and protocols could become overly complex and involve a wide range of issues. Therefore, learners need to be restricted to describing just the general network architecture of perhaps an Ethernet, and provide details of the associated standards and what they generally imply.

M1 builds on the work carried out for pass criteria P1 and P2, as learners need to consider a specific application and apply their understanding of the selection criteria already used. The important point is that they can demonstrate ability in selecting an appropriate PLC type and have knowledge as to why it is an appropriate choice.

M2 can be clearly linked to pass criteria P3 and P4. To achieve M2, learners need to reflect on their choice of programming methods. In their justification (D1) learners should identify why one programming method has been chosen and make it clear why the others have been rejected.

M3 builds on the work undertaken to achieve P6 and P7. It requires learners to compare two different networks used for a modern programmable controller system. This should include details of the networks, standards and key differences. Learners need to demonstrate that they realise the important differences between networks and how they may influence the associated PLC systems.

Finally, D2 requires learners to reflect on the unit as a whole. The comparison could include aspects such as memory capacity, the types of PLC available, the growing development in networking technologies (for example wireless implications), the use of smart sensors and how this may impair the programme and feedback loops, how processor power may influence the programming method etc. Satisfactory achievement of this criterion will require learners to have considered the range of issues covered by the unit content and undertaken some independent research of trends and potential benefits.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Selection and Applications of PLCs	A written assignment requiring learners to demonstrate an understanding of PLC selection and application	A series of three written tasks. Learners provide a description of the selection and application of PLCs and explain hardware and software requirements. Learners are then given an application for which they choose a suitable PLC.
P3, M2, D1	Using Programming Techniques	Learners are required by their employer to produce a program for a specific programmable controller to meet a customer's needs.	A practical programming task. Learners should produce a program, which should be printed out, annotated and stored.
P4, P5	Applications of Programmable Controllers	Learners investigate an industrial application of programmable controllers, and explain the documentation and health and safety considerations that relate to it.	A series of written descriptions/ explanations.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3, D2	Data Communications Media and Networks	Learners investigate the different forms of media, their selection criteria and their applications.	A series of written descriptions/ explanations.

Essential resources

Centres will need access to a range of PLCs, communication media and interface devices. Software packages and tools should also be available to permit programming and implementation of device/applications for circuit performance and debugging. Learners will require access to a range of relevant manuals, reference data and manufacturers' information.

Indicative reading for learners

Textbooks

Bolton W–Instrumentation and Control Systems (Newnes, 2004) ISBN 0750664320

Bolton W–Programmable Logic Controllers (Newnes, 2006) ISBN 0750681128

Hooper J-Introduction to PLCs (Carolina Academic Press, 2004) ISBN 0890893896

Unit 20: Applications of Computer Numerical Control in Engineering

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

There are three basic principles to CNC machining. These are: positional control of the cutting tool relative to a workpiece using axes coordinates, the setting of cutting speeds and control of other functions such as the application of cutting fluid. To do this machine tools need to be loaded with a series of instructions which is acted upon in sequence. These instructions are called program code and in this unit learners will be shown how to produce a working program using an industry-standard language.

The unit will consider two aspects of CNC machining. First, learners will investigate machine tools which have an in-built computer system. These are set up by a skilled operator who interprets data taken from an operational plan and converts this into program code.

Learners will then look at machine tools which are downloaded with code generated by a remote computer system running computer aided design/manufacturing (CAD/CAM) software. The advantage that this type of system has over the stand-alone CNC machine is that a full three-dimensional (3D) simulation of the machining process can be carried out before any cutting of material takes place. This is an important aspect of economic manufacture because incorrect machining of a component will result in lost production and additional costs.

The unit has a high practical content and learners are expected to manufacture actual components. Learners will follow the various steps in the CNC process, starting with interpreting drawings and choosing a suitable machining process, correct cutting tools and work holding devices. They will then write and prove a part program, machine the product and carry out dimensional checking against specification.

The final part of the unit investigates the integration and use of CAD/CAM in the CNC machining process. Learners will be given a drawing file containing details of a component which they will then use to produce a 3D image of the component. Its functionality is confirmed before moving on to the simulation of the machining process using CAM software.

Once the machining operation has been proven and any problems corrected, the data needed to control the movements of cutting tools and other machine operations is downloaded from the computer into the machine's control unit. Machining then takes place, with the program data saved for future use.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of computer numerical control (CNC) and machine structures

2 Be able to interpret a component specification and produce an operational plan for its manufacture

3 Be able to produce a part program and manufacture a component

4 Be able to use a CAD/CAM software package to generate a part program and manufacture a component.

Unit content

- 1 **Understand the principles of computer numerical control (CNC) and machine structures**

  CNC principles: system e.g. machine control unit, drive mechanisms, tool/workpiece interface, transducers, feedback, correction; datum points e.g. machine, component; definition of parameters using numerical coding e.g. position, movement, spindle speeds, cutting tools, clamping, application of coolant; CNC process e.g. select machine, select tooling, identify machining sequence, calculate positional coordinates, calculate spindle speeds, programming, post-processing, setup sheet, verify and edit, store for future use

  Machine structures: types e.g. milling, drilling, turning centre, machining centre; designation of axes e.g. 2 axis, 3 axis, x, y, z; motor and drive units e.g. spindles, stepless drives, ball screw, stepper motors; transducers e.g. positional, linear, rotary, analogue, digital, optical encoders, inductive, capacitive, magnetic; tooling e.g. modular, quick change, turret; tool transfer e.g. automatic, chain magazine, circular magazine; work holding e.g. pallets, sub tables, rotary work changer, grid plate; swarf removal e.g. chutes, chip controllers, conveyors; cooling e.g. cutting fluid, cooling systems; computer hardware e.g. keypad, display, Central Processing Unit (CPU), storage, cabling links, machine control unit (MCU); computer software e.g. programming language, CAD/CAM DXF files; safety e.g. overloading the cutting tool, guards, light barriers, interlocks, operator safety

- 2 **Be able to interpret a component specification and produce an operational plan for its manufacture**

  Component specification: detailed drawing; material e.g. steel, aluminium, polymer, other stable material; reference points e.g. edge datum, centre line datum; dimensional e.g. external, internal, centres distances, bore diameters, tolerances; surface finish e.g. R_a, R_z values

  Operational plan: zero datums; work holding e.g. clamps, fixtures, chucks, vices, setting points; changing components e.g. pallets, sub tables, rotary work changer, grid plate; sequence of operations e.g. loading, machining, roughing and finishing operations, measurement, unloading; calculations e.g. cutter path coordinates for intersections, polar centres, arc centres, cutter compensation, cutting speeds, feed rates; use of trigonometric ratios e.g. sine, cosine, tangent; cutter speed (surface speed/*π* x cutter diameter); feed rate (feed per tooth x number of teeth x spindle speed); grouping of similar operations; canned cycles e.g. irregular pockets, geometric, hole patterns; tooling e.g. cutters, drills, reamers; other reference data e.g. cutting fluids, special requirements relating to specific materials; inspection e.g. first off proving against specification, on machine measurement; set up sheet and tool list

- 3 **Be able to produce a part program and manufacture a component**

  Part program: user interface e.g. menu bar, identification line, tool display window, system status; work/tool relationships e.g. position, direction, amount of movement; rates of change e.g. feed rates, spindle speeds; auxiliary functions e.g. metric/imperial units, tool selection, cutting fluids, workpiece loading and holding, tool changing; CNC codes e.g. block number, preparatory functions (G codes); miscellaneous functions (M codes); other letter addresses (arc centres, spindle speed, feed rate); dimensional information e.g. axis coordinates (x, y, z), absolute, incremental; words e.g. modal, non-modal; block format e.g. block number, G code, coordinates; special function G codes e.g. movement system, measuring system, tool compensation, canned cycles, subroutines; M codes e.g. coolant, tool change, work holding, spindle speed, spindle direction

  Manufacture: post-processing e.g. transfer of files/data between systems, download program to machine tool; pre-manufacture e.g. run through using graphics display on machine tool, prove program, dry run, load workpiece, stepping, adjust feed rates; run program e.g. machine workpiece, first off inspect and check against specification, store verified program for future use, quality monitor; shutdown

- 4 **Be able to use a CAD/CAM software package to generate a part program and manufacture a component**

  CAD/CAM package: hardware e.g. CAD workstation, data storage, hard copy equipment, network system to download data to machine tools; software e.g. Autodesk Inventor, Esprit, Solid Works, Edge CAM, Denford VR milling/turning; universal formats e.g. extensions (such as DXF, IGS, AI, EPS, PLT, NC), proprietary formats (such as DWG, CDR, CDL, GE3, NC1, BMP, MSP, PCX, TIF)

  Part program: e.g. 3D geometric model using CAD software, select machining operations, select tooling, generate CNC program using CAM software, simulation of tool changing and tool paths in the machining process, correction and editing

  Manufacture: post-processing e.g. transfer of files/data between systems, download program to machine tool; manufacturing e.g. load and clamp workpiece, set tooling, initiate program cycle, machine workpiece, first off inspect and check against specification, store verified program for future use, quality monitor; shutdown

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principles on which a machine tool operates when controlled by a CNC system		
P2 describe, with the aid of suitable diagrams, the structure of a given CNC machine type		
P3 interpret the specification for a given component and produce an operational plan for its manufacture	M1 explain the importance of producing an accurate and detailed operational plan for a component which is to be manufactured using a CNC machine tool	
P4 produce a part program for a given component	M2 explain the importance of correct programming and setting up in order to produce a component to a required specification.	
P5 manufacture a component using a two- or three-axis CNC machine		
P6 use a CAD/CAM package to produce a part program from a given component detail drawing	M3 test the program explaining how it meets the requirements of the drawing	D1 compare and contrast the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming

P7 manufacture a component on a CNC machine using a post-processed program generated using CAM software.	M4 explain how the manufactured component meets the requirements of the program.	D2 evaluate the cost benefits of using CAD/CAM software when programming CNC machines.

Essential guidance for tutors

Assessment

This unit could be assessed through the use of five assignments. To achieve a pass grade, learners need to have an understanding of the principles of CNC and be able to manufacture a component. It is not expected that they should be able to program and set up CNC machines at an expert level and this should be taken into account when designing assignments.

It is suggested that the first assignment covers grading criteria P1 and P2, with learners being asked to produce a written report. Evidence for P1 should be generic and not specific to a particular type of machine. There is a lot of material that learners will have access to and care should be taken to ensure the validity of the evidence they provide.

P2 relates to a given type of machine, details of which should be specified in the assignment brief. Some learners may be working in a CNC environment and if they have specialised knowledge about a particular machine tool they could use this towards their evidence for P2.

Grading criteria P3 and M1 complement each other and can be assessed through a second assignment. The assignment brief covering P3 should provide learners with hard copy information about the component and a detailed drawing presented in printed form to an acceptable industry standard. The brief could also include a pro forma for setting out the operational plan, although learners working in a CNC environment may wish to use their own style of layout. Care should, however, be taken to ensure there are sufficient aspects of an operational plan covered by the content section for learning outcome 2. It must be remembered that a plan for CNC machining is different from one for traditional machining.

Further evidence in the form of annotated drawings and specification sheets, calculations to support machining decisions such as speeds and feeds and trigonometric ratios to calculate coordinates and intersections will also be needed to support P3. Evidence presented for M1 should make reference to the operational plan produced for P3 but additional evidence drawn from wider sources should be included.

The third assignment could be designed around P4, P5 and M2. It will add realism if the same component is used for both pass criteria. Learners should be given a pre-produced operational plan to work from, although if they wish they could use the one produced for P3, providing it is fit for purpose. Three-axis machining would be the preferred option, using something like a vertical milling machine. As the assignment involves a lot of practical work, evidence presented for assessment should include screenshots, witness statements, observation records and annotated digital images.

The fourth assignment could cover P6, P7, M3, M4, D1 and D2. Learners who wish to gather evidence for D1 will probably want to use the component specification provided in the third assignment so that they can contrast the effectiveness of the two methods of programming. The starting point for P6 is a detailed drawing and this should be given to learners as a file which can be opened using CAD/CAM software. With the agreement of the tutor, some learners who are taking the CAD unit may wish to use a component which they have previously drawn but it needs to be in a form which can be easily processed.

Evidence presented for assessment should include screen shots showing tool path simulation, witness statements, observation records and annotated digital images. A written task will need to be given asking learners to compare and contrast the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming (D2). They will obviously need to identify benefits and limitations of each approach and draw valid supported conclusions. The focus of D1 is very specific and some of the evidence presented could relate to the tasks undertaken to achieve P4, P5, P6 and P7. M3 and M4 are logical extensions of P6 and P7 respectively requiring explanations of how the entities produced meet the original requirements.

When writing about their experiences learners should include an evaluation of their own effectiveness in using the two systems of manufacture. Factors to be considered might include something on how easy it was to learn the software packages, ease of program editing and the lead times needed to produce the components. Discussions with a manufacturing engineer who works for a company using both systems or which has moved from CNC part programming to an integrated CAD/CAM setup could be used as further evidence.

A further task can be included to cover D2, in the form of evaluative writing supported by evidence gathered from published case studies. Learners should consider the effectiveness of CAD/CAM programming in the wider context and not just concentrate on the components that they have manufactured.

Some of the evidence for D2 could be come from work produced for *Unit 22: Computer Aided Manufacturing* and it may be possible to integrate assignments across units. Because there are well documented examples of the cost benefits achieved by companies who use CAD/CAM software to program CNC machines, care must be taken to ensure that what the learner presents as evidence is authentic. Use could be made of experience from *Unit 35: Setting and Proving Secondary Processing Machines*, particularly about work holding and machining parameters. Where appropriate, employed learners should be given the option of using examples taken from their own company.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	CNC Principles and Machines	An assignment requiring learners to demonstrate their knowledge of the underlying principles of CNC machines and CNC machine structures.	Two written tasks for which learners need to produce an explanation of the principles on which machine tools operate and a written description of CNC machine structure.
P3, M1	Component Specifications and Operational Plans for Manufacture	A practical assignment requiring learners to interpret a component specification and produce a plan for its manufacture.	A practical task for which learners are provided with a detailed drawing and information about a component which they need to interpret. Learners produce an operational plan to manufacture the product on a CNC machine. A further written task gives learners an opportunity to explain the importance of an accurate and detailed plan.
P4, P5, M2	Part Programs for Manufacturing Components	A practical assignment requiring learners to produce a part program and use it to manufacture a component.	Practical tasks in which learners are given a pre-produced operational plan for which they produce a part program and manufacture a

			component using three-axis machining.
P6, P7, M3, M4, D1, D2	Using CAD/CAM to Manufacture Components	A practical assignment supported by written tasks requiring learners to demonstrate their ability to use CAD/CAM to manufacture a component.	Practical and written tasks. Learners are given a detailed drawing for which they write a part program. Learners then need to use their post-processed program to manufacture the component. Written tasks will ask learners to compare CAD/CAM to CNC part-programming and evaluate the cost benefits of CAD/CAM.

Essential resources

In order to deliver this unit centres will need to have 2D/3D commercial CAD software and CAM software that integrates with the CAD package used for designing. They will also need to have access to a two- or three-axis CNC machine tool and a two- or three-axis machine tool which can be downloaded with data from a computer system.

Indicative reading for learners

Textbooks

Evans K – *Programming of CNC Machines* (Industrial Press, 2007) ISBN 9780831133160

Smid P – *CNC Programming Handbook* (Industrial Press, 2008) ISBN 9780831133474

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Unit 21: Welding Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

The industrial processes used to produce welded joints rely on the application of heat to melt and fuse the materials together. The amount of heat used varies according to the process, but one common factor is that the metallurgical structure of the metal will be changed to some extent by the welding operation.

This unit provides the learner with an understanding of the effect that the heat input has on a welded component. The unit is suited to welders and those responsible for the specification of the welding process and any post-weld heat treatments. The unit will develop learners' knowledge of the structure of pure metals and the effects of adding alloying elements. Learners will develop an understanding of the effect that heat has on metals and their alloys once they have been welded, and how this influences the performance of a welded component. Learners will also gain knowledge of the post weld heat treatment processes that are available to improve the performance of the structure and relieve stress. The testing of welds is also covered in the unit so that learners appreciate the need for a component to meet a quality standard.

Learners will perform a range of practical and investigative tasks to develop their understanding of different welding processes and the suitability of their application. Learners will prepare materials for welding and the post-welding treatments of welded materials. Identification of defects is vital in ensuring the quality of the finished product and learners will demonstrate their knowledge of the techniques employed in defect detection and the quality standards used in industry.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Know the physical features of welding processes
2. Know the effects of welding and select post-weld heat treatments
3. Understand the weldability of metals
4. Be able to use and interpret quality standards and weld testing techniques.

Unit content

- 1 **Know the physical features of welding processes**

  Welding processes: main processes e.g. manual metal arc (MMA), metal-arc gas shielded (MAGS), tungsten narc gas-shielded (TAGS), oxy-acetylene; additional processes e.g. resistance (such as spot, seam), friction, flash butt, laser, electron beam, explosive, exothermic (thermit), capacitor discharge stud welding, friction stir welding; choice of processes; working environment e.g. workshop, site work, suitability of machinery and plant

  Electric arc: alternating current (AC); direct current (DC); heat distribution at the anode and cathode; effect of magnetic fields; applications of AC and DC; consumable and non-consumable electrodes; metal transfer and deposition; plasma-arc

  Shielding gases: functions e.g. atmospheric protection, arc initiation; shielding gases e.g. inert gases, argon, helium; active gases used in mixtures e.g. carbon dioxide (CO2), nitrogen, oxygen; applications e.g. MAGS, TAGS, plasma-arc

  Electrode coverings and fluxes: functions of coverings and fluxes e.g. atmospheric protection, slag, removal of impurities, alloying, arc initiation; composition e.g. basic, rutile, cellulosic, iron powder; fluxes e.g. fused, agglomerated; applications of coverings and fluxes e.g. MMA welding, submerged arc welding, braze welding

  Oxy-acetylene combustion: chemical composition of the inner and outer envelope; heat distribution; applications of flame types, e.g. neutral, oxidising, carburising

- 2 **Know the effects of welding and select post-weld heat treatments**

  Effects of welding heat input: distortion control e.g. pre-setting, pre- and post-heating, total heat input, weld deposition (skip and back step) techniques; effects e.g. distortion (expansion and contraction), expansivity, residual stress; effects of cooling rate e.g. hardening, grain growth, cracking; structure of the welded joint e.g. heat-affected zone (HAZ), crystal structure (such as equi-axed, columnar), grain growth; heat distribution during welding e.g. thermal gradients, heat flow, joint configuration (butt, tee, cruciform); use of chills; comparison of processes

  Post-weld heat treatments: for ferrous metals e.g. annealing (full, process), normalising; for heat treatable aluminium alloys e.g. solution treatment, precipitation hardening

- 3 **Understand the weldability of metals**

  Weldability: factors e.g. melting temperature, carbon equivalent, rate of heating and cooling (thermal shock), thermal conductivity, residual stress, degree of restraint (the rigidity of the construction), similar and dissimilar metals; dilution, hardenability, dissolved hydrogen, pre- and post-heat temperature; impurities e.g. phosphorous (cold shortness), sulphur (hot shortness); mechanical properties e.g. tensile strength, impact strength

- 4 **Be able to use and interpret quality standards and weld testing techniques**

  Weld test techniques: non-destructive e.g. visual (weld gauges, dimensional), radiographic (such as x-ray, gamma ray), ultrasonic, dye penetrant, magnetic particle; destructive e.g. fracture, bend test, macro and microscopic examination, tensile, fatigue, hardness

  Weld defects: visual (surface defects) e.g. undercut, overlap, excess weld metal, leg length of fillets, concavity, cracking (such as cold cracking, hot cracking, crater, transverse, longitudinal, centre-line, HAZ), blowholes, oxidation, restarts; internal e.g. porosity, inclusions (such as slag, metallic, gaseous), lack of inter-run fusion, cavities

  Quality standards: in relation to relevant standards e.g. British Standard/European Standard BS EN 970, BS EN 1011, BS EN ISO 10042, BS EN ISO 15607, BS EN ISO 15609, BS EN ISO 15614, American Society of Mechanical Engineers (ASME) IX

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria

To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 select suitable welding processes for four given applications	M1 explain the operation of two welding processes for given welding applications, with respect to heat input and the fusion of welded materials	
P2 describe the physical features of an electric arc used in a welding process		
P3 describe the function of two given shielding gases, and two electrode coverings/fluxes used in welding processes		
P4 describe oxy-acetylene combustion and its application when using gas welding equipment		
P5 describe three methods of controlling the effects of heat input when using welding processes	M2 explain how a post-weld heat treatment process will affect the grain structure and properties in two given materials	D1 explain the advantages and disadvantages of using post-weld heat treatments in a steel or aluminium welded component
P6 describe the effect of heat input, heat distribution and cooling rate on the grain structures of two welded joints		
P7 identify suitable post-weld heat treatment processes for joints in steel and aluminium alloys that have been welded		

P8 describe the factors that will affect a given metal's weldability	M3 explain how impurities affect quality in terms of the weldability and material properties of a welded joint.	
P9 use two weld testing techniques to detect surface defects and internal weld defects in accordance with quality standards		
P10 produce a test procedure for a destructive or non-destructive weld test to detect weld defects in welded components.		D2 analyse the defects found in a component that has been weld tested and identify possible causes in relation to the heat input.

Essential guidance for tutors

Assessment

The learning outcomes of this unit may be linked with those of other units, in particular *Unit 18: Welding Technology*. Written assignments should be supported with appropriate photographs and diagrams.

Pass criteria P1, P2, P3 and P4 could be achieved by learners selecting and describing the functions and features of welding processes and their application in industry. Learners' responses could include both written and oral questioning. The four given applications should include processes across the range of those outlined in the unit content. A further written task to cover M1 should ensure that learners cover the range of processes and physical features identified in the unit content.

Achievement of P5 could be achieved by means of a written task. To enable learners to understand the effects of distortion it may be appropriate for them to participate in an associated practical task. This could, for example involve measuring the angle between two plates before and after the welding of a tee fillet joint. Evidence for P6 is also likely to come from a written task in which learners are asked to consider two joints that are subjected to extremes of heat input due to the process parameters. One joint could be in thin metal, welded by a process with a high deposition rate (for example MAGS or laser), compared with a thicker metal welded using a slower deposition process (for example MMA or oxy-acetylene welding). A further task covering P7 could require learners to investigate and recommend post-weld heat treatment processes appropriate to welded joints in steel and aluminium alloys. Another written task can then build on this to cover M2.

For P8, a written task could be used based on a range of factors and impurities known to affect the weldability and properties of metals. This could be extended to also cover M3, with learners providing an explanation of how impurities can affect welded joints.

A written task covering P9 should ask learners to produce a procedure for carrying out non-destructive and destructive tests as identified in the unit content. There is an opportunity to set different procedures for the range of learners or to concentrate on testing techniques that may be found in the learners' workplace, where applicable. P10 could be achieved using a combination of practical assessments and research. Learners could either use welds produced in the welding workshop or commercially produced weld specimens with known defects, to correctly detect surface and internal defects in welds relevant to a given quality standard. Learners should perform this on a range of materials, ferrous and non-ferrous. Whilst this criteria is suitable for assessing by a written report, the assignment may be assessed using an oral presentation where photographs, diagrams and samples should be used.

To achieve distinction criterion D1 learners need to explain post-weld heat treatment processes and discuss the advantages and disadvantages. This will combine the knowledge gained in P1 to P7 as this will depend upon the materials, welding process and the heat input.

Assessment of D2 could be in the form of a written task though this may be better assessed as part of the oral presentation suggested for the assessment of P10. Learners would be expected to demonstrate their knowledge of not only the applications and operation of the weld testing technique, but also that of the quality standards and welding process used.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1	Welding Processes	An assessment based on learners' knowledge and investigations into the physical features of welding processes.	This assessment will use a written report and oral questions to assess learners' knowledge across a range of welding processes. Learners will need sufficient knowledge to select appropriate processes for given applications. They will also need to know the physical features of those processes. Learners will need to explain welding processes in terms of how the heat is input, and how the fusion of the material takes place to produce the weld.
P5, P6, P7, M2, D1	The Effects of Welding	This assessment requires the learner to investigate and report on the effects of welding in terms of controlling distortion, the grain structure and the heat treatment of materials.	A written assessment based on joints or components that the learner has investigated in the workshop, these may have been produced by the learner, or commercially produced. Those learners who are employed may benefit from applying procedures used in the workplace. The effects of welding should be considered in context with the welding process used. The learner may also explain the effects of welding and analyse these effects further.

Criteria covered	Assignment title	Scenario	Assessment method
P8, M3	Weldability of Metals	An assessment that focuses on the weldability of materials. Learners will report on their research and tutor-led activities.	This written assessment considers the factors that affect the weldability of a material and the effect of impurities on the welded material. An opportunity is given to explain the effect of impurities on a welded joint.
P9, P10, D2	Weld Testing and Quality Standards	This assessment reports on the findings of practical investigations when working to quality standards applicable to weld testing.	This may be assessed in the form of a written report, but would be better assessed by oral presentation (which may utilise ICT to produce a visual presentation). The learner should present a test procedure that has been produced to identify weld defects. Learners should also present information on their use of weld testing techniques and the defects found, comparing them to relevant quality standards.

Essential resources

Centres will require access to welding equipment to allow learners to observe at least one welding process. Weld testing facilities will be required for visual examination and at least one destructive and one non-destructive test. Centres will need samples which are commercially produced which use a range of welding processes.

Indicative reading for learners

Textbooks

Davies A – *The Science and Practice of Welding, Volume 1* (Cambridge University Press, 1993) ISBN 9780521435659

Davies A – *The Science and Practice of Welding, Volume 2* (Cambridge University Press, 1993) ISBN 9780521435666

Smith B – *Welding Practice* (Routledge, 1995) ISBN 9780340614068

Timings R – *Fabrication and Welding Engineering* (Routledge, 2008) ISBN 9780750666916

Unit 22: Computer Aided Manufacturing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

An understanding of how computer aided manufacturing (CAM) systems operate within an engineering business is important for anyone thinking of a career in the design and manufacture of products.

This unit aims to develop an appreciation of the use of computer systems in a world-class manufacturing environment and how they are applied to product design and manufacture. Emphasis is placed on the need for a total approach to product development, in particular the interface between the various functions of the design and make process and the use of simultaneous engineering.

Learners will start by investigating how CAM systems are used to increase the profitability of a business by reducing manufacturing costs, improving quality and being more responsive to customer needs. This is followed by a look at how simultaneous engineering is used to bring together the many functions of a manufacturing business so that there is a team-based, multi-disciplinary approach to problem solving. Learners then investigate how simultaneous engineering can be used to meet the demands of a customer-driven economy where people expect an off-the-shelf service for customised products.

The unit also covers how newly designed components are modelled using three-dimensional CAD software so that their functionality can be assessed and any errors corrected before the machining process is simulated using CAM software. Raw materials and the cutting of metal are expensive and getting it right first time is a crucial aspect of economic manufacture.

Learners will investigate how manufacturing processes can be automated by using industrial robots to move materials and components between the machine tools and the workstations that make up a flexible manufacturing system (FMS). Finally, learners will be given the specification for a component, use CAD software to design it and use CAM software to produce a set of instructions for downloading to a machine tool which could be used to make it.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the benefits of CAM and the significance of simultaneous engineering

2 Understand how the CAD/CAM interface operates and modelling is used to simulate the manufacturing process

3 Understand the use of industrial robots and flexible manufacturing systems in engineering

4 Be able to design a simple component and generate a programme for a CNC machine using a CAD/ CAM software package.

Unit content

- 1 **Understand the benefits of CAM and the significance of simultaneous engineering**

  Benefits of CAM: increased profitability e.g. reduced machine set-up times, greater flexibility in terms of batch sizes, reduction in lead times, reduction of labour costs, lower unit costs, optimised use of cutting tools, production of complex shapes; improvements in quality e.g. elimination of human error, consistent accuracy; greater responsiveness to the requirements of the customer; competing in the world market place

  Simultaneous engineering: parallel operation of tasks; multi-discipline team-based working e.g. marketing, design, modelling, rapid prototyping, manufacturing, development; time-based management e.g. integration of activities, lean manufacturing, total quality management (TQM), shorter development times, faster time to market, right first time, improved communication

- 2 **Understand how the CAD/CAM interface operates and modelling is used to simulate the manufacturing process**

  CAD/CAM interface: CAD e.g. product design using industry-standard CAD software, modification of design ideas, production of working drawings; CAM e.g. generation of part programmes, scheduling of raw materials; specialised linking software e.g. edgeCAM, Autodesk Inventor/Esprit, SolidWorks; universal formats e.g. extensions (such as DXF, IGS, AI, EPS, PLT, NC), propriety formats (such as DWG, CDR, CDL, GE3, NC1, BMP, MSP, PCX, TIF)

  Modelling and simulation: use of CAD/CAM software e.g. 3D modelling of the product, simulation of tool changing and toolpaths in the machining process, simulation of sequential manufacturing processes, rapid prototyping; benefits e.g. elimination of machining errors, reduction in scrap rates

- 3 **Understand the use of industrial robots and flexible manufacturing systems in engineering**

  Robots: applications e.g. pick and place systems, product handling, product assembly, machine loading, safe operation, codes of practice (Health and Safety Executive HSG43, Reducing error and influencing behavior HSG 48, Provision and Use of Work Equipment Regulations); advantages e.g. consistency of performance, 24/7 continuous working, reduced cycle times; limitations e.g. high standard of maintenance required, precise programming needed, computer systems failure will cause breakdown, new products require complete reprogramming, certain processes still need a skilled operator, complex and expensive equipment

  Flexible manufacturing systems: benefits e.g. production of different parts without major re-tooling, efficient production of customised products, ease of responding to changes in product mix and production schedules, lean manufacture; processing machines e.g. CNC machine tool, machining centre, flexible cell, welding station, assembly; loading and unloading systems e.g. material handling, pick and place, fixed position robot, conveyors; coordination of the working schedule e.g. process monitoring by computer, optical recognition, inspection, total quality management (TQM)

- 4 **Be able to design a simple component and generate a programme for a CNC machine using a CAD/CAM software package**

  Using CAD/CAM software: hardware e.g. CAD workstation, data storage, hard-copy equipment, network system to download data to machine tools; software e.g. 2D/3D CAD, databases, single-component CAD files, part programming, macros, cutter path simulation; post-processing e.g. transfer of post-processed files/data between systems, download to machine tools, inspection and quality management

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain how the use of a CAM system can benefit the operation of a manufacturing business	M1 describe the criteria used to assess the viability of introducing CAM and simultaneous engineering systems into a business	D1 analyse a current low-technology manual manufacturing system for suitability to move to a CAM environment
P2 describe the strategies used in simultaneous engineering		
P3 explain how the interface between design and manufacture can be integrated using suitable CAD/CAM software	M2 explain the cost benefits of moving from low-technology manual manufacturing to high-technology automated manufacturing	
P4 explain the reasons for carrying out modelling of a component and simulation before actually cutting metal		
P5 describe the applications, advantages and limitations of industrial robots	M3 explain the use and operation of robots to move parts between workstations in a flexible machining system	
P6 explain why a flexible manufacturing system will produce productivity gains for a business deploying a range of processing machines, loading and unloading systems and coordinated work schedules		

P7 use appropriate software to design a simple component and produce a part program which could be post-processed and used to manufacture it on a CNC machine.	M4 explain the hardware and software used for this process.	D2 discuss post-processing procedures utilised.

Essential guidance for tutors

Assessment

Assessment of this unit could be through five assignments.

It is suggested that the first assignment covers P1 and P2, with learners being asked to support their thoughts with evidence taken from published case studies relating to well-known companies (e.g. Toyota and Airbus Industries). It is important that learners demonstrate a good understanding of the reasons why, in a customer-driven, global market environment, a manufacturing company can survive only if it uses smart systems in the operation of its business. There is scope to expand this first assignment to include M1. A visit to an engineering company which has moved to using world class manufacturing systems would be a good way of gathering research information.

Grading criteria P3 and P4 complement each other and can be assessed through a second assignment. Learners should not be expected to demonstrate proficiency in the use of CAD/CAM software. A visit to a company to look in detail at the way a component is designed and manufactured would be a useful way to gather evidence. This could involve talking to a CAD designer and being shown the processes of design, modelling and manufacturing. There is scope to include M2 in this assignment.

A third assignment could cover grading criteria P5 and P6. Thought needs to be given to structuring the tasks so that learners restrict themselves to just the applications of robots and do not get sidetracked into explaining in great detail their operating principles. As recommended earlier, restricting learners to three applications will be enough to produce valid evidence to meet P5. As criterion M3 builds on P5 and P6 it can be a part of the third assignment.

The fourth assignment could be a practical activity covering P7. The component to be designed should be kept very simple as learners are not required to prove competence in using high-level design skills. As suggested earlier, a simple embossed key fob design which uses the line, arc, diameter and text commands in its design will produce a profile sufficiently complex for a part program and its post-processing. Screen prints could be used as evidence of tool path simulation, supported by witness statement or observation records of learner performance.

M1 builds on P1 and P2. To achieve it there should be evidence of thought having been given to the pressure on design and manufacturing engineers to optimise resources and use business improvement techniques.

M2 links into P3 and P4 but also draws on knowledge from P1 and P2. Explanations should be supported by examples taken from real companies which have successfully moved from low-technology to high-technology manufacturing systems and might include figures for the amounts of cost savings achieved.

M3 requires a greater understanding of how a robot operates and will build on knowledge gained when achieving P5 and P6. Evidence presented should be at a systems (black box) level and the assignment tasks should not be asking for detailed knowledge about, for example, the internal workings of a specific drive or sensor unit within the robot. Tasks based on a scenario which relates to a specific machining system could be used to generate evidence. Learners are not expected to explain how the actual machining functions operate because the criterion relates only to the handling and moving of parts. M4 requires an explanation of the hardware and software used for component design.

Grading criterion D1 builds on content covered in learning outcomes 1, 2 and 3 and could be a very detailed piece of writing based around a scenario. For this reason it might be best covered by a fifth assignment. Learners could assume the role of a manufacturing engineer who has been tasked with presenting proposals to senior management on the implications and suitability of moving from low-technology manufacturing to a CAM environment. There are a lot of well documented examples of how this has been achieved successfully by well-known companies and care must be taken to ensure that what learners present as evidence is authentic. Where appropriate, employed learners should be given the option of analysing their own company. D2 requires a discussion of the post-processing utilised in the component designed in P7.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Using CAM and Smart Systems in an Engineering Business	Learners have been asked by their employer to produce a report on the benefits of using CAM and the strategies used in simultaneous engineering.	A written assignment for which learners produce a report detailing the benefits of CAM to a modern manufacturing business and the use of simultaneous engineering.
P3, P4, M2	CAD/CAM Interfacing	Learners need to provide an explanation of how CAD/ CAM software is integrated and the reasons for simulation for a local manufacturer considering moving over to CAM systems.	A written assignment for which learners produce a report into the interface between design and manufacture and the purpose of simulation. A further task would require learners to explain the cost benefits of modern manufacturing systems.
P5, P6, M3	Industrial Robots and Flexible Manufacturing Systems	Learners have been asked by their employer to produce a report on the benefits and limitations of using industrial robots and the use of flexible manufacturing systems.	A written assignment consisting of tasks requiring learners to discuss the applications of industrial robots and explain why a flexible manufacturing system can produce gains for a business.

Criteria covered	Assignment title	Scenario	Assessment method
P7, M4, D2	Using CAD/CAM Software	Learners need to design a component for a client and produce a part program for its manufacture.	A practical assignment for which learners will need to design a component and produce the part program necessary for its manufacture. Evidence is likely to be supported by screen prints and tutor observation records.
D1	Evaluating the suitability of a CAM Environment	Learners have been asked by senior management to investigate the implications and suitability of moving from low-technology manufacturing to a CAM environment.	A written assignment for which learners produce a report detailing the suitability of moving to a CAM system for a low-technology manual system.

Essential resources

Centres will need to give learners access to 2D/3D commercial CAD software and CAM software which integrates with the CAD package used for designing.

Extracts from appropriate standards and legislation and access to industry-standard CNC machining centres and flexible manufacturing systems are also needed.

Indicative reading for learners

Textbooks

Amirouche F – *Principles of Computer Aided Design and Manufacturing* (Prentice Hall, 2004) ISBN 9780130646316

Colestock H – *Industrial Robotics: Selection, Design and Maintenance* (McGraw-Hill, 2005) ISBN 9780071440523

Narayan et all- Computer aided design ISBN 9788120333420 *Manufacturing* (Prentice Hall, 2008)

Unit 23: Electronic Circuit Design and Manufacture

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

A diverse range of techniques is used in the manufacture of electronic circuits. The techniques used for manufacturing prototype electronic circuits are often significantly different from those used in high volume production. This unit provides an introduction to prototype manufacture, as well as the techniques used for the mass production of electronic circuits.

Large-scale electronic manufacture generally involves fully automated assembly techniques using equipment that can produce complex circuits quickly, accurately, at low cost and with minimal human intervention. Alternatively, if only one circuit is to be built (perhaps for evaluation or testing purposes) then a hand-built prototype is much more appropriate.

Computer aided design (CAD) and computer aided manufacture (CAM) are widely used in the production of electronic circuits. This unit will introduce learners to the use of modern production methods including printed circuit board (PCB) layout and computer numerical control (CNC) drilling and mask production.

When an electronic circuit is developed for a commercial application it is usually tested and proved using computer simulation prior to manufacture. This unit will give learners an opportunity to develop and test circuits using SPICE (simulation program with integrated circuit emphasis) software. The unit also gives learners an understanding of the use and application of surface mount technology (SMT) in the manufacture of electronic circuits.

The unit will also enable learners to experience and gain skills in the full cycle of design, manufacture and testing of an electronic circuit assembled on a simple single-layer printed circuit board.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit an learner should:

1 Know the design processes and production methods used in the manufacture of a printed circuit board

2 Understand the use of software and thermal analysis techniques in the design, simulation and manufacture of an electronic circuit

3 Understand the use and application of surface mount technology in the manufacture of an electronic circuit

4 Be able to design, manufacture, assemble and test a prototype printed circuit board for a given electronic circuit.

Unit content

- 1 **Know the design processes and production methods used in the manufacture of a printed circuit board**

  Design processes: design strategy e.g. methodology and techniques used in its realisation (build type, number of layers, net rules, track and gap, via size); design tools e.g. PCB design software, schematic design and capture, creating and modifying component geometries; creating and modifying schematic diagrams; design verification and design rule checking for both tracking and component layout; auto-routing tools; related documents e.g. parts lists, bills of materials, machine files, component geometries

  Production methods: artwork generation; board production e.g. etching, masking, drilling, silk screening, cutting; automated production techniques e.g. robotics and automated assembly, CNC drilling and mask production; soldering methods e.g. wave soldering, automated wave soldering; fabrication and assembly requirements e.g. placement on one side, placement on both sides, combination of surface mount technology (SMT) and through-hole technology (THC); test strategy e.g. electromagnetic compatibility (EMC), signal integrity, high frequency requirements; manufacturability analysis

  Types of PCB: laminates e.g. single and double sided, plated through-hole, fibreglass-resin laminate; solder mask over bare copper (SMOBC); tinned; conventional component and surface mount; single, double and multi-layer boards; gold plated contacts, flexible and membrane PCB, chip-on-board (COB)

- 2 **Understand the use of software techniques and thermal analysis techniques in the design, simulation and manufacture of an electronic circuit**

  Computer aided design (CAD) software: simulation program with integrated circuit emphasis (SPICE) software; direct current (DC) analysis, alternating current (AC) small-signal analysis; more complex analysis methods e.g. mixed-mode analysis, transient analysis, pole-zero analysis, distortion analysis, sensitivity analysis, noise analysis, thermal analysis; software integration methods e.g. export and import data, links with companion software for circuit layout and PCB manufacture

  Thermal analysis: heat dissipation methods; thermal ratings of semiconductor devices; thermal calculations e.g. total power dissipation, thermal resistance, $\theta_T = \theta_{JC} + \theta_{CS} + \theta_{SA}$, junction temperature, $T_J = (P_T \times \theta_T) + T_A$, temperature rise above ambient, $\Delta_T = P_T \times \theta_T = T_J - T_A$, de-rating, correct rating for thermal dissipator/heatsink

- 3 **Understand the use and application of surface mount technology in the manufacture of an electronic circuit**

  Surface mount technology (SMT): types of SMT device e.g. passive components (resistors, capacitors, inductors and transformers), active components (transistors, diodes and integrated circuits), connectors and sockets; surface mount device (SMD) outlines, packaging and storage; manufacturers' markings and supporting data; hybrid circuits and multi-chip modules (MCM)

SMT circuit manufacturing: manufacturing methods e.g. use of solder pastes, flow and wave soldering equipment; SMT quality assurance methods e.g. batch testing, statistical methods; SMT component reliability and testing of finished SMT assemblies; assembly-level packaging and interconnection

- 4 **Be able to design and manufacture a prototype printed circuit board and use it to assemble and test an electronic circuit**

PCB design: single-sided printed circuit board for a given electronic circuit design that includes no more than four active devices e.g. transistors, diodes and conventional dual in-line (DIL) packaged integrated circuits; associated passive components e.g. PCB mounted resistors, capacitors, inductors, transformers; means of connection e.g. external controls, connectors, power sources; layout techniques based on the use of electronic CAD to generate PCB master artwork

PCB manufacture: developing, etching, drilling

Electronic circuit assembly: component mounting, soldering

PCB and circuit testing: functional testing using a supplied test specification to determine circuit design inputs and outputs e.g. test-point voltages, output signals

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the processes used in the design of both a single and multi-layer PCB for electronic circuits of different complexity	M1 explain the benefits of using automated techniques for the manufacture of an electronic circuit	
P2 describe typical production methods used in the manufacture of both a single and a multi-layer PCB for electronic circuits of different complexity		
P3 explain how computer aided design software is used to analyse an electronic circuit prior to manufacture	M2 use SPICE software to carry out DC and small-signal AC analysis of a simple electronic circuit	
P4 explain the need for thermal analysis and effective heat dissipation for an electronic circuit	M3 carry out thermal calculations to solve a range of defined problems	D1 apply thermal analysis techniques in order to determine the heat dissipation requirements for the electronic circuit

P5 explain the use of SMT in the manufacture of an electronic circuit and give two examples of the outlines and packages used for surface mounted devices	M4 evaluate the use of typical quality assurance methods in the manufacture of electronic circuits using SMT	
P6 explain methods used for the manufacture of an electronic circuit using SMT		
P7 design, manufacture and test a prototype printed circuit board for a given electronic circuit to a valid standard.	M5 justify the design of the printed circuit board with regards to function and suitability for use.	D2 evaluate the design and manufacture of the prototype PCB and circuit and make appropriate recommendations for mass production.

Essential guidance for tutors

Assessment

P1 and P2 are closely related and evidence could be gathered from either an extended case study or from research and investigation. Case studies and investigations should ideally be based on production techniques and manufacturing processes that are used locally. Learners would benefit from visits to local industry to view the processes in action. An alternative to an extended case study or investigation might be the use of one or more written essay-type questions. However, this approach is likely to be less effective in bringing the topic to life.

To achieve P1, evidence should focus on design strategy, design tools (for example, schematic capture and auto-routing PCB CAD), creating and modifying schematic diagrams (for example, exchanging logic functions), design verification and design rule checking for both tracking and component layout.

It is important that learners demonstrate that they understand the additional processes required to produce multi-layer boards and that they appreciate the need for this type of board in conjunction with more complex electronic circuits. For example, circuits where microprocessor bus systems are realised on different layers or where power and ground connections are separated from signal tracks.

For P2, learners should be able to describe typical production methods used in the manufacture of both single and multi-layer types of printed circuit board for electronic circuits of different complexity.

The explanation of the use of computer aided design software required for P3 should normally be based on the use of a SPICE package to verify a circuit design before it is manufactured.

For P4, learners should explain the need for thermal analysis and effective heat dissipation in terms of the total power dissipated and the maximum junction temperature ratings for the semiconductor device(s) present. They should explain that the requirements are satisfied by means of appropriately designed heat dissipaters on which the semiconductor devices are mounted.

To satisfy P5, learners should provide a written or verbal presentation of the use of surface mount technology (SMT) in the manufacture of electronic circuits. Learners should be able to state the advantages and disadvantages of SMT and surface mounted devices (SMD) and should be able to describe the typical outlines and packages used for SMD.

For P6, learners should explain the typical methods used for the manufacture of electronic circuits using SMDs. Note that learners are not expected to know how SMDs themselves are manufactured.

For P7, learners should design, manufacture and test a prototype printed circuit board for a given electronic circuit, to a valid standard. The electronic circuit should be supplied, complete with a full component list and component supplier's references. Learners will be able to use these to determine physical constraints such as lead diameter, pin spacing and package outlines as well as any specialised mounting requirements such as the fitting of a heat dissipater. The circuits chosen should use no more than four active devices (for example transistors, diodes and conventional dual in-line (DIL) packaged integrated circuits) and associated passive components (for example PCB mounted resistors, capacitors, inductors, and transformers). The circuit should have an identifiable function and should be capable of functional testing without specialised equipment.

In order to carry out this task, learners should be supplied with a simple test specification based on test-point voltages, output signal levels etc. Centres are encouraged to provide learners with a standard test-jig in order to carry out these functional checks.

Typical examples of circuits that learners might develop include:

- a variable pulse generator (based on two 555 timers)
- a function generator (based on a single integrated circuit waveform generator)
- an audio amplifier (based on a complementary symmetrical output stage with driver and pre-amplifier stage)
- a regulated power supply (based on a bridge rectifier and a three-terminal fixed voltage regulator).

Note that these last two examples could require learners to undertake some thermal analysis and incorporate appropriate arrangements for heat dissipation (extending the work required for P4 and providing a basis for developing evidence for D1).

Evidence for M1 could be gathered through a written assignment or formal written test. M2 could be assessed through appropriately designed practical activities. M3 could be achieved by carrying out problems related to a case study and M4 by means of an assignment in which learners investigate modern industrial processes used for the high-volume manufacture of electronic circuits. For M5 learners should gather evidence through the evaluation of the design and manufacture of a Prototype PCB and create a written report that includes recommendations.

Learners can achieve D1 by means of an extended assignment involving thermal analysis and the design of a heat dissipator (for example, a heatsink for fitting to a three-terminal integrated circuit voltage regulator).

For D2, the exercise carried out to satisfy P7 could be developed further as learners evaluate their designs and make appropriate recommendations for mass production (based on the understanding that they have evidenced in relation to P1 and P2).

These recommendations will typically include size reduction (including the use of miniaturised or equivalent surface mounted components), the use of multi-layer boards and the use of appropriate interconnecting technologies (for example the use of multi-pole insulation displacement connectors (IDCs) fitted with PCB headers).

rogramme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	PCB Design And Manufacturing Techniques	Learners investigate the techniques and processes used in the design and manufacture of PCB (including manufacture of both single and multilayer PCB as well as both manual and automated component assembly).	A report containing written responses including, where appropriate, sketches that describe and explain the techniques and processes used in the design and manufacture of PCB.
P3, M2	Circuit Simulation And Analysis Using SPICE	Learners investigate and use simulation programs with integrated circuit emphasis (SPICE) to carry out a DC and small-signal AC analysis of a simple electronic circuit (e.g. a single stage amplifier with given circuit data, component values and SPICE models).	A report containing written responses including, where appropriate, sketches that describe and explain the use of computer aided design software in the analysis of a simple electronic circuit prior to manufacture. Learners should include evidence of their use of a SPICE package to carry out a DC and small-signal AC analysis in the form of screen grabs and/or hard copies of the results obtained.
P4, M3, D1	Thermal Analysis and The Design of Heat Dissipaters	Learners investigate thermal analysis techniques and use them to design an effective heat dissipater for an electronic device (e.g. a TO3 or TAB encapsulated transistor, voltage regulator or other integrated circuit for which electrical and thermal data is supplied).	A report containing written responses including, where appropriate, sketches that describe and explain the use of heat dissipaters. Learners should include evidence of their thermal analysis including the use of appropriate formulae and relevant calculations of thermal resistance, junction and surface temperature.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M4	Surface Mounting Technology	Learners investigate the use of surface mounting technology (SMT) and surface mounted devices (SMD).	A report containing written responses including, where appropriate, sketches of SMT packages and mounting arrangements.
P7, M5, D2	Design, Manufacture, Assembly and Testing of a Prototype PCB	Learners will design, manufacture and test a prototype electronic circuit. In order to complete this task they will need to design and produce a printed circuit board (PCB). The PCB layout should be produced using computer aided design techniques.	A process portfolio containing a circuit diagram, detailed component list, sketches, notes, screen dumps, component and PCB track layout diagrams, test voltages and currents, waveform sketches (as appropriate) together with the learner's final prototype electronic circuit. The portfolio should include an evaluation of the design and manufacture of the electronic circuit together with an appropriate set of recommendations for its mass production.

Essential resources

Learners will need access to an electronics workshop with a range of electronic manufacturing equipment sufficient to meet the needs of the grading criteria (e.g. developing tanks, heated etching baths, PCB drilling equipment, soldering and wiring equipment). Centres will need to provide sufficient electronic test equipment to confirm the functionality of printed circuit boards and provide access to PCs equipped with PCB CAD and SPICE simulation packages. Learners will also need to be provided with relevant personal protective equipment (e.g. goggles, gloves, protective clothing) when manufacturing circuit boards, handling chemicals, soldering etc.

Indicative reading for learners

Textbooks

Sinclair I – *Practical Electronics Handbook* (Newnes, 2007) ISBN 9780750680714

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006) ISBN 9780750669238

Websites

Electronic component suppliers and parts catalogues

Farnell Electronic Components – www.farnell.co.uk

Greenweld – www.greenweld.co.uk

Jaycar Electronics – www.jaycarelectronics.co.uk

Magenta – www.magenta2000.co.uk

Maplin Electronics – www.maplin.co.uk

Quasar Electronics – www.quasarelectronics.com

Electronic CAD, PCB design and SPICE resources

5Spice Analysis – www.5spice.com

B2 SPICE software – www.spice-software.com

CadSoft Online Eagle PCB Design – www.numberonesystems.com

Electronics Workbench Multisim – www.electronicsworkbench.com

Labcenter Electronics – www.labcenter.co.uk

Matrix Multimedia – www.matrixmultimedia.co.uk

WebEE Electronic Engineering Homepage – www.web-ee.com

WinSpice – www.winspice.com

Unit 24: Principles and Applications of Electronic Devices and Circuits

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

Electronics and electronic devices are used in a huge variety of manufactured products. From everyday popular items such as cameras and thermometers to the robotic welding machines used in industry, the use of electronics is continually growing.

This unit provides a practical introduction to basic electronic devices along with analogue and digital electronic principles. It provides learners with an opportunity to investigate the operation of diodes and transistors, two of the most important building blocks in electronic circuits. Learners will then go on to build and test circuits that make use of these devices and will consider the operation of integrated circuits such as the operational amplifier. Logic gates and flip-flops are also investigated both in practice and by using simple electronic principles, such as voltage gain or truth tables.

Finally, the unit will introduce learners to computer-based circuit design and simulation software packages that will allow them to build and test analogue and digital circuits. This will enable learners to recognise the importance of simulation software in the design of electronic circuits.

The overall aim of this unit is to build learners' confidence in their ability to construct and test simple electronic circuits. The emphasis is on prototyping, constructing and measuring. The unit treats systems in terms of their functionality and their input/output relationships.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function and operation of diodes, transistors and logic gates
2 Be able to build and test operational amplifier-based analogue circuits
3 Be able to build and test combinational and sequential logic circuits
4 Be able to use computer-based simulation software packages to construct and test the operation of analogue and digital circuits.

Unit content

- 1 **Understand the function and operation of diodes, transistors and logic gates**

  Diodes: types e.g. Zener, light emitting diode (LED), PN-junction; circuit applications e.g. voltage stabiliser, indicator light, half-wave rectifier

  Transistors: types e.g. NPN, PNP or field-effect transistor (FET); analogue circuit (single-stage amplifier); digital circuit e.g. comparator, transistor as a switch (automatic vehicle head lights or night light); operation e.g. analogue (voltage gain, phase inversion), digital (set-point of operation); function of components in circuits

  Logic gates: types of gates e.g. AND, OR, NOT, NAND, NOR, XOR; gate symbols e.g. British Standards (BS), International Electrotechnical Commission (IEC), American National Standards Institute (ANSI); truth tables; Boolean expressions e.g. A+B, $\bar{A}$, A • B

- 2 **Be able to build and test operational amplifier based analogue circuits**

  Building analogue circuits: method of construction e.g. prototype/bread-board, printed circuit, strip-board; types of circuits e.g. oscillator, filter circuit, comparator circuit, inverting and/or non-inverting amplifier

  Testing analogue circuits: performance against given design requirement; recording actual input and output voltages (tabulating data, plotting graph of results); circuit measurements e.g. measurement of resonant frequency, cut-off frequency, switching point, gain at mid-frequency, bandwidth

- 3 **Be able to build and test combinational and sequential logic circuits**

  Building combinational and sequential logic circuits: types of combinational circuit e.g. at least three gates and three input variables; types of sequential circuit e.g. R-S bi-stables, JK bi-stable, 3-stage counter, 3-stage shift-register based on JK or D-type bi-stables; types of logic family e.g. transistor-transistor logic (TTL) and complementary metal oxide semiconductor (CMOS); characteristics of chips e.g. supply voltage, input and output operating voltages, input and output impedance, propagation delay, power

  Testing of logic circuits: records of performance against given design requirement; input and output states; use of truth tables; use of test equipment e.g. logic probe, signature analyser

  Minimisation of logic circuits: e.g. use of De-Morgan's theorem; Karnaugh maps

- 4 **Be able to use computer-based simulation software packages to construct and test the operation of analogue and digital circuits**

  Simulation of analogue circuit: types of circuits e.g. transistor amplifier, op-amp, active filter, rectifier; types of components e.g. resistor, capacitor, transistor, diode; instrument simulation e.g. voltmeter, ammeter, oscilloscope; records of performance against given design requirement e.g. screen print, input/output waveforms (with scales), gain-frequency response

Simulation of digital circuit: types of circuit e.g. three input combinational circuit, counter, shift register; types of gates/sequential circuit e.g. R-S bi-stables, JK bi-stable, 3-stage counter, 3-stage shift-register based on JK or D-type bi-stables; instrument simulation e.g. on/off indicator, logic probe, word generator, logic analyser; records of performance against given design requirement e.g. screen print, digital input/output waveforms (with scales)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the function of different types of diodes, transistors and logic gates in different electronic circuit applications		
P2 explain the operation of two different types of transistor, one in an analogue and one in a digital circuit		
P3 build two different types of analogue circuit using operational amplifiers, testing appropriately	M1 modify an existing analogue circuit to achieve a given revised specification by selecting and changing the value of one of the components	
P4 explain the operation of three different logic gates with appropriate gate symbols, truth tables and Boolean expressions		
P5 build a combinational logic circuit that has three input variables, testing appropriately	M2 modify a digital circuit to achieve a given revised specification by selecting and changing up to two logic gates	D1 compare and contrast two different types of logic circuits referencing five key characteristics

P6 build a sequential circuit using integrated circuit(s), testing its efficiency	M3 minimise a three input variables combinational logic circuit containing three gates.	
P7 use a computer software package to simulate the construction and testing of an analogue circuit with three different types of components	M4 explain the benefits and limitations of a computer software package used to simulate the construction and testing of both analogue and digital circuits.	D2 analyse the effects of changing the values of circuit parameters on the performance of an analogue circuit containing transistors.
P8 use a computer software package to simulate the construction and testing of a digital logic circuit with three gates.		

Essential guidance for tutors

Assessment

The learning outcomes and related criteria can be assessed in any order. The criteria P1, P2 and P3 are related and it would make sense to build a practical assignment or project around them. The focus would be to build two different types of analogue circuit (P3) that would allow learners to explain the operation of two different types of diodes, transistors and logic gates (P1) and the operation of one of the two different types of transistor (P2). Learners would then need to work on another circuit or simply explain the operation of a transistor in a digital circuit.

A second assignment could be used to cover the practical work required for P5 and P6. This could be linked to the explanation of theory that is necessary to achieve P4.

The last two pass criteria, P7 and P8, could be covered by a third assignment, either before the build and test exercise to prove the circuits, or afterwards, to simulate the circuit performance and testing that learners have already experienced.

Opportunities for the achievement of the merit criteria can be set within the assignments suggested above. For example, a task could be set for M1 that requires learners to modify a circuit to produce a different voltage gain from the one used in P3, or for a different resonant frequency for an oscillator.

M2 could be obtained through a task additional to that used for P5, such as to modify the circuit given for P5. M3 simply requires a minimisation (for example using a Karnaugh map). M4 could then be completed as this requires an explanation of the benefits and limitations of a computer software package, essentially encompassing P7 and P8.

To achieve D1, learners need to compare and contrast two different types of logic family with reference to at least five characteristics. The comparison, which can be partly but not wholly achieved using a table, should consider common logic families such as TTL and CMOS. Where a table is used for comparison it is expected that the meaning of any terms used (for example sink current) should be clearly explained. The comparison as a whole (table, written explanations, diagrams etc.) must make it clear how one logic family can be differentiated from another.

D2 requires an analysis, using a simulation package, of the effects on the performance of an analogue circuit containing transistors of changing the values of circuit parameters (for example components or component values, input/output voltages or signals). To meet the criterion it would require at least one other parameter to be changed – possibly the supply voltage, or input voltage – and noting how ‘clipping’ can occur. Part of the analysis could be to use calculations to show how the theoretical results align with those actually obtained through simulation.

Again, careful selection of the circuits used for the pass/merit assignment could enable this final step to be a natural development from the work already carried out. Establishing firm links between the pass, merit and distinction criteria in this way will encourage learners to work towards higher levels of achievement and will improve the relevance and coherence of the assessment activities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Construction and Operation of Analogue Circuits	Learners have been asked by their employer to build and test analogue circuits to meet a new design requirement.	A practical assignment accompanied by written tasks/oral questioning in which learners construct and test two different analogue circuits, each circuit containing a diode and one containing a transistor. One of the circuits could then be modified to meet a revised specification. Additional tasks would then require the learner to explain the purpose/operation of the diodes and transistor, plus an additional transistor from a further digital circuit.
P4, P5, P6, M2, M3, D1	Construction and Operation of Logic Circuits	Learners have been asked by their employer to build and test logic circuits to meet a new design requirement.	A practical assignment accompanied by written tasks/oral questioning, in which learners construct and test combinational and sequential circuits. Additional tasks would then require the learner to explain the operation of logic gates and compare and contrast different types of logic family.
P7, P8, M4, D2	Using Simulation Software to Construct and Test Circuits	Learners have been asked by their employer to use software to simulate the construction and testing of circuits to meet a new design requirement.	A practical assignment in which learners construct and test analogue and digital circuits using simulation software. They should also be given the opportunity to analyse the effect of changing circuit parameter values.

Essential resources

Centres will need to provide access to an appropriate electronics laboratory with a range of measuring and test equipment, as listed in the unit content. For example, facilities for circuit construction and proto-typing, a range of components, logic-tutor boards, hardware and software to support computer-based analogue and digital schematic capture and circuit simulation will be needed. Learners will also need access to publications, reference data and manufacturers' product information to enable them to consider the different types of components listed within the unit.

Indicative reading for learners

Textbooks

Bell D – *Fundamentals of Electronic Devices and Circuits* (Oxford University Press, 2007) ISBN 9780195425239

Tooley M – *Electronic Circuits – Fundamentals and Applications* (Routledge, 2006) ISBN 9780750669238

Unit 25: Engineering Maintenance Procedures and Techniques

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

The correct maintenance of engineering systems results in improved efficiency and can save organisations time and money in relation to system downtime and stoppages in production. This unit introduces learners to a range of commonly used engineering maintenance procedures and monitoring techniques, which may be encountered in any manufacturing, plant or process environment. The unit will also help learners understand how the data gathered from monitoring engineering systems can be used.

Learners will examine the consequences of maintenance and maintenance planning in terms of cost, and the implications for production, personnel, the environment and safety. They will gain an understanding of engineering maintenance and process planning and develop the skills needed to plan scheduled and preventative maintenance activities on engineering systems.

The unit has been designed to reflect the multidisciplinary nature of maintaining manufacturing plant and process engineering systems, rather than being confined to specialist knowledge of a single discipline. Learners will need to produce a maintenance plan for an engineering system involving two or more interactive technologies from mechanical, electrical, fluid power, process control or environmental systems.

Learners will be required to know about the methods, procedures and documentation that must be completed before handing over maintained systems, and how to confirm that the system is ready to run in a safe and operable condition.

Finally, learners will gain an understanding of the basic techniques of condition monitoring and how computerised maintenance systems can be used to capture data and predict specific failure trends in plant, machinery, equipment and systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Know about the types of maintenance associated with engineering plant, equipment and systems
2. Know about maintenance frequency, the cost of maintenance and its effects on production
3. Be able to produce a maintenance plan for a specific engineering system
4. Understand how data gathered from monitoring the performance and condition of engineering plant, equipment and systems can be used.

Unit content

1 Know about the types of maintenance associated with engineering plant, equipment and systems

Type of maintenance: types e.g. planned, total preventative maintenance (TPM), breakdown, scheduled, corrective, emergency, post fault, scheduled servicing, modification to equipment, condition-based maintenance; maintenance activities e.g. visual examination, monitoring, replacement, sensory, testing, checking alignment, making routine adjustments, removing excess dirt and grime, recording results and reporting defects

Reasons for maintenance: issues relating to higher plant reliability and availability e.g. longer equipment life, improved product quality, greater cost effectiveness, improved safety, legal requirements; issues relating to health and safety e.g. statutory regulations and standards, company rules, codes of conduct, reduction in environmental damage

Engineering systems, plant and equipment: systems e.g. process monitoring and control, mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical; plant and equipment e.g. gearboxes, pumps, engines, compressors, machine tools, lifting and handling equipment, process control valves, mechanical structures, company specific equipment, electrical plant, motors, starters, switchgear and distribution panels, cardiovascular equipment, medical imaging equipment

2 Know about maintenance frequency, the cost of maintenance and its effects on production

Frequency of maintenance: time e.g. daily/weekly/monthly/yearly; activities e.g. data logging and checking, adjustments, tests, routine maintenance, fixed-interval overhaul, equipment replacement, use of computerised techniques; methods for determining frequency e.g. calendar maintenance, hours run meter

Costs: representative data of cost e.g. maintenance as a proportion of total expenditure, utilisation of operator (frontline maintenance), maintenance labour, maintenance contracting, lost production, levels of spares and consumables in stores, equipment hire/replacement, safety and environmental effects

Effects on production: e.g. downtime, effects on operating performance, product quality, customer service, financial penalties, effects on associated equipment or plant, higher energy costs, secondary damage

3 Be able to produce a maintenance plan for a specific engineering system

Maintenance plan: maintenance planning e.g. methods, sequence and timing, frequency, check lists, planned repairs, use of planning techniques, Gantt and Pert charts, team working, computerised methods; resources e.g. personnel, supporting equipment, tools, manuals, materials, components, facilities, stores spares and consumables; procedures e.g. safety procedures, risk assessment, Control of Substances Hazardous to Health (COSHH) and other relevant safety regulations, safe access and working arrangements for the maintenance area, isolation requirements for plant/equipment, disposal of waste, handover procedures, liaison with other departments

Engineering systems: process monitoring and control e.g. mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical (such as cardiovascular, anaesthetic and ventilation, medical imaging)

Supporting documentation: manufacturers' drawings and maintenance documentation; maintenance logs, databases, records, results and defect reports; plans and schedules; production records; standing instructions; handover documentation

4 Understand how data gathered from monitoring the performance and condition of engineering plant, equipment and systems can be used

Monitoring techniques: e.g. condition monitoring, scheduled overhauls, routine servicing, planning systems, hazard studies, failure mode and effect analysis (FMEA), teamwork, self-diagnostic and computerised systems

Data collection: collected at identified points; data e.g. types, operational characteristics, output quality, throughput, environmental operating conditions; interpreting data e.g. electronic-based data, data recording and presentation

Need for monitoring: physical aspects e.g. improve safety, reduce environmental hazards, extend equipment life, ensure accurate equipment performance; cost-related aspects e.g. improve product quality, reduce downtime, reduce costs; other aspects e.g. produce comprehensive computer database, better communications

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe two types of maintenance	M1 justify the suitability of particular types of maintenance for specific applications	
P2 describe the reasons for maintaining a specified engineering system		
P3 describe four maintenance activities for a specified engineering system		
P4 identify two items of plant and equipment for a specified engineering system that require maintenance, describing the frequency at which it should be carried out		
P5 describe the effects on production of carrying out maintenance on a specified engineering system	M2 from a given range of data, calculate the maintenance costs for a specified engineering system in relation to maintenance type, resources and production downtime	D1 discuss how the frequency of maintenance affects production and costs for a specified engineering system

P6 produce a basic maintenance plan for a specified engineering system containing supporting documentation with resource and procedure requirements	M3 justify planned maintenance for a specified engineered system in terms of system downtime, environmental and health and safety considerations	D2 produce a comprehensive plan for the maintenance of a specified engineered system containing all supporting documentation.
P7 describe an application of monitoring, the technique used and how the data is collected and interpreted	M4 analyse given condition monitoring and quality control data to predict specific machinery/plant failure.	
P8 explain the need to monitor the performance and condition of engineering systems.		

Essential guidance for tutors

Assessment

Evidence of achievement could be obtained from investigative assignments, reports of workshop activities or through learners building a portfolio from maintenance operations carried out in the in the workplace.

The unit could be assessed through a mixture of written assignments and practical tasks. Assuming that the learning outcomes are delivered in order, a first assignment with a series of written tasks could be used to cover the criteria associated with learning outcomes 1 and 2. The first task could ask learners to describe two types of maintenance (P1) and four maintenance activities (P3). Learners would then need to describe the need for maintaining a specific engineering system (P2). The system might be mechanical, fluid power, electrical, process control, or an environmental system. This could be extended to cover M1, for which learners must be able to justify the suitability of particular types of maintenance for specific applications. The work produced for M1 should include total preventative maintenance (TPM), scheduled or condition-based maintenance.

A second assignment to cover P4 could ask learners to identify items of plant and equipment that require maintenance and the frequency at which maintenance should be carried out. They will also need to give reasons for carrying out maintenance, for example longer equipment life, improved product quality, greater cost effectiveness, improved safety or legal requirements. The task also needs to ensure that learners cover timing, activities carried out and methods of determining the frequency. It should also ensure that learners have opportunities to give reasons for the required maintenance covering plant reliability/availability and issues relating to health and safety.

A third assignment covering P5 and M2 and D1 could ask learners to calculate from given data the cost of maintenance and describe the effects on production. A further task requiring learners to explain how the frequency of maintenance can affect production and cost would enable M2 to be met.

A well planned, investigative practical assignment could be used to cover criteria P6, M3 and D2. To achieve P6 learners need to produce a basic maintenance plan for a specified system with accompanying documentation with resource and procedure requirements.

This basic maintenance plan should include at least the following:

- identification of the plant/equipment/machinery to be maintained
- identification of the person with overall responsibility for the maintenance process
- the maintenance procedures to be adopted
- timescales for preparation and implementation of the maintenance activities
- a list of the physical resources required for the maintenance activities (for example lifting equipment, tools, test and measuring equipment)
- details of the administrative support that is to be provided for the maintenance work
- details of the maintenance documentation systems to be provided.

This then needs to be built on in order to achieve D2, where a comprehensive maintenance plan containing all supporting documentation needs to be produced for a specified engineering system. The comprehensive maintenance plan should contain the entire basic plan together with at least the following:

- health and safety procedures
- identification of appropriate types of maintenance compatible with production requirements
- identification of who is to carry out the maintenance (for example in-house labour, contractors, specialists)
- lists of sub-assemblies and spare parts to be held
- the quality control procedures that need to be followed during maintenance activities, together with maintenance tools/equipment control and test instrument calibration
- environmental considerations such as the procedures to be adopted for the disposal of all types of waste material arising from the maintenance activity including the safe disposal of toxic and/or hazardous materials if relevant
- handover documentation.

To achieve M3 the practical activity could be supported by written evidence showing that learners are able to justify the maintenance plan in terms of system downtime, environmental and health and safety considerations.

The criteria associated with learning outcome 4 could be assessed through a written assignment. Learners need to explain the need for monitoring the performance and condition of engineering systems (P8). This should include the physical aspects, cost related aspects and other aspects as outlined in the unit content. Systems do not need to be given as the task should be tackled as a generic response outlining the need in systems in general. The task also needs to ask learners to describe an application of monitoring, the technique used and how data is collected and interpreted (P7).

To achieve M4 learners need to carry out an in-depth analysis of given condition monitoring and quality control data to predict specific machinery/plant failure. An example would be data produced by vibration analysis for a large motor bearing. The data could come from computer analysers, inspection and test, SPC (Statistical Process Control), or from general product quality control.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Types of Maintenance Activities	Learners need to report to their manager on types of maintenance and maintenance activities and justify particular reasons for maintenance.	Written report relating general maintenance types to specific examples.
P4	Maintenance Needs in a Complex Engineering System	Learners need to write a report on the maintenance of a complex engineering system.	A written report describing the practical needs for maintenance of plant and equipment that also discusses frequency that maintenance is carried out.
P5, M2, D1	Costing a Maintenance Schedule	Using plant data and a maintenance schedule, learners calculate the cost and effect of maintenance on system production.	A written assessment of the plant maintenance data to identify the costs of maintenance and its impact on production and cost.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M3, D2	Maintenance Planning	Learners produce a maintenance plan and justify the maintenance programme.	An investigative practical assignment. Evidence includes a written basic maintenance plan for the specified system with accompanying documentation and resource and procedure requirements. A comprehensive maintenance plan containing all supporting documentation for the specified engineering system. Additional written evidence justifying the maintenance plan in terms of system downtime, environmental and health and safety considerations.
P7, P8, M4	Monitoring Techniques	Learners need to describe condition monitoring and how data is used to a new member of staff.	Written explanation of the need for monitoring the performance and condition of engineering systems. Written or oral description of an application of monitoring, the technique used and how data is collected and interpreted. Written analysis of given condition monitoring and quality control

			data to predict specific machinery/plant failure.

Essential resources

In order to deliver this unit centres will need to provide learners with access to complex engineered systems or test rigs, relevant data books, manufacturers' specifications, system manuals, functional flow charts and system diagrams. Learners will also need appropriate test equipment and tools and access to maintenance records/documentation from modern factories/plant. Computer software for data logging and self-diagnostics should also be provided.

Indicative reading for learners

Textbooks

Kelly A – Maintenance Systems and Documentation (Butterworth-Heinemann, 2006) ISBN 0750669942

Kelly A – Strategic Maintenance Planning (Butterworth-Heinemann, 2006) ISBN 0750669926

Mobley R K – Maintenance Fundamentals (Butterworth-Heinemann, 2004) ISBN 0750677988

Snow D – Plant Engineer's Reference Book (Butterworth-Heinemann, 2001) ISBN 0750644524

Unit 26: Monitoring and Fault Diagnosis of Engineering Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Condition monitoring and quality control techniques are used to detect potential failure symptoms in engineering systems. The methods used by engineering technicians range from fully automated monitoring down to the use of the human senses. This unit provides learners with an understanding of the fundamentals of engineering system monitoring and fault diagnosis and explains the basic concepts of condition monitoring. The unit examines the development of engineering system monitoring and fault diagnosis and how modern technology, quality control and environmental issues have affected current thinking.

The unit will give learners an understanding of the precautions required to protect themselves and others in the workplace and focuses on the safety measures needed when carrying out monitoring activities, especially those for isolating equipment.

Learners will understand how to use a range of condition monitoring equipment and will develop the skills and knowledge required for the location and identification of faults in engineering systems. Learners will be required to select the appropriate monitoring technique and equipment based on the type of plant or equipment being monitored and the conditions checked.

The unit will enable learners to check and set up monitoring equipment before using it to carry out diagnostic condition monitoring on engineering systems, in accordance with approved procedures. Learners will be expected to use a variety of fault diagnosis methods and techniques, and utilise a number of diagnostic aids and equipment. From the evidence gained they will then identify the fault and its probable cause.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the health and safety requirements relevant to monitoring and fault diagnosis of engineering systems

2 Know about system monitoring and reliability

3 Be able to use monitoring and test equipment

4 Be able to carry out fault diagnosis on engineering systems.

Unit content

- 1 **Know the health and safety requirements relevant to monitoring and fault diagnosis of engineering systems**

  Legislation: appropriate statutory acts and regulations e.g. Health and Safety at Work Act 1974, Management of Health and Safety Regulations 1999, Provision and Use of Work Equipment Regulations (PUWER) 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013 Lifting Operations and Lifting Equipment Regulations 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Health and Safety (First Aid) Regulations 1981; specific safety requirements e.g. company rules, permit to work procedures, risk assessment, environmental issues; health and safety procedures e.g. response to alarms, use of safety equipment, reporting of accidents, reporting of hazardous items of plant or equipment; personal safety e.g. appropriate dress, protective clothing, appropriate or protective headgear, protective gloves and footwear, eye protection, face masks and respirators, appropriate use of barrier creams, personal cleanliness, prompt attention to injuries

  Hazards and practices: workplace hazards e.g. compressed air, hydraulic fluid, gases, hot surfaces, electrical equipment, unfenced machinery, toxic substances and fumes, falling objects, liquid spillage, untidy work area, badly maintained tools and test equipment; safe working practices e.g. isolation procedures, methods of immobilising equipment, precautions to be observed when operating or working on live equipment, permit to work, use of danger tags, warning notices, safety barriers, cones and tapes

  Engineering systems: process monitoring and control; fault diagnosis; systems e.g. mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical (such as cardiovascular, anaesthetic and ventilation, medical imaging)

- 2 **Know about system monitoring and reliability**

  Monitoring terminology: condition monitoring methods e.g. offline portable monitoring, sampled monitoring, continuous monitoring, protection monitoring, human sensory monitoring; monitoring techniques e.g. vibration analysis, temperature analysis, flow analysis, particle analysis, crack detection, leak detection, pressure analysis, voltage/current analysis, thickness analysis, oil analysis, corrosion detection, environmental pollutant analysis

  Failure and reliability: calculations concerning failure e.g. degrees and causes of failure, failure rate, failure modes, functional failure, primary and secondary functions, mean time between failures (MTBF), reliability; factors affecting reliability e.g. design, operation, environment and manufacture, reduction in system/device failure e.g. routine servicing, adjustments; data e.g. defects examination, statistical process control (SPC), quality

- 3 **Be able to use monitoring and test equipment**

  Monitoring and test equipment: use of fixed and portable monitoring equipment for on and offline monitoring including continuous and semi-continuous data recording e.g. vibration monitoring of bearings, self-diagnostics (such as PLCs/smart sensors, computerised data acquisition, data logging, electrical data, gas analysis); use of handheld instruments e.g. meters, thermal imaging; test equipment for taking measurements of parameters e.g. temperature, pressure, viscosity, speed, flow, voltage, current, resistance, sound, vibration

  Procedures: practical methods e.g. crack detection, leak detection, corrosion detection, flow analysis, vibration analysis, pressure analysis

- 4 **Be able to carry out fault diagnosis on engineering systems**

  Diagnostic terminology and techniques: terminology (definitions and explanations of symptoms, faults, fault location, fault diagnosis and cause); techniques e.g. six point, half-split, input–output, emergent problem sequence, functional testing, injection and sampling, unit substitution

  Diagnostic aids: test and measuring equipment; other aids e.g. plant personnel, manufacturers' manuals, system block diagrams, circuit and schematic diagrams, data sheets, flow charts, maintenance records/ logs, self-diagnostics, software-based test and measurement, trouble shooting guides

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

<table>
<tr><th colspan="3">Assessment and grading criteria</th></tr>
<tr><th>To achieve a pass grade the evidence must show that the learner is able to:</th><th>To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:</th><th>To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:</th></tr>
<tr><td>P1 outline the aspects of health and safety legislation that apply to monitoring and fault diagnosis of an engineering system</td><td></td><td></td></tr>
<tr><td>P2 describe workplace hazards and safe working practices relevant to specific monitoring and fault diagnosis situations</td><td></td><td></td></tr>
<tr><td>P3 describe a condition monitoring method and technique related to a given engineering system</td><td>M1 explain four factors which influence either failure or reliability in a given engineering system</td><td rowspan="3">D1 analyse the environmental effects on reliability of temperature, humidity, vibration and pressure for a given engineering system</td></tr>
<tr><td>P4 use given data to calculate failure rates for a range of components and equipment</td><td rowspan="2">M2 explain the environmental conditions which affect the reliability of the components in given items of congruent equipment</td></tr>
<tr><td>P5 describe the factors affecting reliability for a given engineering system</td></tr>
</table>

P6 describe the monitoring and test equipment used for measuring given system condition parameters	M3 evaluate the quality of measurements made and the limitations of given items of condition monitoring equipment	
P7 use procedures to carry out system monitoring on two separate engineering systems		
P8 describe the terms and two different techniques related to fault diagnosis	M4 use diagnostic techniques, test and measuring equipment and aids to locate faults on two separate engineering systems where two malfunction symptoms are evident on each system.	D2 analyse monitoring/quality control data and information to predict/detect potential failures in given engineering systems.
P9 use diagnostic techniques, test and measuring equipment and aids to locate faults on two separate engineering systems where two malfunction symptoms are evident on each system.		

Essential guidance for tutors

Assessment

Evidence of achievement of the learning outcomes and grading criteria may be obtained from well-planned investigative assignments or reports of workshop activities. Alternatively, it may be accumulated by learners building a portfolio from investigations and monitoring and fault diagnosis operations in the workplace or through realistic exercises and tests. In either case the opportunity should exist for merit and distinction grades to be achieved with relevant and sufficient evidence to justify the grade awarded.

Assuming that the unit is delivered in the same order as the learning outcomes, a first assignment could cover the criteria for learning outcome 1 (P1 and P2). This assignment could be a written or practical task requiring learners to identify appropriate health and safety procedures and personal safety requirements for an engineering system. Such a system might be mechanical, fluid power, electrical, process control or an environmental system (such as fume extraction or air conditioning).

Learning outcome 2 could be assessed through a written or time-constrained assignment requiring learners to calculate, from given data, failure rates for a range of components and equipment. These could be pumps, actuators, compressors, air receivers, accumulators, valves, generators, motors, transformers, switch gear, machine tools, engines or gearboxes (P4). The assignment could contain a task requiring learners to describe factors affecting reliability (P5) and monitoring methods and techniques (P3). A third task could be added to cover M1, requiring learners to identify and describe four factors that influence either failure or reliability in a given engineering system. A further task requiring learners to identify and describe environmental conditions affecting the reliability of components in items of equipment and analyse the effects of the environment on component/asset reliability could enable achievement of M2 and D1. The range of components and equipment should be sufficient to allow these higher grading criteria to be achieved. However, the range required for pass criterion P4 would need to be at least one mechanical type, one electrical type and one fluid type system. Therefore, a range of data for each is required to be given to learners.

Assessment of learning outcome 3 could be by a well-planned practical investigative assignment covering criteria P6, P7 and M3. This would require learners to carry out monitoring activities on two separate engineering systems, such as bearing vibration analysis, temperature, flow, particle, oil, pressure, voltage/ current corrosion, environmental pollutant, crack and leak detection. Such systems may be mechanical, fluid power, electrical, process control or environmental systems. This could be supported by written evidence that shows the learner is able to describe the use of monitoring and test equipment and evaluate the quality of measurements and the limitations of given items of monitoring equipment. Witness statements and annotated photographs would be suitable evidence to support the use of procedures to carry out system monitoring.

Learning outcome 4 is best suited to practical investigation. For P8, learners need to explain the terms and two different techniques from those in the unit content, such as six-point, half-split, input-output, emergent problem sequence, functional testing, injection and sampling and unit substitution. For P9, they need to use diagnostic techniques, test and measuring equipment (such as dial test indicators, torque instruments, logic probes, multimeters etc.) and aids to locate faults on two separate engineering systems where two malfunction symptoms are evident on each system.

The assignment to cover this could have a task requiring learners to carry out fault diagnosis on a given engineered system. This could be either in a simulated situation or in the workplace using evidence gathered in a logbook containing items such as equipment used, tests carried out and measurements taken. This should be supported by the inclusion of witness statements.

Learners must describe typical fault conditions and find faults independently on equipment, which exhibits symptoms of more than one function failure. For example, a pump can have two functions, one to pump water at a given rate, the other to be free of water leaks whilst pumping. To achieve M4 learners must demonstrate a logical approach to fault finding and be able to distinguish between symptoms, faults and causes. A second task supported by written evidence would enable learners to demonstrate that they are able to analyse data and use this information to predict/detect potential failures in given engineering systems for D2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Health and Safety in System Monitoring and Fault-Finding	An investigation of practical health and safety issues and legislation, relating to system monitoring and fault diagnosis.	A learner report and risk assessment, identifying and discussing relevant H&S issues, including the methods used to address these.
P3, P4, P5, M1, M2, D1	System Condition Monitoring and Reliability	Practical and theoretical investigations into the factors affecting component and system reliability, including: failure rate calculations; factors affecting reliability and system and component monitoring techniques, in general and as applicable to a specified engineering system.	A written and/or time-constrained assignment containing the learner's: calculations of failure rates for specified components and equipment; discussions on reliability; and on system monitoring methods. Supported by the learner's engineering sketches and diagrams.
P6, P7, M3	Performing System Monitoring and Measurements	A practical investigation into the monitoring and evaluation of two different engineering systems.	A learner report or portfolio of evidence and data describing the monitoring techniques and equipment used, and interpreting the measurements made on the two systems. Supported by the learner's engineering sketches and diagrams. Witness statements and annotated photographs.
P8, P9, M4, D2	System Fault-Finding Techniques	A practical investigation into across two systems(4 in total) and using 'diagnostic techniques, test and measuring equipment and aids.	A learner report containing an explanation and evidence of the investigations and tests performed, and the conclusions drawn.

			Supported by the learner's engineering sketches and diagrams. Witness statements and annotated photographs.

Essential resources

This unit is intended to provide learners with a practical introduction to monitoring and fault diagnosis methods and techniques. Therefore, it is essential that learners have access to:

- actual engineered systems or test rigs designed for monitoring/fault finding
- data books and manufacturers' specifications
- system manuals and functional flow charts and system diagrams
- computer software for data logging and self-diagnostics
- appropriate test equipment and tools
- maintenance records.

Indicative reading for learners

Textbook

Yardley E – *Condition Monitoring – Engineering the Practice* (Wiley-Blackwell, 2002) ISBN 9781860583612

Website

Health and Safety Executive www.hse.gov.uk

Unit 27: Principles and Applications of Engineering Measurement Systems

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

There is now a wide range of systems and methods used to measure performance and operations within engineered systems.

This unit is designed to develop learners' knowledge and understanding of the use of measurement and testing in engineered systems whilst providing them with opportunities to explore both traditional and modern methods. The unit explains the physical principles used in transducers and shows the way that these principles are exploited in practice across a range of industrial measurement applications.

The selection of correct measurement systems is key to the optimum performance and operation of an industrial plant. The unit gives learners an insight into the main elements of a measurement system and shows how these elements working together provide a required function.

The unit describes recording and display devices and their operational characteristics, so that learners will be able to use and make informed choices between similar devices on technical grounds. Modern display and recording techniques are discussed and learners' are given the opportunity to use and design virtual instrumentation systems using computer software.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Understand the applications of common measurement systems
2. Understand the operation of measurement system components
3. Be able to use testing, recording and display equipment for a measurement application
4. Be able to test and calibrate a measuring system.

Unit content

- 1 **Understand the applications of common measurement systems**

  Main purpose and elements of measurement: producing or obtaining data; carrying out inspection and testing; monitoring health and safety; checking outputs e.g. meeting specifications, quality control, condition monitoring; controlling processes; carrying out statistical analysis

  Measurement system elements: block diagrams; elements e.g. transducers, signal conversions, signal conditioning, recording and display, transmission links; common measurement systems e.g. pressure transmitter, level transmitter, temperature transmitter, flow transmitter

  Measurement system performance: performance terms e.g. accuracy, error, linearity, reliability, repeatability, sensitivity, resolution, range, transfer function, static and dynamic characteristics, electrical noise, calibration

- 2 **Understand the operation of measurement system components**

  Transducer types: output of common measurement transducers e.g. temperature, pressure, flow, level, vibration, weight, displacement; physical principles e.g. resistive, capacitive, piezo-electric, inductive, opto-reflective, static pressure, elasticity

  Signal converters: conversion process e.g. voltage to current, pressure to current, current to pressure, frequency to voltage, analogue to digital (ADC), digital to analogue (DAC); signal converter types e.g. Wheatstone bridge, V/I converter, P/I converter, I/P converter, F/V converter, ADC, DAC

  Signal processors: types e.g. voltage and current amplifiers, mechanical amplifiers, simple signal filters, multiplexers, decoders; specification requirements e.g. voltage amplitude, current amplitude, signal frequency, noise reduction

- 3 **Be able to use test, recording and display equipment for a measurement application**

  Test equipment: electrical/mechanical types e.g. multimeters, handheld oscilloscope, signal generator, logic testers, earth loop impedance meter, pressure injector, 4-20mA loop calibrators, insulation tester, optical alignment; safety; functions and operation; specification e.g. output, input, range of operation, resolution

  Recording and display devices: computer elements in monitoring and recording e.g. data acquisition, interface cards, software; specification e.g. acquisition speed, resolution, input type; plotters and chart recorders

  Virtual instrumentation: software available e.g. NI LabVIEW, Visual Basic, Discovery; mimics; trending; alarms

4 **Be able to test and calibrate a measuring system**

Test and calibrate: calibration parameters (component specification, system requirements); calibration of measurement equipment e.g. pressure, level, temperature, flow, nucleonic, position, speed

System specification and function: measurement system specifications; characteristics and limitations of measuring systems e.g. operating range, environment

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the main purpose and elements of measurement	M1 justify the design of a measurement system, ensuring that it meets the required specification	D1 evaluate the performance of a given measurement system against a required specification
P2 explain the main elements within three given common measurement systems		
P3 explain the performance of a given common measurement system		
P4 explain the operational principles of three different types of transducer		
P5 explain the conversion process that takes place within three given signal converters		
P6 describe the signal processors needed to meet a given specification		
P7 use appropriate test equipment to test the function and operation of a common measurement system against specification		
P8 use an appropriate recording or display device to meet a given specification	M2 design a graphic display for a given measurement system	

P9 use virtual instrumentation software to display, record and generate a report on a given measurement system		
P10 test a given common measurement system to meet the requirements of the system specification, calibrating as required to ensure its performance limitations are not exceeded.	M3 explain the testing methods used and the calibration process.	D2 evaluate the performance limitations of the calibrated system.

Essential guidance for tutors

Assessment

Assessment evidence for the first six pass criteria (P1–P6) could be produced through a written assignment. After explaining the various purposes of measurement systems (P1), learners could be asked to explain the main elements of three different measurement systems using block diagrams (P2), given manufacturers' data sheets for each of the given systems.

The block diagram could provide learners with a basis to explain, select and explain the functionality and performance of the transducer, signal converter and signal processor elements (P3, P4, P5 and P6). The assignment must include reference to common performance terminology.

A practical workshop assessment could be used to assess pass criteria P7 and P10. Firstly, learners could be provided with a measurement system and data sheets. They could then be provided with details of the required output tests that must be carried out to ensure it can be checked for function and operation. Learners will need to select an appropriate test instrument that meets the test requirements, and perform the test(s). A written report should be produced presenting the results clearly, with appropriate conclusions. A witness statement/observation record could be used to confirm the safe use of the test equipment for P7 and that testing and calibration was carried out successfully (P10). This could be extended to include a written explanation of the testing methods and calibration process (M3) and an evaluation of the performance limitations to achieve D2.

The final assessment could be a combined practical and written assignment which asks learners to use a computer with previously produced screen mimics and interfaces to record and display data from the output of a measurement system (P9). Learners could then be asked to compare this display/recording/trending system with alternatives, select an alternative and provide reasons for the selection (P8).

Assessment evidence for M1 is likely to be an extension to the assignment covering pass criteria P1-P6. Learners could be asked to design a new measurement system (block diagram form may be sensible) to meet a given measurement specification. The specification will need to include a transducer, a signal converter and a signal processor. This type of activity could be supported through simulation software to confirm that the specification has been met.

Assessment evidence for M2 could be achieved through an extension to the assignment covering criteria P8 and P9. Learners will need to be provided with a computer interfaced to the previous measurement system. They could then be asked to design a software graphic, input the measured data and display in an appropriate form to meet a given specification.

Assessment evidence for D1 could be achieved through an extension of the assignment covering criteria P1-P6 and M1. Learners could be asked to evaluate the performance of a measurement system that is measuring a variable within an industrial process plant. This evaluation will consider the operation and performance of the system. Learners could be asked to suggest improvements to the system or suggest an alternative, having identified and discussed advantages and limitations.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, P6, M1, D1	Measurement Systems and System Components	Learners need to produce an information booklet detailing the purpose of measurement and the function of the main elements within a measurement system.	A written assignment including a task requiring learners to explain the purpose of measurement and a series of descriptions, based on block diagrams, of the main elements within a measurement system.
P7, P10, M3, D2	Testing and Calibrating Measurement Systems	Learners need to use suitable equipment to test and calibrate a measurement system.	A practical assignment supported by observation records and a written report in which learners select equipment, perform tests to meet requirements and calibrate a measurement system.
P8, P9, M2	Recording and Display Equipment	Learners need to record and display data from a measurement system and write a report comparing the system used with alternatives.	A mixed practical and written assignment. Learners are to use a computer with previously produced screen mimics and interfaces to record and display data from the output of a measurement system. They should then compare this display/recording/trending system with alternatives and select an alternative.

Essential resources

Process rigs and associated measurement and test equipment are essential for the delivery and assessment of much of this unit. Learners should have access to relevant workshop or laboratory facilities including:

- process plant or system simulators
- measurement and data acquisition software
- measurement and data acquisition hardware (PCs and interface cards)
- data books and manufacturers’ specifications
- measurement and test equipment manuals
- appropriate tools.

Indicative reading for learners

Textbook

Bolton W – *Instrumentation and Control Systems* (Elsevier, 2004) ISBN 9780750664325

Unit 28: Electrical Technology

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning: 60

Unit introduction

Electricity is used in a wide range of applications, such as manufacturing, healthcare, transport and entertainment. All of these are reliant on electrical technology in one form or another. For example, for someone to be able to visit a holiday destination, go to a music festival or download the latest track by their favourite performer, numerous electrical activities and concepts must be coordinated.

Electrical technology provides the link between science and its application. It is underpinned by a range of enabling technologies and concepts such as materials science, energy efficiency, environmental impact, geological characteristics and design.

This unit provides an introduction to ways in which electricity is produced, the options we have about how and why we produce it, and the disposal of related by-products. The unit considers how the electricity that has been produced is then moved to where the customer (end-user) needs it. It also examines the materials used and whether alternatives exist or could be found.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the methods used to produce electrical energy
2 Understand the properties and applications of conductors, insulators and magnetic materials
3 Understand the physical arrangements of supply, transmission and distribution equipment
4 Understand how electrical energy is used to support applications of electrical technology.

Unit content

- 1 **Know the methods used to produce electrical energy**

  Electromagnetic generation: characteristics and principles of operation of alternating current (AC) and direct current (DC) generators e.g. relative motion between conductors and magnetic fields, production and regulation of AC using field/slip-ring control, production of DC using commutators and brushgear; features of different types of electrical power generating stations and their energy sources e.g. coal, gas, oil, nuclear, hydroelectric, pumped storage, wind farms, tidal, biomass

  Solar panels: developments in photoelectric cells e.g. photo-electric effect, PN-junction for basic photocell, need for use of converters to convert to alternating current source; small and large scale applications of solar panels e.g. roadside furniture such as school crossing warning signs, domestic/commercial roofing

  Electro-chemical cells and batteries: construction, applications and disposal; primary and secondary e.g. lead/acid, alkaline, nickel-iron (NiFe), nickel-metal-hydride (NiMH), nickel-cadmium (NiCad), lithium

- 2 **Understand the inherent electrical and magnetic properties of conductors, insulators and magnetic materials**

  Conductors: properties e.g. conductivity, resistivity, tensile strength, rigidity; electrical applications of solid conducting materials e.g. copper, aluminium, steel, brass, carbon, soil (for Earth continuity); applications of liquids and gases e.g. electrolytes, fluorescent and discharge lighting

  Insulators: properties e.g. resistivity, maximum voltage capability, operating temperatures, mechanical strength; applications of solid, liquid and gas insulating materials e.g. poly-vinyl-chloride (PVC), butyl-rubber, glass, paper, oil, air

  Magnetic materials: properties e.g. retentivity, coercivity, B-H curve, hysteresis, iron losses; electromagnetic applications e.g. permanent magnets, electromagnets, soft iron, silicon steel, mu-metal, ferrites for use at audio and high frequencies

- 3 **Understand the physical arrangements of supply, transmission and distribution equipment**

  Electrical generation: energy conversion methods e.g. generating plant and equipment (coal, gas, oil, nuclear, hydroelectric, pumped storage, wind farms, tidal, biomass, photo voltaic, Gas turbine); by-products (useful and not so useful, C02 emissions, carbon neutral); speed governing and voltage regulation for supply standardisation

  Electrical transmission: use of transformers for feeding into and out of the grid network; construction and operation of power transformers e.g. double-wound and autotransformers; construction and operation of switchgear and protection systems e.g. air circuit breakers, oil circuit breakers, fuses, over current and over voltage devices; transmission voltages e.g. 400kV, 275kV and 132kV and the reasons for using them; cross-channel/intercontinental links for electricity supply

Electrical distribution: ring and radial feeders; sub-stations; use of distribution voltages e.g. 33kV, 11kV; plant and equipment e.g. isolators, oil breakers, air breakers; three-phase and single-phase distribution systems and voltages (400V and 230V); earthing arrangements

- 4 **Understand how electrical energy is used to support applications of electrical technology**

Applications of electrical technology: manufacturing e.g. automated processes, robotics, control systems; healthcare e.g. magnetic resonance imaging (MRI) scanners, operating theatre uninterruptible power supplies (UPS); entertainment e.g. sound and video systems, theme parks, music festivals; transport e.g. electric trains, inner-city trams, electric cars, solar powered space travel

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the characteristics and principles of operation of a DC electromagnetic generator	M1 compare the features of three prime energy sources that are in general use for the production of electricity by mechanically driving an electromagnetic generator	D1 justify the use of different energy sources, including fuels and renewable sources, to provide a nation's electricity supply
P2 describe the characteristics and principles of operation of an AC electromagnetic generator		
P3 describe the operation and an application of a solar power source		
P4 describe the characteristic features of two different types of electro-chemical cells or batteries		
P5 explain the properties and a typical application of a solid and a liquid or gas electrical conductor		

P6 explain the properties and a typical application of a solid and a liquid or gas electrical insulator		
P7 explain the properties and an application of two different magnetic materials commonly used in electrical and electronic engineering		
P8 describe the arrangements and features of an electrical supply system from generation through to transmission and distribution to end users	M2 explain the reasons for the use of a range of voltages in an electricity supply system	D2 evaluate an electrical supply system suggesting possible improvements.
P9 explain two different applications of electrical technology and, for each of them, describe how electrical energy is used to enable them to function.	M3 explain how a practical application of electrical technology could be improved by making effective use of available technologies.	

Essential guidance for tutors

Assessment

Although this unit could be delivered completely in class, the learning and assessment experience is much more relevant if the learners make use of the outside world and visit real applications of electrical technologies.

The pass criteria could be achieved through the use of written assignments and/or illustrated posters with relevant text boxes to describe the concepts covered, e.g. the characteristics and principles of operation of a DC electromagnetic generator.

For P1, (DC generator) and P2 (AC generator), motor vehicle/motorcycle parts are cheap and are a relatively safe resource that could be investigated and described. The larger items in power stations are just scaled-up models (figuratively speaking) with somewhat larger brush gear and coils, etc. Hence, an assignment could require learners to use such an easily obtainable device to help them describe the principles and operation of electromagnetic generation.

Learners could then use this simple model to illustrate the similarities and differences between these and larger machines when they consider the characteristics of a power station and its energy sources (e.g. a coal, gas, oil, nuclear, hydro-electric, pumped storage, wind farm, tidal, biomass) used to generate power commercially.

Solar cells (P3) can be found on a range of items including calculators and street signs, as well as small kits used by many college and school science departments. The learners' description of their operation should be limited to developments in photoelectric cells and a consideration of the action of the atoms in crystal lattice PN-junctions when subjected to illumination. An in-depth atomic theory explanation is not expected.

Cells and batteries take many forms and, although a wide range should be taught, learners only need to select two for P4. Liquid conductors and insulators (P5 and P6) could also be part of the learners' response to P4 if a wet cell such as lead acid were to be described. Reference could also be made to the potential hazard of topping up the cell with tap water if living in a hard water, high mineral content region. This would short out the plates and ruin the cell(s) whereas distilled or de-ionised water would not.

There is a wide range of other examples that could be examined for P5 and P6. For example, oil is a good insulator and is used on oil circuit breakers to quench the spark and prevent conduction. Fluorescent lights contain a variety of conductive gases and vapours requiring different arcing voltages and producing a range of colours. Overhead lines are insulated by air and any simple electric switch uses air as an insulator when in the 'off' position.

To cover P7, learners could consider electrical relays, motors, generators or similar devices that rely on electromagnetism. For example the soft iron formers of transformers and motors or a radio tuner's use of ferrite core inductors. Some devices use permanent magnets, which could also be explained to address P7.

P8 requires learners to describe the arrangements and features of an electrical supply system to cover the key aspects of the content. This will include the generation method, transformer construction, types and operation including single wound (autotransformers) and double wound voltages and distribution method. Learners might also include the finer details of distribution such as an electronics workshop having isolating transformers on bench supplies and reasons why they are used.

P9 provides an opportunity for learners to apply their knowledge by considering complete real-world applications. Examples could include lighting systems, sound systems or systems including motion (ranging from a model containing an electric motor to the electrification of the rail network). The Docklands Light Railway and some airport transport systems have no driver and an investigation of these systems could allow learners to work on an area in which they may be interested and learn through the application of electrical technology. This should take learners into such aspects as electromagnetic effects and sensors for control, computer control, or the requirement for emergency or uninterrupted power supplies (UPS).

To achieve a merit, learners should be able to differentiate between the mechanical prime movers of electromagnetic generators (M1), ranging from nuclear, coal and gas to wind and wave power and water storage such as that used at Dinorwic in Wales. Things to compare and contrast could include cost, response time, maximum demand, pollution, environmental issues including appearance, hazards (and perceived hazards), locality of employees, life span of the project and post-service decommissioning.

While reporting on a supply system (P8), learners could address M2 by explaining why a range of voltages is used such as 15 to 25kV at the generators and up to 400kV for transmission, and the reasons for other voltages (e.g. 33kV, 11kV and 3.3kV down to 400/230 volts) for light industrial and domestic end users.

To address D1 learners need to produce a thorough justification of why a nation might use a range of different energy sources. This could include (as a source and focus for the learner's own justifications) suitably referenced third party comments from parliamentary reports, Greenpeace opinions, local opposition groups and the projected impacts on national and global economies. Other considerations could include the future of different methods and fuels, lifespan of equipment and the actual fuel, cost of fuel production, hazards and environmental impact assessments.

D2 provides an opportunity for learners to develop the ideas of P8 and M2, electrical supply systems. For D2 learners are expected to provide suggestions for improvements to many aspects of effectiveness and efficiency of a chosen system. The suggestions made, and their explanations and justifications, should be feasible and possible. This could include an evaluation of the learner's ideas by a third party/engineer in that chosen industry. The learner could then make effective use of this through further reflection and subsequent development of their own work by following the professional feedback.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, D1	Electrical Energy Production	Learners produce an information poster for learners detailing the main forms of electrical energy production.	A written assignment with a series of tasks requiring learners to describe AC and DC generators, solar power and two different batteries.
P5, P6, P7	Conductors, Insulators and Magnetic Materials	Learners need to produce a report detailing the properties and applications of different conductors, insulators and magnetic materials to determine the best for a particular application.	A written assignment with a series of tasks requiring learners to explain conductors, insulators and magnetic materials.
P8, M2, D2	Electrical Supply, Transmission and Distribution Equipment	Learners produce a report on the electrical supply system.	A written assignment for which learners describe the electrical supply system and explain the reasons for a range of voltages.
P9, M3	Applications of Electrical Technology	Learners have been asked to investigate the use of electrical energy.	A written assignment requiring learners to explain the use of electrical energy in different applications.

Essential resources

Centres will need simple models or alternators/dynamos from motor vehicles to demonstrate AC and DC generation. Because cells and batteries can be hazardous, videos/DVDs or pictures are recommended to illustrate these along with manufacturers' data.

Indicative reading for learners

Textbooks

Hughes E – *Electrical and Electronic Technology* (Pearson Education, 2012) ISBN 9780273755104

Kiameh P – *Power Generation Handbook* (McGraw-Hill, 2011) ISBN 9780071772273

Patrick D and Fardo S – *Electrical Power Systems Technology* (Fairmont Press, 2008) ISBN 9781439800270

Unit 29: Electrical Installation

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

We all use electricity, almost without thinking about it. Although we are surrounded by and rely on electrical appliances, most people have little understanding of how electricity arrives at its final point of use.

This unit will give learners an understanding of the circuits regularly found in domestic premises, the components and accessories used, cables, sockets and light switches etc. Learners will gain some practical experience of constructing and investigating some of these circuits and systems. The unit will provide an understanding of installations where there is an increased shock risk, mainly to illustrate the hazards associated with these areas.

Safety and safe working practices are essential to reduce the risks of working with electricity to an absolute minimum. Learners will gain a knowledge of selecting types of cable for their insulation properties, current-carrying capacity and physical strength, and choosing the correct type and rating of protective devices to prevent over-current. Learners will also be introduced to how the design and provision of earth-bonding conductors helps prevent electric shock.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to interpret lighting and power circuits diagrams

2 Understand the methods used to protect circuits

3 Be able to install and test lighting and power circuits

4 Know the non-statutory and statutory regulations relating to the provision of an electrical installation.

Unit content

- 1 **Be able to interpret lighting and power circuits diagrams**

  Lighting circuits: e.g. one way, two way (loop-in method, junction box, singles)

  Power circuits: e.g. fused plug socket outlet, ring circuit, radial circuit, switched fused spur, cooker, immersion heater, heating control

  Choice of cables and protection devices: cable calculations e.g. design current, correction factors, tabulated cable ratings and voltage drops; maximum demand and diversity e.g. determination and application of maximum demand and diversity (individual householder, small shops/offices, small hotels/guest houses); segregation of circuits; categories of circuit proximity to non-electrical services

  Increased risk of electrical shock areas: e.g. inside the main property (rooms containing a fixed bath or shower, sauna, swimming pool), equipment outside equipotential zone (shed, garage, workshop, garden, pond)

- 2 **Understand the methods used to protect circuits**

  Types of over-current protection device: fuse e.g. rewireable, cartridge; miniature circuit breakers (MCBs); residual current breaker with overload protection (RCBO)

  Circuit protection methods: earthing and bonding e.g. ADS automatic disconnection of supply. earthed neutral system, system classification (terra-terra (TT) and terra-neutral (TN) with combined (C) and separate (S) variations (TNC, TNS, TNC-S)), earth electrodes, protective multiple earthing (PME), earth fault loop impedance, typical values; protective conductor circuit e.g. main and supplementary equipotential bonding conductors, earthing terminal; residual current devices (RCDs); other protection methods e.g. class 2 equipment, class 3 equipment; cable size e.g. from tables for current loading and thermal constraints; protection from mechanical damage e.g. armoured cable, cable trunking, cable tracking

- 3 **Be able to install and test lighting and power circuits**

  Lighting and power circuits installations: use of flexible and non-flexible cable; use of tables to select cable type and size; circuit components (consumer unit/circuit isolation device, light switching e.g. 1-gang, 2-gang, 1-way, 2-way, intermediate; power socket outlets e.g. ring, radial, switched fused spur connection units; other types of power circuits e.g. immersion heater, heated towel rail)

  Circuit testing: for compliance with circuit diagram e.g. operation of switches, circuit continuity, polarity, insulation resistance checks

- 4 **Know the non-statutory and statutory regulations relating to the provision of an electrical installation**

  Statutory regulations: scope, object, principles and use of relevant parts of statutory wiring, installation and site regulations e.g. Health and Safety at Work Act, Electricity Supply Regulations, Electricity at Work Regulations, the Building Regulations (particularly Part P), Construction (Design and Management) Regulations, Electricity Equipment Safety Regulations, Electromagnetic Compatibility Regulations

  Non-statutory regulations: scope, object, principles and use of relevant sections of the wiring regulations e.g. BS7671: 2008 plus amendments and relevant guidance notes

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 interpret two different lighting circuit diagrams, explaining the function of the circuits and why the cables and protective devices have been chosen for each installation	M1 carry out calculations to obtain cable sizes, given the power and voltage, taking installation methods and correction factors into account	D1 analyse the design specification of a domestic installation with at least six circuits, including the use of diversity when determining the final maximum demand current
P2 interpret two different power circuit diagrams, explaining the function of the circuits and why the cables and protective devices have been chosen		
P3 describe the extra considerations required for an electrical installation in an area of increased risk of electrical shock	M2 explain the steps taken to prevent electric shock by indirect contact	
P4 explain the operation of the three types of over-current protective devices, describing a suitable electrical installation application for each		

P5 describe the function and application of two different circuit protection methods		
P6 install and test two different lighting circuits in accordance with current wiring regulations	M3 inspect and test a given electrical installation for compliance with installation instructions and relevant regulations.	D2 justify the inspection and testing methods carried out for a lighting and a power circuit.
P7 install and test two different power circuits in accordance with current wiring regulations		
P8 describe the statutory and non-statutory regulations that apply to an electrical installation on the inside of a building		
P9 describe the statutory and non-statutory regulations that apply to an electrical installation on the outside of a building.		

Essential guidance for tutors

Assessment

P1 requires learners to demonstrate their ability to interpret two different lighting circuit diagrams, explain the function of each circuit and say why the cables and protective devices have been chosen for each of the installations.

P2 is similar but focuses on power circuit diagrams. In order to satisfy the cable calculation requirements of P1 and P2, learners should be able to perform calculations based on design current. However, to satisfy M1, learners should take into account appropriate correction factors, use tabulated cable ratings and work with voltage drops.

For P3, learners could use diagrams/sketches to help describe a relevant installation inside a property or equipment outside the equipotential zone. This should include the positioning of equipment and any other safety features and reference to appropriate regulations.

For P4, learners must explain the operation of all three types of overcurrent protective device listed in the unit content (fuse, miniature circuit breaker, residual current breaker with overload protection). They will then need to describe a suitable electrical installation application for each device.

For P5, learners need to describe the function and application of two different circuit protection methods (for example earthing residual current devices) or any other protection methods (for example class 2 equipment, class 3 equipment). Learners must refer to issues of cable size (for example from tables for current loading and thermal constraints) and the method used to protect the circuit from mechanical damage (for example armoured cable, cable trunking, cable tracking).

P6 and P7 require learners install and test two different lighting circuits and two different power circuits in accordance with current wiring regulations. One approach to assessment might be to use these four circuits as the focus for the assessment of all the other criteria. This type of approach to assessment would provide maximum coherence but, by necessity, would fragment the criteria. Therefore centres would need to take care when tracking learner achievement.

Records for each installation would need to be planned carefully to indicate learners have met the relevant criteria and unit content and only when all four installations have been completed satisfactorily would each criterion be fully achieved.

Evidence for this work could be a mix of tutor observation records, annotated photographic evidence, the learner's research and preparation notes and formal reporting. For example, in addition to the installation, a formal written description of the extra considerations required for an electrical installation in an area of increased risk of electrical shock would be required. The evidence could be brought together as a portfolio record for each installation. The constraint to this approach would of course be the centre's ability to provide sufficient installation facilities to cope with a reasonable group size.

For P8 and P9 descriptions of the statutory and non-statutory regulations that apply to an electrical installation on the inside and outside of a building could also be planned to fit into the above assessment approach. Learners will need to summarise the relevant legislation (statutory and non-statutory) that needs to be considered when electrical installation work is carried out in and around buildings. The list given in the unit content should not be seen as exhaustive and centres should ensure that the most current, relevant and up-to-date legislation is covered.

Less integrated approaches could also be used to good effect where equipment or other constraints apply. However, a circuit should only be deemed to be correctly wired when any single cores of conductors with diameters less than 2.5mm2 are terminated into a screwed terminal. Other elements of good practice also need to be demonstrated, all connections must abide by the latest UK/EU colour code standards (or equivalent for other countries), and the circuit must work.

M1 and D1 build on learners' understanding from P1 and P2. For the application of diversity in D1, the circuits could include examples such as upstairs and downstairs ring circuits, upstairs and downstairs lighting circuits, cooker (with or without 13A socket), immersion heater, or outside supply to a garage/shed.

Having carried out the installations for P6 and P7, the learner should be expected, as simply a matter of good practice, to check their own work for compliance ahead of assessment. This can be extended to meet M3, where learners inspect others' work.

In doing this, learners should follow relevant inspection and test procedures using appropriately annotated inspection and testing documentation (such as those illustrated in the wiring regulations or the on-site guide or other centre devised certification). The activity for this could be the supervised assessment of the work carried out by a fellow learner who is presenting their installation as evidence for P6 and P7.

M2 builds on the work carried out for P3, P4 and P5. This will include earthing connections and other means. To differentiate the work at merit from that at pass, it is expected that at this level learners not only know what needs to be done but can explain and justify the actions taken. This should include, why an RCD is needed outside the equipotential zone, and how it operates, why it needs to operate in a certain specified time and the relevance of its current sensitivity ($I\Delta n$) to the effects of electricity passing through a human body or livestock.

D2 builds on the inspection work undertaken for M3. Learners are required to explain and justify the inspection and testing methods carried out for one lighting and one power circuit. This should take into account the what, where and how of the inspection process for compliance with circuit diagram e.g. operation of switches, circuit continuity, polarity, insulation resistance checks and should give learners an opportunity to demonstrate their understanding of the unit as a whole.

The evidence, which is likely to be a technical report, should clearly explain what they were doing during the inspection and why. It should also include what they were looking for and why; which test equipment they used, how and why it was 'proved' before and after use and, finally, how well the results show the installations comply with the respective circuit diagrams.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Interpreting Wiring Circuit Diagrams	Learners interpret provided lighting and power circuit diagrams, perform calculations of cable size and analyse the provided design specification of a domestic electrical installation.	A learner report including supporting calculations, engineering sketches and diagrams.
P3, P4, P5, M2	Investigating Circuit Protection and Safety Techniques	Learners investigate, inspect and report on different measures for providing protection against circuit overload and the risk of electrical shock.	A learner report including descriptions, and evaluations, supported by engineering sketches and diagrams.
P6, P7, M3, D2	Implementing Electrical Installations	A practical activity in which learners install, test and inspect prescribed lighting and power circuits.	A learner report including descriptions, and evaluations, supported by engineering sketches and diagrams.
P8, P9	Non-Statutory and Statutory Wiring Regulations	Learners investigate and then describe pertinent wiring regulatory requirements.	A learner report, including descriptions supported by engineering sketches and diagrams.

Essential resources

Centres will need to provide access to suitably equipped workshops for the installation of electrical circuits (preferably with some installation onto walls or, where necessary boards), together with relevant test equipment to carry out tests to prescribed regulations (e.g. BS7671 and Guidance Note 3).

Learners will also require access to a range of wiring diagrams, test rigs and wiring boards, electrical tools and components and cabling required for lighting and power installations.

Centres will need to provide appropriate documentation such as statutory and non-statutory regulations, manufacturers' catalogues, data sheets and relevant cable, component and equipment specifications.

Indicative reading for learners

Textbooks

Hinsley A – *Testing Electrical Installations: A Practical Guide for Electricians* (Castleknight Publications, 2006) ISBN 9782952413831

Scaddan B G – *IEE Wiring Regulations Explained and Illustrated: A Practical Guide to BS7671:2001* (Newnes, 2011) ISBN 9780080969176

Whitfield J – *The Electrician's Guide to the 17th Edition of the IEE Wiring Regulations* (EPA Press, 2008) ISBN 9780953788552

Unit 30: Electronic Measurement and Testing

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Practical electronic engineering demands the extensive use of electronic test equipment and measurement techniques. These range from basic measurements of parameters such as voltage, current and resistance to highly sophisticated software-controlled measurements based on advanced mathematical techniques such as Fast Fourier Transformation (FFT).

This unit will give learners an understanding of a variety of electronic measurement equipment such as voltmeters, ammeters, analogue/digital multimeters and oscilloscopes or specialist diagnostic equipment. The unit also examines a range of electronic test equipment such as signal generators, digital counter/frequency meter, alternating current (AC) bridge, logic probe, logic pulsar and current tracer.

Learners will develop an understanding of the function, features and characteristics of electronic measurement and test equipment. They will also gain practical experience of their use when carrying out electronic testing and measurements in a wide range of electronic engineering applications. This will include selecting, connecting and operating different types of test equipment and applying measurement techniques.

Learners will demonstrate that they can apply common testing methods and be able to assess errors inherent in the instruments used. Particular attention is paid to ensure that the test procedure, as well as the test and measurement equipment used is fit-for-purpose and properly calibrated. Learners will be expected to explain the effects of instrument characteristics such as accuracy, display resolution and loading and how these affect the measured quantity.

Finally, learners will be introduced to the use of virtual test instruments and software to make measurements and analyse measurement data. They will examine equipment such as a digital storage oscilloscope, spectrum analyser, digital voltmeter, digital frequency meter, arbitrary waveform generator or logic analyser. Learners will be expected to make measurements using virtual instruments and analyse the captured data using appropriate software.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function, features and characteristics of electronic measurement and test equipment

2 Be able to select and use electronic measurement and test equipment to make meaningful measurements on an electronic circuit

3 Know the principles of calibration and configuration of electronic test equipment

4 Be able to select and use virtual test instruments and software to make measurements and analyse measurement data.

Unit content

- 1 **Understand the function, features and characteristics of electronic measurement and test equipment**

  Function of equipment: as appropriate to the measurement and test equipment e.g. accurate measurement of alternating current (AC) and direct current (DC) voltage and current, resistance, waveform and distortion measurement, accurate measurement of waveform parameters (period, duty cycle, on-time, off-time, rise time, fall time, frequency, pulse repetition frequency (PRF), impedance, logic level)

  Features of equipment: as appropriate to the measurement and test equipment e.g. displays ands display technology, input and output connectors, attenuators, manual and automatic range selection (auto ranging), in-built calibration facilities, portability, power sources, external bus interfaces

  Characteristics of equipment: measurement and test equipment specifications e.g. input impedance, output impedance, resolution, accuracy, distortion, bandwidth, input signal range, output level, sample rate, trigger sources

  Measurement instruments: meters (voltmeter, ammeter); analogue/digital multimeter; oscilloscope to include specialist or manufacturer diagnostic/ measuring equipment

  Electronic test equipment: signal generator e.g. audio frequency (AF), radio frequency (RF) and pulse generators, waveform/function generators; digital counter/frequency meter; AC bridge; logic probe; logic pulsar; current tracer

- 2 **Be able to select and use electronic measurement and test equipment to make meaningful measurements on an electronic circuit**

  Selection of equipment: selection based on instrument specifications, characteristics and limitations e.g. output, level, input sensitivity, frequency range, accuracy, resolution and distortion

  Measurement techniques: test-point voltage and waveform measurement; supply voltage and current measurement; power, impedance and phase angle measurement using variable loads; frequency and PRF measurement; rise and fall time measurement; distortion and noise measurement (qualitative only); use of test specifications e.g. in the case of a variable DC power supply, measurement of the actual output voltage delivered at a specified load current when the power supply has been set to a specified voltage under no-load conditions; in the case of an audio amplifier, measurement of the output power delivered to an externally connected load of specified resistance, using a specified test frequency and waveform and at a specified level of distortion

  Measurements: use of test points, test leads and probes; minimisation of loading effects; use of appropriate instrument ranges; precautions to be taken when measuring high voltages and currents; precautions to be taken when working on low voltage and computerised systems; effect of DC levels on AC signals and waveforms; effect of signals present at DC test points; effect of drift and temperature; need for calibration; relevant test specification and measurement techniques e.g. sampling, averaging

Electronic equipment: industrial/consumer electrical and electronic equipment including low-voltage DC power supplies e.g. linear, switched-mode types; amplifiers e.g. AF, RF, small-signal, power; oscillators e.g. sinusoidal, square wave, crystal controlled; radio equipment e.g. radio receivers, low-power transmitters and transceivers; digital electronic equipment e.g. microcontrollers, microcomputers, programmable logic controllers; manufacturer specific equipment; video equipment e.g. television and video players/recorders

3 **Know the principles of calibration and configuration of electronic test equipment**

Calibration principles: procedures e.g. check, adjust, systematically standardise measuring instrument, set-up arrangement; reference standards e.g. standard resistors, standard inductor; theory e.g. accuracy, uncertainty; impact of calibration on quality, productivity and safety; applications e.g. during manufacture, following installation, periodic scheduled maintenance, in response to identified deviation, after repair or change in environment; terminology e.g. zero shift, range (or span) error, combined zero shift and range error, non-linearity

Health and safety issues: e.g. precautions to be observed when setting and adjusting mains supply voltages, replacing/charging/disposing of batteries, dismantling and reassembling equipment, removal/replacement of external and internal covers, making adjustments on 'live' equipment, continuity of earth (grounding or bonding) of electrical equipment, safety cut-outs and residual current device (RCD), earth leakage circuit breaker (ELCB)

Configuration issues: pre-conditions and checks to ensure that system/equipment is safe to test and instruments safe to use; test equipment set-up e.g. use of the equipment manufacturer's procedures, using commissioning guides

4 **Be able to select and use virtual test instruments and software to make measurements and analyse measurement data**

Virtual measurement and test system: e.g. digital storage oscilloscope, spectrum analyser, digital voltmeter, digital frequency meter, arbitrary waveform generator, logic analyser

Measurement techniques, connection, hardware and software: tests carried out on electronic equipment using virtual test and measuring instruments; instrument connection e.g. external/internal PC interface, instrument connection standards (parallel port, serial port, USB, PCI/PXI bus, IEEE-488, PCMCIA); use of hardware and software to carry out measurements e.g. voltage, frequency, frequency spectra measurements (for sinusoidal and non-sinusoidal waveforms); measurement software, data storage and data transfer e.g. to a spreadsheet, automated measurement/data collection techniques

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the function, features and characteristics of a measurement instrument		
P2 explain the function, features and characteristics of three different pieces of electronic test equipment		
P3 select and use test equipment and measuring techniques to take measurements from three different pieces of electronic equipment	M1 use a manufacturer's recommended procedure together with laboratory instruments and standards to calibrate and configure an item of electronic test equipment	D1 evaluate the accuracy of own test measurements and relate them to limitations of the test equipment, test procedures, or possible emerging fault conditions
P4 explain the importance of test specifications as an aid to ensuring the validity and consistency of measurements		

P5 describe the principles and need for the calibration of an item of electronic test equipment	M2 explain the importance of resolution, accuracy, sensitivity bandwidth and input impedance on the performance of a piece of test equipment	D2 devise and demonstrate a calibration procedure for an item of electronic test equipment.
P6 explain the health, safety and configuration issues that need to be considered when connecting test equipment to an item of electronic equipment that requires testing		
P7 use a virtual measurement and test system to carry out a test on a piece of electronic equipment		
P8 describe the measurement techniques, instrument connection, hardware and software used.	M3 use appropriate software to display and analyse voltage/ time data captured from a virtual oscilloscope.	

Essential guidance for tutors

Assessment

To achieve P1 and P2, learners will need to describe the function, features and characteristics of one measurement instrument and three different pieces of electronic test equipment. The evidence for this could be block diagrams/sketches (with appropriate annotation) and short notes. The actual function, features and characteristics explained will be dependent on the electronic test equipment selected but examples of the types of things to consider are provided in the unit content.

P3 requires learners to select and use test equipment and measuring techniques to take measurements from three different pieces of electronic equipment. These can be low-voltage dc power supplies, amplifiers, oscillators, radio equipment, digital electronic test, measurement or diagnostic equipment or display equipment. Further examples of each of these are provided in the unit content.

Learners will need to perform practical measurements in an electronic laboratory or electronic workshop. Given a particular measurement requirement (for example, to investigate the frequency range of an oscillator) learners should then be able to select the appropriate items of test and measurement equipment to carry out the task. Both the selected item(s) of test equipment and the measuring technique(s) should be appropriate to each measured quantity. For example, an oscilloscope and x10 probe would not be appropriate for the accurate measurement of the output frequency produced by an oscillator. The three different pieces of electronic equipment should enable as wide a range of test equipment and measuring techniques to be applied as possible. All three pieces could come from one category (e.g. consumer electrical and electronic equipment) as long as the chosen equipment provided for the use of a sufficient range of test equipment and measuring techniques. It is expected that all the content listed under measurement techniques and measurements will have been covered by the time learners has carried the measurements on all three pieces of equipment.

Evidence for P3 is likely to take the form of tutor observations and learner records of the selection and use of equipment and techniques employed. Suitably annotated photographic records could also be used (e.g. a photograph of the equipment being tested, the test equipment and the test set-up, all suitably labelled to highlight the key features of the test/measurements).

For P4, learners should provide a written or verbal presentation to explain the importance of test specifications as an aid to ensuring the validity and consistency of measurement. Centres should ensure that learners have access to a variety of test specifications for common measurements (e.g. determining the output impedance of a power supply by voltage/current measurement when a suitably rated variable load is applied). The achievement of this criterion could be effectively linked with the practical work in any one of the tests carried out for P3.

P5 requires learners to describe the principles and need for calibration of an item of electronic test equipment. Again, one of the tests undertaken for P3 could provide the focus for this criterion. The description, which is likely to be a written report, must include the electronic test equipment calibration procedures that need to be carried out, the reference standards required and any relevant theory. Examples of each of these and typical applications are given in the unit content. As an aid to understanding the calibration process, centres should demonstrate the calibration procedures for equipment used in the laboratory (e.g. oscilloscopes, digital multimeters, signal generators, etc.).

For P6, learners must be able to describe the health, safety and configuration issues that need to be considered when connecting test equipment to an item of electronic equipment that requires testing. The health and safety issues considered will depend upon the equipment being tested. The configuration issues considered must, as a minimum, enable the learner to take into account the required pre-conditions and checks to ensure that it is safe to test the system/equipment. For example the selection of an adequately rated load in terms of both impedance and power rating when testing an audio amplifier or the need to check that an oscilloscope probe is correctly matched to the oscilloscope that it is to be used with. Learners will also need to ensure instruments are safe to use (e.g. use of a high-voltage probe when measuring DC voltages in excess of 500 V) and test equipment set-up correctly e.g. use of equipment manufacturer's procedures, using commissioning guides. Again it would make sense to link this criterion to one of the tests undertaken for P3.

To satisfy P7 and P8 learners should use a virtual measurement and test system to carry out a test on a piece of electronic equipment. They should provide a written or verbal description of the procedure used, explaining the connections made, the software settings, and the measuring techniques used. A typical example would be the use of a virtual digital storage oscilloscope used in conjunction with a personal computer (PC). Learners should connect and configure the instrument in conjunction with the software running on the PC and select, for example, appropriate sampling rates, input ranges and display and data capture settings. Evidence of individual learner's work can most conveniently be presented in the form of a selection of screen dumps that have been suitably annotated by the learner.

For M1, learners are required to calibrate and configure a test instrument (such as a waveform generator), using the manufacturer's recommended procedures and appropriate laboratory instruments and standards. Learners should be supplied with relevant documentation (e.g. manufacturer's handbook) and laboratory standards (such as a standard frequency or time generator). Evidence is likely to be a logbook record of the calibration exercise or a technical report of the calibration activity. Tutor observation records should be used to support either of these forms of evidence. There is a clear link between this merit criterion and P5.

To achieve M2 learners need to explain the importance of resolution, accuracy, sensitivity bandwidth and input impedance on the performance of a piece of test equipment. This could be achieved as a natural extension to one of the tasks carried out for P3.

To satisfy M3, learners should use a virtual storage oscilloscope (using a PC with appropriate interface hardware and software) to display and analyse a waveform. Note that the emphasis should be on the analysis of the waveform rather than its display. A typical example might involve the production of a frequency spectrum for the sampled waveform using FFT techniques. Once again, learners should keep a record of their work in a logbook, supported by tutor observation records. Relevant screen dumps and print outs that have been suitably annotated by the learner could also be incorporated.

The learner's work towards D1 should require them to evaluate the accuracy of their own test measurements and relate them to limitations of the test equipment, test procedures, or possible emerging fault conditions. For example, learners should be aware of the inability of an oscilloscope to accurately display a transient pulse due to the oscilloscope's own finite rise-time and bandwidth. Another example would be the need to be aware of the effects of aliasing on the captured and displayed waveform when sampling a fast waveform.

For D2, learners need to be able to devise and demonstrate a calibration procedure for an item of electronic test equipment. A typical example might be a procedure to calibrate a 'x10' oscilloscope probe using a fast-rise time square wave generator, a high-speed oscilloscope, and a matching ‘x10’ probe. Evidence is likely to be in the form of a technical report although it would be beneficial if the devised calibration could be linked into the work done for P5 and M2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Measurement Instruments and Test Equipment	Learners are requested to generate an information booklet and an accompanying report for new staff.	Written assignment
P3, P4, P5, P6, M1, M2, D1, D2	Selecting, Using and Calibrating Electronic Test Equipment	Learners have been asked to show a new learner how to take measurements from electronic equipment and talk them through the calibration of test equipment and relevant health, safety and configuration issues.	A practical assignment with additional written tasks
P7, P8, M3	Virtual Testing	Learners have been asked by their employer to carry out tests on a piece of electronic equipment.	A practical assignment

Essential resources

Centres will need to provide access to an electronics laboratory fitted with a range of electronic test and measurement equipment (such as multimeters, signal generators, oscilloscopes, or specialist manufacturer equipment within industry etc.). A limited number of specialist items of electronic test equipment and calibration sources (e.g. standard cells and off-air signal sources) should also be available. Specialist items of electronic equipment (such as AC bridges, earth continuity testers, logic analysers, component testers, etc.) may be required as appropriate to the needs of local industry.

A small number of computer-based virtual instruments should also be available together with the appropriate hardware and software (e.g. LabVIEW, DASYLab, DADiSP, MATLAB etc.). Test and measurement applications should be installed on these systems.

Indicative reading for learners

Textbooks

Hughes E – *Electrical and Electronic Technology* (Pearson Education, 2012) ISBN 9780273755104

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006) ISBN 9780750669238

Tooley M – *PC Based Instrumentation and Control* (Routledge, 2005) ISBN 9780750647168

Unit 31: Features and Applications of Electrical Machines

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

All electrical machines use applications of electro-magnetic principles where electric currents create magnetic fields, which either attract or repel each other. This is the basis of all electric motors, whether they operate on alternating current (AC), direct current (DC) or are universal motors that operate on both.

Transformers are devices that also use the principle of electromagnetism. These are generally very efficient and their output power can be almost 100 per cent of the input power, depending on the application.

This unit has been designed to help learners understand the complexities of electromagnetism and its applications to everyday electrical devices, systems and apparatus. Learners will consider a range of machines, their application and their control. In addition, the unit will help learners understand relevant electrical hazards, legislation, regulation and standards.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the electrical hazards and the legislation, regulations and standards related to working with electrical apparatus

2 Understand features and applications of alternating current (AC) machines

3 Understand features and applications of direct current (DC) machines

4 Know how electrical machine control circuits and systems operate.

Unit content

- 1 **Know the electrical hazards and the legislation, regulations and standards related to working with electrical apparatus**

  Electrical hazards: safe working procedures e.g. isolation (safe isolation, switch off, lock off, display notices, testing for dead with test lamp and proving unit), earthing, interlocking, warning notices, permit to work; risk assessment when working on electrical apparatus e.g. hazard evaluation and recording of risk, controlling risk; personal protective equipment (PPE) e.g. insulated gloves, mats, tools, barriers

  Legislation, regulations and standards: e.g. Health and Safety at Work Act 1974, The Electricity at Work Regulations 1989, Personal Protective Equipment at Work Regulations 1992, Electrical Equipment (Safety) Regulations 1994, Machinery Directives, HSE publications e.g. GS38, Codes of Practice, British and International Standards, BS7671 17th Edition IEE Wiring Regulations

- 2 **Understand features and applications of alternating current (AC) machines**

  Alternating current (AC) motors: single and polyphase; construction, principles of operation, starting characteristics and torque; types (induction motors, split-phase, capacitor start, capacitor start and run, shaded pole, universal, variable frequency drives); applications of AC motors e.g. conveyor belt drives, pumps, machine shop equipment, fixed loads, variable loads

  AC generator: types e.g. single-phase, polyphase; construction and principles of operation; applications e.g. stand-by generators, remote site generators, vehicle alternators with regulation and rectification

  Transformers: principles of operation; efficiency and losses; construction of single and double wound; types e.g. step up, step down, safety isolating transformer; applications e.g. incoming mains step down, portable transformer for hand tools, safety isolating transformer for electrical test-bench work, machine power supplies

- 3 **Understand features and applications of direct current (DC) machines**

  Direct current (DC) motors: types e.g. series, shunt, compound (long and short shunt), brushless; construction, principles of operation, starting characteristics and torque; applications e.g. motor vehicle starters and window operation, toys and models, industrial drives, crane hoists, fixed loads, variable loads

  DC generators: construction and principles of operation; production and control of DC voltages and current; applications e.g. motor vehicles, speed control/feedback systems (tacho-generators)

- 4 **Know how electrical machine control circuits and systems operate**

  Stop/start/retain relay control: relay/contactor with retaining/latching contact; start, stop, overload, 'inch' (non-latching) control; remote stop/start; safety relays for production/manufacturing equipment e.g. several guards closed sensors, oil level detectors, temperature sensors, body heat (passive infra-red) detectors; control circuits e.g. AC machine control (direct on line (DOL), star-delta, soft start and other solid state techniques such as triac, inverter drives, slip ring rotor resistance control, auto transformer, power factor correction), DC machine control (starting methods and speed control such as face plate, solid state systems); emergency stop e.g. closed contact device to stop the machine/system from running or starting and turn power off under emergency conditions; emergency stopping e.g. dynamic braking by either DC injection braking or timed phase reversal, solenoid operated mechanical brakes, instantly stopping the machine

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe hazards that may exist when working with two different pieces of electrical apparatus		
P2 describe control measures that should be used to reduce the risk of harm to self and others when working with two different pieces of electrical apparatus		
P3 describe aspects of legislation, regulations and standards that relate to work being carried out on two different pieces of electrical apparatus		
P4 explain the features, characteristics and application of two different types of AC motor	M1 explain the operational features of a speed control system for an AC machine	D1 compare the applications of a DC and an AC motor for two contrasting modern electrical installations
P5 explain the features, characteristics and an application of one type of AC generator		

P6 explain the features, characteristics and application of two different types of transformer		
P7 explain the features, characteristics and application of two different types of DC motor	M2 explain the operational features of a speed control system for a DC machine	
P8 explain the features, characteristics and an application of a DC generator		
P9 describe the operation and use of a stop/start/retain relay control circuit for an AC or DC machine.	M3 explain the use of a safety relay system and how its use addresses the issues raised in relevant legislation, regulations and standards.	D2 compare the construction and operation of two different types of stop/start/ retain relay control circuit for either an AC or a DC machine.

Essential guidance for tutors

Assessment

P1, P2 and P3 are linked and are likely to be achieved through investigations based on the same two different items of electrical equipment, e.g. transformers, isolators, AC and DC motors. Evidence could be presented in the form of a written report or as a presentation to a group using appropriate visual aids.

When describing hazards and control measures for P1 and P2, learners should include all the aspects identified in the unit content.

For P3, learners should include relevant quotes from their sources and specific references and it is important that these are shown to be specific to the work being undertaken and not just general quotes.

For P4, the learner needs to carry out investigations based on two different types of AC motor (e.g. induction, split-phase, capacitor start, capacitor start and run, shaded pole, universal, variable frequency drives, single or polyphase motors). Ideally, these should be combined into one single investigation of two different motors rather than two separate investigations. This will avoid the need to assess the criterion twice before it can be reported as achieved. Learners need to describe the features, characteristics (e.g. construction, principles of operation, starting characteristics and torque) and a typical application for each type of AC motor considered. Evidence could include written descriptions plus relevant drawings, circuit diagrams, photographs and exploded views (as appropriate), annotated to aid the description.

P5 and P6 require a similar approach. However, it is important to note that while P5 only requires one AC generator to be considered, for P6, like P4 above, learners must describe two different types of transformer (e.g. step up, step down or safety isolating transformers).

P7 and P8 simply replicate the criteria for P4 and P5 but for two different DC motors (e.g. series, shunt, compound (long and short shunt), brushless) and one DC generator. As above, P7 should be done as one activity to avoid splitting the criterion.

P9 requires learners to be able to describe the operation and use of a stop/start/retain relay control circuit. This can be an AC or DC machine and can be chosen by the tutor or the learner. The choice of AC or DC control circuit is only limited by the need to draw as extensively as possible from the unit content to cover such aspects as safety relays and emergency stop/stopping requirements. The assignment should be based on a practical investigation if possible and learners should provide a careful description of the circuit that they have investigated. This should include an itemised list of components (together with a description of the function of each component) and should be supported by a suitably annotated circuit diagram.

To achieve M1 and M2, learners should be able to explain the operational features of the speed control systems for an AC machine and a DC machine respectively. Learners will need to consider the speed control aspects of machines within specific applications, which will draw from and build upon their knowledge and understanding developed through P4–P8.

For M3, learners need to explain the use of a safety relay system and how the system addresses the issues raised in relevant legislation, regulations and standards. The system considered could be the same as that described for P9. Learners must be able to set the circuit within a particular context or application and demonstrate that they understand the importance of the circuit within that application.

Learners must also have recognised the relationship of such a circuit to the requirements of relevant legislation, regulations and standards. Note that there is a further link from the work undertaken for P9 and M3 to that required for D2 (see notes below) and this might form the basis of a single assignment.

To satisfy D1, learners should show that they can bring together their understanding of P4 to P8 by comparing the applications of a DC and an AC motor for two contrasting modern electrical installations. Learners should investigate two sufficiently complex and contrasting installations that enable them to draw from and show that they can apply the understanding that they have gained at pass and merit level. Typical applications might be a variable-speed motor drive for an electric vehicle and a high-torque constant-speed drive used in an industrial conveyor belt.

Learners should justify the type of DC and AC motor as well as its supply configuration (e.g. triac speed controller) and output drive systems (e.g. gearbox or belt reduction system). They should also make reference to the operating principles and actual machine characteristics (e.g. starting torque, on-load torque, efficiency).

D2 builds on the work undertaken for P9 and M3. As such, the circuit considered for P9 could be one of the stop/start/retain relay control circuits that is used for comparison and against which a second is compared. However, centres may prefer to get learners to consider two completely different relay control circuits to provide them with a wider range of experience.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Electrical Hazards and Legislation and Regulations	A technician has been asked to show potential electrical hazards to a new learner and explain the legislation and regulations with which they need to be familiar.	A written report or a presentation
P4, P5, P6, P7, P8, M1, M2, D1	AC and DC Electrical Machines	A technician has been asked to write a report explaining and comparing the key features of a range of new AC and DC machines.	A written report
P9, M3, D2	Machine Control Circuits and Systems	A technician has been asked to describe the operation of a stop/start/ retain relay control to a new member of staff.	A written report

Essential resources

Centres will need a workshop equipped with electrical machines and associated switchgear and control equipment. Learners will require access to a range of AC and DC motors and generators. A selection of different types of transformer (e.g. step-down, step-up, isolating variable voltage) will also be required. In addition, to permit testing of motor speed controllers, learners will require one or more variable speed controllers (for both AC and DC motors) together with variable loads and machine braking systems.

Learners will also require access to appropriate statutory and non-statutory regulations, health and safety legislation as well as catalogues, data sheets and relevant equipment specifications.

Indicative reading for learners

Textbooks

Bird, J – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN9780415662857

Hughes A – *Electric Motors and Drives: Fundamentals, Types and Applications* (Newnes, 2013) ISBN 9780080983325

Schultz G – *Transformers and Motors* (Newnes, 1997) ISBN 9780750699488

Unit 32: Three-Phase Motors and Drives

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

Three-phase motors are used where greater amounts of power are required and single-phase motors would not be effective. A good example of this is a large compressor where a constant speed is required. The two main advantages of three-phase types over single-phase types are the smoother torque they provide and a higher power to weight ratio, giving smaller frame sizes for comparable power outputs.

This unit will develop learners' knowledge of the design and operation of three-phase motors which use electrical and electronic control devices to make them work. This will include being able to read and produce simple circuit diagrams and understand the principles of installation, commissioning and maintenance. Learners will be made aware of the requirements of a drive and the need for the motor and drive to be matched to the characteristics of the application.

The unit will provide a good foundation for anyone interested in taking up a career in the manufacturing or processing industry, particularly where large motor drives are involved.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how squirrel-cage and wound rotor three-phase induction motors operate

2 Know how three-phase synchronous and synchronous-induction motors operate

3 Understand about the function and operation of motor starters and control gear

4 Understand a range of industrial applications for installing, commissioning and maintaining three-phase motors.

Unit content

- 1 **Know how squirrel-cage and wound rotor three-phase induction motors operate**

  Principle of operation: production of rotating magnetic field e.g. distributed winding, salient pole, frequency, pole pairs, synchronous speed, rotor speed; induction motor types e.g. squirrel cage, wound rotor (slip ring)

  Constructional features: cores e.g. stator, rotor, laminations, spiders, materials; frame e.g. cast, fabricated, end covers, materials; rotor e.g. squirrel cage, wound type; stator e.g. distributed windings, single layer, double layer; enclosure e.g. cooling/ventilation, open, totally enclosed, drip proof, flameproof; shaft and fittings e.g. bearings, slip rings, brushes, brush lifting gear enclosure ratings e.g. Ingress Protection, BS 490, BS 5345

  Characteristics and calculations: characteristics e.g. frequency, poles, speed/load, torque/speed, torque/slip; calculations e.g. speed, slip, starting current, load, torque, power, efficiency

- 2 **Know how three-phase synchronous and synchronous-induction motors operate**

  Principle of operation: production of rotating magnetic field e.g. distributed winding, salient pole, frequency, pole pairs, synchronous speed, effect of excitation; synchronous motor types e.g. pony motor, synchronous-induction motor, synchronising; characteristics e.g. open circuit, v-curves; reasons for calculations e.g. speed, torque, leading/lagging power factor, power, efficiency

  Constructional features: rotor e.g. cylindrical, salient pole; stator e.g. distributed windings, single layer, double layer; excitation methods e.g. DC exciter, AC exciter, brushless

- 3 **Know about the function and operation of motor starters and control gear**

  Starters: circuit diagrams and operation of induction motor types e.g. direct on line (DOL), star-delta, autotransformer, soft start, rotor resistance; circuit diagrams and operation of synchronous motor types e.g. pony motor, synchronous-induction motor, synchronising; effects of reduced voltage starting e.g. current, starting torque; protection devices e.g. short circuit, earth leakage, overload, interlocks, trips

  Control gear: speed control e.g. variable frequency, inverters, pulse width modulation (PWM); motor drives e.g. DC transistor/thyristor, inverter types, braking, soft starting; programmable logic controllers e.g. simple ladder logic

- 4 **Know about a range of industrial applications for installing, commissioning and maintaining three-phase motors**

  Load characteristics: load characteristics and demands of machinery e.g. centrifugal fans and pumps, compressors, machine tools, mechanical handlers, plastic extruders, lifts, hoists, conveyors

  Ratings and calculations: electrical parameters e.g. power, KVA, KVAr, power factor, voltage, current; mechanical parameters e.g. power, speed, slip, torque, efficiency, gear ratios, volume, pressure, flow

  Installation, commissioning and maintaining: installation procedures e.g. foundations, mountings, insulation checks, rotation, couplings; commissioning procedures e.g. starting, running, load test, temperature monitoring; maintenance procedures e.g. rotor/bearing checks, lubrication, brushes, brushgear, control gear, insulation tests

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the principle of operation and the constructional features of a three-phase squirrel-cage and a three-phase wound rotor (slip ring) induction motor	M1 explain the production of a rotating magnetic field from a three-phase supply suitable for three-phase induction motors	D1 evaluate the speed control methods used for three-phase induction motors and explain the effects of changing speed on torque/slip characteristics
P2 carry out calculations involving frequency, poles, speed, torque, power and efficiency for a three-phase induction motor from given data	M2 explain the variation of torque and slip for a three-phase induction motor using values from given data	
P3 describe the principle of operation, constructional features and excitation methods of a three-phase synchronous motor	M3 explain the methods of starting a three-phase synchronous motor and the effects of variation of excitation with reference to the v-curve characteristics	

P4 explain, with the aid of suitable circuit diagrams, the operation of two different reduced voltage starters for induction motors, one starting method for a synchronous motor, and a protection device for use with a three-phase induction motor		
P5 explain the control gear required for a three-phase induction motor and a three-phase synchronous motor		
P6 explain the characteristics of typical loads for four types of machinery driven by three-phase motors	M4 justify the selection of a three-phase motor and its drive for a given application using calculations involving electrical and mechanical parameters.	D2 analyse an installation, commissioning and maintenance process for a three-phase motor and its drives and suggest possible improvements.
P7 select a suitable three-phase motor for a given application giving details of ratings, starter types and control gear requirements		
P8 explain the installation, commissioning and maintenance procedures for a three-phase motor.		

Essential guidance for tutors

Assessment

This unit could be assessed through the use of four assignments.

The first assignment could be about induction motors and cover criteria P1, P2, M1, M2, D1 and D2. A written task should be given to cover P1. Learners will need to consider the production of the rotating magnetic field when describing the principle of operation. They will also need to consider cores, frame, rotor, stator, enclosure and shaft and fittings when describing the constructional features.

Learners should be given data to use when carrying out the calculations required by P2. This data could be varied for each learner to aid authenticity, or the task could be time-constrained. A further task should be set asking them to explain the production of a rotating magnetic field and the variation of torque and slip using given values to achieve criteria M1 and M2 respectively. Learners' evidence will be written and will include their calculations. For criterion D1 a task should be set that asks them to write a report that shows an evaluation of the speed and control methods, and explain the effects of the changes on torque/s torque/slip.

The second assignment could cover synchronous motors and cover criteria P3 and M3. A written task could cover the construction, operation and excitation of synchronous motors. A practical exercise or demonstration could be done for starting and variation of excitation. From this information, learners can formulate relevant descriptions and explanations. Starting voltage, current and torque are useful parameters to be measured.

A third assignment on starting and control could cover criteria P4 and P5. While a written task could be used to cover both criteria, it would be more interesting for learners if they could operate starters and drives and take appropriate measurements. Explanation of the control gear could be as a result of stripping down or opening up starters, drives and other control gear. In doing so it is important that learners also consider the effects of reduced voltage such as current and starting torque.

The fourth assignment on applications could cover criteria P6, P7, P8, M4 and D2. Tasks should require learners to refer to details of typical loads and machinery to be driven (P6). Learners must then consider the types of motor and control gear appropriate for driving different loads and select and describe the features (P7). For M4 choices need to be supported by detailed calculations, with relevant justification of some depth using calculated parameters. The evaluation of speed control (D2) must be linked to the torque/slip characteristics and include details of more than one method, e.g. thyristor drives and inverter drives. A further written task could ask learners to describe the installation, commissioning and maintenance procedures for a three-phase motor (P8).

Manufacturers' literature and specifications are a useful source of practical information for the above tasks.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P1, P2, M1, M2, D1	Induction Motors	A technician needs to strip-down, inspect and report on the operation of induction motors.	A report including a set of written descriptions, the results of calculations and an explanation of the production of a rotating magnetic field and the variation of torque and slip.
P3, M3	Synchronous Motors	A technician needs to strip-down, inspect and report on the operation of synchronous motors.	A written report, including descriptions based on practical demonstration of excitation methods.
P4, P5	Starters and Control Gear	A technician needs to show a new learner the operation of starters and control gear.	A written report
P6, P7, P8, M4, D2	Applications of Three-Phase Motors	A technician has been asked to produce a report on the three-phase motors used in an industrial application in their workplace.	A written report based on a practical investigation or case study of local industrial applications.

Essential resources

Centres delivering this unit must have access to industrial standard three-phase electric motors, starting/ control gear and associated drives. In addition, appropriate and adequate testing instruments and fault-finding assemblies should be provided. European and British Standards, health and safety and other publications should also be available.

Indicative reading for learners

Textbooks

Hughes A – *Electric Motors and Drives: Fundamentals, Types and Applications* (Newnes, 2013) ISBN 9780080983325

Petruzella, F – *Electric Motors and Control Systems* (McGraw-Hill Education, 2009) ISBN 9780073521824

Unit 33: Further Electrical Principles

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Electrical technicians need to apply practical and theoretical principles of electrical engineering to the development, manufacture and servicing of complex electrical and electronic systems.

They can expect to perform technical functions involved in assembling, installing, repairing and maintaining electrical equipment. These could include the calibration, prototyping, modification and general maintenance of electrical equipment in accordance with manufacturers' instructions and company technical procedures.

Other tasks could include using electrical test equipment on various types of instruments, equipment and systems and replacing faulty components and parts using safe working practices and precision instruments.

The unit will extend learners' understanding of simple direct current (DC) circuits that can be solved by Ohm's law and Kirchhoff's laws. This will require learners to apply advanced circuit analysis theorems such as Thévenin's, Norton's and the maximum power transfer theorems for DC networks.

Learners will develop their understanding of DC transients and of series and parallel alternating current (AC) circuits. They will consider series and parallel circuits that include resistors (R), inductors (L) and capacitors (C) in AC circuits.

The unit will also introduce learners to the theory and advantages of three-phase AC systems. This will include power measurements in a three-phase AC system and the construction and principles of operation of a three-phase AC induction motor.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1. Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator
2. Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits
3. Be able to apply single-phase alternating current (AC) theory
4. Be able to apply three-phase alternating current (AC) theory.

Unit content

- 1 **Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator**

  Direct current (DC) circuit theorems: Thévenin's theorem e.g. application of theorem to a parallel circuit having two sources of electromotive force (emf) and three resistors; Norton's theorem e.g. application of theorem to a parallel circuit having two sources of emf and three resistors; maximum power transfer theorem e.g. application of theorem to a series circuit with a source of EMF, internal resistance and a load resistor; application to a more complex circuit where Thévenin needs to be applied first

  Direct current (DC) motor: type e.g. shunt, series, compound; construction e.g. windings, motor starter circuits, speed control (series resistance in the armature circuit); characteristics e.g. EMF generated, torque, back emf, speed and power, efficiency

  Direct current (DC) generator: type e.g. separately-excited, shunt, series compound; construction e.g. main frame or yolk, commutator, brushes, pole pieces, armature, field windings; characteristics e.g. generated voltage/field current (open circuit characteristics), terminal voltage/load current (load characteristic), $V = E - I_a R_a$

- 2 **Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits**

  Transient behaviour of RC circuit: variation of current and voltage with time when charging/discharging; time constant; graphical determination of growth and decay of voltage and current when charging/discharging; practical RC circuit to demonstrate transient behaviour; demonstrate the effect of the circuit time constant on a rectangular waveform e.g. integrator and differentiator circuits; calculations e.g. time constant, growth of capacitor voltage, initial and steady state values of current, decay of resistor voltage

  Transient behaviour of RL circuit: variation of current and voltage with time when connected/disconnected to a DC voltage source; time constant; graphical determination of growth and decay of current and voltage when connected/disconnected to a DC voltage source; practical RL circuit to demonstrate transient behaviour; calculations e.g. time constant, growth of current, decay of induced voltage, current decay

- 3 **Be able to apply single-phase alternating current (AC) theory**

  Series R, L and C alternating current (AC) circuits: current and phase angle in series combinations of RLC circuits (RL, RC, RLC); construction of phasor diagrams and relationship with voltage and impedance triangles for each of the three types of R, L and C combinations; power factor (cosΦ) and power triangle e.g. apparent power ($S = VI$), true or active power ($P = VI \cos\Phi$) and reactive power ($Q = VI \sin\Phi$); conditions for series resonance e.g. inductive reactance equals capacitive reactance ($X_L = X_C$); Q factor (voltage magnification) e.g.

  $Q = V_L$ $\square = \frac{1}{\square}\sqrt{(\frac{\square}{\square})}$

  *a*nd its importance in high and low frequency circuits

Parallel: evaluation of the voltage, current and phase angle in parallel combinations of resistance, inductance and capacitance e.g. RL, RC, LC and RLC; construction of phasor diagrams for impedance and phase angle; conditions for parallel resonance in an RLC circuit e.g. supply current and voltage in phase; impedance at resonance e.g. dynamic resistance $R_D = \frac{\square}{\square\square}$

Q factor (current magnification) e.g. $Q = I_C/I$; filter circuits e.g. high pass, low pass, band pass, band stop

- 4 **Be able to apply three-phase alternating current (AC) theory**

Three-phase AC theory: principles of single-phase and three-phase supplies e.g. rotation of a single coil in a magnetic field, rotation of three identical coils fixed 120° apart in a magnetic field; star and delta methods of connection for power distribution systems; three and four wire systems; voltage relationships for star and delta connections under balanced conditions of load; calculation of power in balanced and unbalanced three-phase loads, e.g. $P = \sqrt{3}.V_L I_L \cos\theta$, $P = 3I_p^2R_p$

Power measurements in a three-phase AC system: e.g. delta system – one wattmeter method, star system – two wattmeter method

Three-phase AC induction motor: construction e.g. stator, rotor, poles; principle of operation e.g. production of torque, synchronous speed, number of poles, starting methods, characteristics (speed/torque/efficiency versus current curves); concept of a rotating magnetic field e.g. application of a three-phase supply to the stator windings, flux generated by each phase of the stator winding

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 use DC circuit theorems to solve one circuit problem using Thévenin's theorem, one using Norton's theorem and one using the maximum power transfer theorem for DC networks	M1 explain the need for a DC motor starter and discuss its operation	
P2 explain the construction and characteristics of a DC motor and a DC generator		
P3 explain the transient behaviour of current and voltage in an RC circuit, verifying through calculation		
P4 explain the transient behaviour of current and voltage in an RL circuit, verifying through calculation		

P5 use single-phase AC theory to calculate the current, voltage, impedance, power and phase angle in one of each of the series combinations of R, L and C circuits		
P7 use single-phase AC theory to calculate the input current, voltage, impedance and phase angle for a parallel combination of R, L and C	M2 discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations	D1 analyse the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit
P6 investigate the performance of two filter circuits experimentally		
P8 use three-phase theory to explain the advantages of three-phase systems and star and delta methods of connection	M3 compare two different methods of power measurement in a three-phase system for both balanced and unbalanced loads.	D2 evaluate the performance of a three-phase induction motor by reference to electrical theory.
P9 carry out a practical power measurement on a three-phase system		
P10 describe the construction, principle of operation and concept of a rotating magnetic field of a three-phase AC inductor motor.		

Essential guidance for tutors

Assessment

A good deal of the assessment evidence for this unit can be achieved by practical experimentation, with real components and circuits and/or computer-based software packages where appropriate.

Because of the nature of the learning outcomes and unit content, up to six assessment instruments may be required. If a structured programme of practical work and short tests is also used then the actual total number of pieces of assessed work could be even more than this. However, careful consideration should be given when designing the assessment not to place an unduly high assessment burden on learners or the tutor. Wherever possible, practical work should lead to a final product that can be assessed without further need for report writing.

Practical activities within the laboratory will need careful supervision. Tutors can capture this evidence by using appropriate records of observation and oral questioning for each learner.

For P1 learners will need to be able to solve circuits involving Thévenin's theorem, Norton's theorem and the maximum power transfer theorem. Before attempting this criterion, learners could be introduced to the idea of a constant voltage source and a constant current source by using a suitable practical demonstration. Further development of this could lead to the link between Thévenin and Norton and then on to the use of Thévenin, before applying the maximum power transfer theorem.

P2 involves the explanation and comparison of a motor and a generator. Learners could possibly be shown actual motors/generators and be issued with incomplete diagrams for completion and annotation.

P3 and P4 require learners to explain the transient behaviour of current and voltage in an RC and an RL circuit both practically and theoretically. Use of a simple bread-boarding technique for both criteria would be ideal here.

For both P5 and P7, an in-class assessment involving the evaluation of current, voltage, impedance and phase angle could be utilised. Learners could be given different circuit values and be encouraged to check their answers with a suitable software programme.

The investigation of the performance of two filter circuits (P6) could be achieved by using a signal generator with a low voltage output ($V_{IN} = IV$) connected to an RC network. Learners could then measure the output (V_{OUT}) as the frequency is raised from, for example, 100Hz to 10,000 Hz.

P8 requires learners to explain the advantages of three-phase systems (e.g. smaller conductors, two available voltages). The latter of these leads into the two forms of connection (star and delta). Assessment could take the form of an incomplete handout to be submitted at the end of a lecture or film about the advantages and forms of connection.

P9 requires learners to carry out practical power measurements in three-phase systems. A suitable three-phase resistance load bank together with a three-phase, four wire low voltage supply and three wattmeters could be used to enable learners to measure the power using one, two and three wattmeters for the different configurations.

Evidence for P10 is likely to be in the form of an investigative report. Again, it may be helpful to provide learners with an incomplete diagram for them to complete and annotate. For the principles of operation and concept of a rotating magnetic field of a three-phase induction motor it may be necessary to include a number of key words (e.g. synchronous speed, pairs of poles) and point to one specific type of three-phase induction motor (e.g. squirrel-cage rotor).

All except the smallest of motors require some type of starter to prevent heavy currents being drawn from the supply on starting. M1 is intended to evaluate this requirement in detail and consider the need for a DC motor starter (e.g. DC faceplate starter) and to discuss its operation. It is expected that learners will draw from the work done at pass and produce a referenced technical report, supported by a suitably labelled diagram to aid their discussion of the operation.

For M2, learners need to discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations. These could include reduced cost to the consumer with reference to a practical example. This could follow a practical demonstration of how the supply current reduces on the introduction of power factor correction, but can increase if over-corrected. M3 could be linked to the practical carried out for P9.

The analysis of the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit (D1) builds on and could be linked to P5 and P7. Evidence for D1 could also be provided by considering the difference in resonance frequency, for example when the value of the resistance is varied.

D2 requires learners to evaluate the performance of a three-phase induction motor by reference to electrical theory, e.g. squirrel cage by reference to electrical theory. This could be achieved practically by using appropriate experimental rigs that allow the learner to compare their results with the known characteristics for specific machines.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	DC Circuit Analysis and Generators	An activity requiring learners to complete three tasks that together solve circuit problems, compare a DC motor and generator, and evaluate the performance of a three-phase induction motor.	A report containing solutions to circuit theorems and written responses about DC motor/generator and three-phase induction motor characteristics. Carried out under controlled conditions.
P3, P4	DC Transients	A written activity that requires learners to explain the transient behaviour of an RC and RL circuit with a numerical verification.	A report containing written responses about the transient behaviour of RC/RL circuits supported by numerical calculations carried out under controlled conditions.
P5, P7, M2, D1	AC Single-Phase Series And Parallel Circuits	A written activity requiring learners to carry out calculations relating to the behaviour of series and parallel R, L and C single phase AC circuits.	A report containing the results of calculations to determine specific parameters of series and parallel R, L and C single phase AC circuits carried out under controlled conditions.
P6	Filter Circuits	A practical investigation for learners to measure the response of two simple filter circuits.	A report containing written responses and graphical evidence regarding the response of simple filter circuits.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, M3, D2	Three-phase AC Theory	A combined written and practical activity requiring learners to explain the advantages of three-phase systems, the star and delta method of connection followed by a practical power measurement with a comparison of two different methods for both balanced and unbalanced loads together with an evaluation of its performance.	A report containing written responses to the advantages of three-phase systems, an illustration of the methods of connection and measurements of the practical work carried out.
P10	Three-phase AC Induction Motor	A written activity describing the construction, operation and concept of a rotating magnetic field for a three-phase (AC) induction motor.	A report containing neat diagrams and descriptions relating to a three-phase (AC) induction motor.

Essential resources

Learners will need access to a well-equipped electrical/electronics laboratory with up to date instruments such as digital/analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components as identified in the unit content together with the means to physically construct circuits.

Centres are strongly advised to consider the provision of suitable hardware and software to enable the use of computer-based methods for circuit design and simulation.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9780415662864

Robertson C R – *Further Electrical and Electronic Principles* (Routledge, 2008) ISBN 9780750687478

Unit 34: Manufacturing Planning

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

There are many new technologies involved in planning the manufacturing of products, parts and components but many smaller companies still operate and work with traditional approaches.

This unit will give learners a good understanding of the basic techniques of manufacturing planning and an awareness of scheduling requirements. It introduces learners to different types of production and will give them an understanding of the stock holding policies that still exist in many engineering companies. Knowledge of the costs associated with holding stock can aid future manufacturing strategies and any related business improvement considerations.

Before learners develop a production plan they are expected to have an understanding of the general aspects of planning and control and the techniques used to measure efficiency in a product manufacturing system. Some of these techniques could be explored in detail should learners show an added interest in this area.

Learners are required to produce a production plan from a given range of information within a product specification and prepare a production schedule to support the delivery of the production plan. As such this unit provides underpinning knowledge for a range of other units, particularly those associated with business improvement.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the techniques and policies used to improve product manufacturing efficiency

2 Understand general aspects of planning and control

3 Be able to use a product specification to produce a production plan

4 Be able to produce a production schedule.

Unit content

- 1 **Understand the techniques and policies used to improve product manufacturing efficiency**

  Types of production: jobbing; batch; cellular; flow; mass; automatic

  Stock holding policy: types of inventory e.g. materials, parts, components, tools, consumables, finished goods; stock holding costs e.g. ordering/replenishment, holding, obsolescence; buffer stock; re-order levels; storage areas; economic order quantity e.g. *data*, $Q = \sqrt{2C_s r/C_c}$ *or* $Q = (2C_s r/C_c)^{1/2}$

  Appropriate techniques: e.g. method study, value analysis, job design (ergonomics, layout, safety); work measurement

- 2 **Understand about general aspects of planning and control**

  Aspects of planning: capacity measurement e.g. machine hours, man hours, throughput, department hours; production planning; pre-production planning; other aspects e.g. information technology, documentation, health and safety, environmental issues

  Control: functions e.g. production control, quality control

- 3 **Be able to use a product specification to produce a production plan**

  Product specification: aspects relative to manufacturing and not the customer; type of information required for manufacture e.g. engineering drawings, process description, make and assembly techniques and requirements, materials required, measurements, tolerances and other quality specifications

  Production plan: consideration of a product specification and types of production; requirements (processes, materials required, quantities required, tools and equipment, labour required, estimated process times, quality checks)

- 4 **Be able to produce a production schedule**

  Production schedule: based on the requirements identified within a production plan; presentation techniques e.g. use of a Gantt chart, critical path network, line of balance technique; data e.g. completion deadline, customer requirements, capacity available

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria

To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the six different types of production	M1 explain the circumstances in which cellular production would be better than batch production	D1 discuss the relationship between economic order quantities and stock holding costs
P2 explain a stock holding policy for a given type of inventory		
P3 determine an economic order quantity from given data	M2 explain how you determined the economic order quantity	
P4 explain an appropriate technique used to improve product manufacturing efficiency		
P5 explain the aspects of planning in manufacturing		
P6 explain functions of control used within manufacturing planning		
P7 use a product specification to produce a production plan	M3 compare the importance of different types of information in a product specification when producing a production plan and schedule	D2 evaluate the use of a production plan when preparing a production schedule and the dangers of the schedule not meeting stock holding requirements.
P8 explain the use of a production schedule		
P9 produce a production schedule from a production plan and given data.	M4 analyse how the use of presentation techniques can be used to overcome capacity and	

	production planning problems.	

Essential guidance for tutors

Assessment

It is important that the assessment strategies used are designed to suit the needs of learners and any local industry requirements. Good assessment strategies need to be supported by the proper presentation of appropriate evidence. The portfolio should not contain course notes, research etc. unless it is part of the required evidence and assessment.

Work done through the use of case-study material can be used to generate evidence for learners' portfolios. An integrated approach to this unit would be a suitable way for learners to gather evidence, particularly for learning outcomes 3 and 4.

To achieve a pass grade, learners should demonstrate knowledge of types of production, stocking policies and understanding techniques used to improve manufacturing efficiency. Learners are also expected to explain general aspects of planning and control and the use of a production schedule. They should then be able to demonstrate the correct development of a production plan when using a product specification, a schedule and other data.

This unit could be assessed using three assignments. The first assignment could cover learning outcome 1 and its associated criteria (P1, P2, P3, P4, M1, M2 and D1), with a task set for each criterion. For P3, a range of data – such as ordering or replenishment costs per order (C_s), holding costs (C_c) and usage rate (r) – should be given to allow an economic order quantity (Q) to be determined. This could then be extended to include an explanation for M2 and a discussion of the relationship between economic order quantities against the costs involved in holding stock (D1).

Criteria P5 and P6 could be set within a second assignment as separate written tasks. A final assignment could be developed to cover P7, P8, P9, M3, M4 and D2. A product specification should be made available to each learner for them to use to develop a production plan. They could then be asked to produce a production schedule when given further data, such as completion time and capacity available. Standard templates for both the plan and schedule can be used as this would be similar to industrial practice.

Another task would then need to be given, asking learners to provide a written response when explaining the use of a production schedule. Further written tasks should also be included to cover M3, M4 and D1.

To achieve a merit grade, learners should be able to explain what parts of the product specification are most important when developing a plan and schedule. A task for M1 could be given to build on the response given to criteria P1 in the first assignment. A task for M3 should be left until all pass criteria have been attempted and therefore be in the third and final assignment about planning and scheduling. They should also be able to analyse how information found in Gantt charts and critical path network documents could be used to identify and help overcome any over-capacity problems and how improvements can be made to the production plan (M4). This criteria requires a written task set in the final assignment.

To achieve a distinction grade, learners should demonstrate a comprehensive knowledge understanding and of manufacturing planning. Learners will confidently evaluate the development of a production schedule when using a production plan and other data in terms of whether that schedule will have an effect on stock holding requirements (D2).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1	Types of Production in Manufacturing Industries	A written activity requiring learners to look at a case study of real life production and stock control.	Written responses to case study based questions about the key features of different production types and describing a stock holding policy and the techniques used to improve efficiency.
P5, P6	Product Specifications	A written assignment and oral questioning on developing a product specification for an existing product and designing a common specification template that accounts for control functions in production.	A whole group activity with learners creating a product specification for a real world product they have access to and explaining product template for use in further assignments that explain planning and control aspects of production.
P7, P8, P9, M2, M3, D1	Product Planning and Scheduling	Presenting a production plan and schedule based on a product specification. Write up report on the presentation and production schedule.	Presentation and accompanying documents that explain the use of a production schedule and other data. Written report on presentation evaluating the use made of the production schedule and the

			presentation techniques used.

Essential resources

A range of production data and information as described in the unit content is needed for learning and assessment. Ideally, examples and data from industry will be provided and access to manufactured products will be required.

Indicative reading for learners

Textbooks

Slack N, Chambers S and Johnston R – *Operations Management* (Prentice Hall, 2009) ISBN 9780273730460

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Waters D – *Inventory Control and Management* (John Wiley and Sons, 2003) ISBN 9780470858769

Unit 35: Setting and Proving Secondary Processing Machines

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

For components to be manufactured to a required standard, the machines that produce them need to be correctly set up by technicians, ready for an operator to use. During this process, trial components are made to check accuracy and ensure a minimum amount of waste during production. Once satisfied that a machine's parameters are correctly set, the technician would then brief the machine operator and the mass production of accurate components can begin.

The aim of this unit is to provide learners with a detailed understanding of the setting of secondary processing machines including traditional machines (for example lathes and drilling machines) and others found in a more specialist workshop (for example spark or wire erosion methods). Learners' ability to set a machine and brief an operator will stem from their knowledge of the machine itself and their ability to select and use the most appropriate work holding devices and tooling.

The unit provides an opportunity for learners to examine a range of secondary processing machines, their set up and the best use of work holding devices and tools. Learners will need to be able to gain an understanding of the features of the component to be made to enable them to effectively set up the machine and hand over to an operator.

Safety is an important issue to be considered when setting and using secondary processing machines. In this unit learners will gain and be able to demonstrate safe working practices when carrying out activities. They will also be able to carry out checks for component accuracy and demonstrate this accuracy after setting a machine and when handing over to an operator.

With the knowledge and understanding gained from this unit there are other opportunities for investigation of a wider range of secondary processing machines, their work holding devices, tools and machine parameters.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know how traditional and specialist secondary processing machines function

2 Understand how work holding devices, tools and machine parameters are set up to produce a range of components

3 Be able to safely set up a secondary processing machine to accurately make a component

4 Know how to produce trial components relevant to the use of a secondary processing machine before handing over to an operator.

Unit content

- 1 **Know how traditional and specialist secondary processing machines function**

  Secondary processing machines: basic principles of operation; machine's suitability to manufacture given components; relevant safe working practices for each machine; machine terminology e.g. cross slide, spindle, head stock, generation of shapes, forming of shapes; traditional secondary machining techniques e.g. turning (centre lathe, capstan, turret, single-spindle automatic, multi-spindle automatic), milling (horizontal, vertical, universal), grinding (surface, cylindrical, centreless, universal, thread grinding, tool and cutter grinding, universal or purpose-built machines), drilling (single spindle, multi-spindle); specialist secondary machining techniques e.g. boring (horizontal, vertical), electro discharge (spark erosion, wire erosion), honing and lapping (horizontal and vertical honing, rotary disc lapping, reciprocating machines)

- 2 **Understand how work holding devices, tools and machine parameters are set up to produce a range of components**

  Work holding: devices for traditional secondary machining techniques e.g. chucks (hard or soft jaws, three or four jaw, collet, power, magnetic), fixtures and other machine specific devices for:

    - turning (drive plate and centres, faceplates, magnetic or pneumatic devices, fixed steadies or travelling steadies)
    - milling (clamping direct to machine table, pneumatic or magnetic table, machine vice, angle plate, vee block and clamps, indexing head/device, rotary table)
    - grinding (centres, face plate, machine vices, clamps, angle plates, vee blocks, works rests, control stops, injector mechanisms, magnetic blocks, pots, arbors)
    - drilling (clamping direct to machine table, machine vice, angle bracket, vee block and clamps, drill jigs, indexing device)

  Devices for specialist secondary machining techniques e.g. angle plate, vee block and clamps, other machine specific devices for:

    - boring (clamping direct to machine table, machine vice, pneumatic or magnetic table, indexing/rotary device)
    - electro discharge machining (clamping direct to machine table, machine vice, pneumatic or magnetic table, ancillary indexing device)
    - honing and lapping (pots, magnetic blocks, face plate)

  Tools: materials and form e.g. solid high-speed steel, brazed tungsten carbide, indexible tips, electrode material, abrasive stone, composite wheels; tools for traditional secondary machining techniques e.g. for:

    - turning (turning tools, facing tools, form tools, parting-off tools, thread chaser, single-point threading, boring bars, recessing tools, centre drills, twist/core drills, solid reamers, expanding reamers, taps, dies, knurling tool)
    - milling (face mills, slab mills/cylindrical cutters, side and face cutters, slotting cutters, slitting saws, profile cutters, twist drills, boring tools, end mills, slot drills)
    - grinding (soft wheel, hard wheel, cup, flaring cup, straight sided wheel, recessed wheel, double recessed wheel, dish, saucer, disc, segmented)

- drilling (drill bit, flat-bottomed drill, counterboring tool, countersinking tool, centre drill, spot facing tool, reamer, tap)

Tools for specialist secondary machining techniques e.g. for:

- boring (boring tool, facing, turning, recessing, chamfering or radii, forming, twist drill, tap, reamer, milling cutter)
- electro discharge machining (plain electrode, profile electrode, hollow electrode, wire)
- honing and lapping (mandrel, wedge, honing stone, lapping disc/pad)

Machine parameters: position of workpiece; position of tools in relationship to workpiece; cutting fluid/ dielectric flow rate; position and operation of machine guards/safety mechanisms; parameters for different traditional secondary processing techniques e.g. for:

- turning (threading/profile/taper mechanisms, workpiece revolutions per minute, linear feed rate, depth of cut for roughing and finishing)
- milling (linear/table feed rate, milling cutter revolutions per minute, depth of cut for roughing and finishing)
- grinding (linear/table feed rate, depth of cut for roughing and finishing, cross feed, dressing of wheels)
- drilling (tooling revolutions per minute, linear feed rate, swarf clearance)

Parameters for different specialist secondary processing techniques e.g. for:

- boring (set up and tooling relative to datum, feed rate, cutter/tool revolutions per minute, depth of cut for roughing and finishing)
- electro discharge machining (electrical conditions, wire tension, wire speed, alignment of electrodes and wire, ventilation and fume extraction, filtration)
- honing and lapping (revolutions per minute or reciprocating speed, stroke length, stroke overrun length, stroke speed, stone or disc pressure)

Features of the component: materials e.g. ferrous, non-ferrous, non-metallic; holes e.g. drilled, bored (parallel or tapered), reamed, threaded, blind, through, counterbored, flat bottomed; relevant component features produced using traditional secondary processing techniques e.g. for:

- turning operations (flat faces, parallel diameters, stepped diameters, tapered diameters, profile forms, external threads, eccentric features, parting off, chamfers, knurls or special finishes, grooves, undercuts)
- milling operations (flat faces, square faces, parallel faces, angular faces, steps/shoulders, open ended slots, enclosed slots, recesses, tee slots, profile forms, serrations, indexed or rotated forms, special forms)
- grinding operations (flat faces, vertical faces, parallel faces, faces square to each other, shoulders and faces, slots, parallel diameters, tapered diameters, profiles forms, other thread forms, vee-form threads, right-hand threads, single start threads, multi-start threads, external threads, angular faces)
- drilling operations (countersinking, spot facing, holes)

Relevant component features produced using specialist secondary processing techniques e.g. for:

- boring operations (internal profiles; external profiles e.g. external diameters, grooves/recesses, chamfers/radii, flat faces, square faces, parallel faces, angular faces, slots, index or rotated forms)
- electro discharge machining operations (holes; faces – flat, square, parallel, angular; forms – concave, convex, profile, square/rectangular; other features – threads, engraving, cavities, radii/arcs, slots)
- honing and lapping operations (honing holes; lapping faces e.g. flat, parallel, angular)

- 3 **Be able to safely set up a secondary processing machine to accurately make a component**

Set up: machine guards in place; select and set tooling; checking tool/wheel condition; holding components securely without distortion; selection and use of suitable work holding device(s); set machine parameters to manufacture given component

Safe working: safe set up of moving parts e.g. setting stops, preventing tooling clashes; use of machine guards to protect operator and others; choice and handling of cutting fluids/dielectric flow rate; checks for insecure components; facilities for emergency stop and machine isolation; identification of appropriate protective clothing and equipment; housekeeping arrangements (work area clean and tidy); safe working practices relevant to specific secondary processing technique e.g. for:

- turning (handling turning tools, airborne particles, tool breakage, swarf disposal)
- milling (handling milling cutters, cutter breakage, swarf disposal, backlash in machine slides)
- boring (handling tools and cutters, airborne particles, tool breakage)
- electro-discharge machining (electrical components, handling dielectrics, fumes, handling and storing electrodes and wires)
- grinding (handling grinding wheels, sparks/airborne particles, bursting wheels)
- drilling (handling drills, taps and reamers, tool breakage, swarf disposal)
- honing and lapping (handling and storing stones, airborne particles)

Checks for accuracy: components to be free from burrs and sharp edges; use of appropriate tools and instruments; checks for dimensional accuracy and surface texture; checks relevant to specific secondary machining technique e.g. for:

- turning (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO , surface finish 63 *μ*in or 1.6*μ*m, reamed or bored holes within H8, screw threads BS medium fit, angles within +/- 0.5 degree)
- milling (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO surface finish 63 *μ*in or 1.6 *μ*m, flatness and squareness within 0.001 inch per inch or 0.125 mm per 25 mm, angles within +/- 0.5 degree)
- boring (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO surface finish 63 *μ*in or 1.6 *μ*m, flatness

and squareness within 0.005 inch per inch or 0.025 mm per 25 mm, angles within +/- 0.5 degree, bored holes within H8)

- electro-discharge machining (components to be free from false starts; dimensional tolerance to BS/ISO , surface texture 32 *µ*in or 0.8 *µ*m or 18 VDI; checks e.g. for parallelism, angle/taper, squareness, profile)
- grinding (tolerance to BS/ISO surface texture 8 *µ*in or 0.2 *µ*m, free from false grind cuts)
- drilling (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO, surface texture 63 *µ*in or 1.6 *µ*m, reamed holes within H8, screw threads BS medium fit)
- honing and lapping (components to be free from stone/disc marks; dimensional tolerance equivalent to BS/ISO; surface finish 8 *µ*in or 0.2*µ*m; honed components checked for parallelism and ovality/lobbing; lapped components checked for parallelism and flatness)

- 4 **Know how to produce trial components relevant to the use of a secondary processing machine before handing over to an operator**

Trial components: to meet the features and accuracy required by the specification

Use of machine: correct use of work holding devices; tools; machine parameters and safety

Handing over: correct set up; supplies of components and consumables; machine functions correctly; quality requirements; consideration of safe working

Handover procedures: demonstrating operation; explaining the key stages; highlighting critical areas e.g. safety, specific tolerances, finishes; observing operator and correcting any errors; ensuring operator is working safely and competently before leaving; periodic checks of machine and operator performance

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe how four different secondary processing machines function when machining a given component for each	M1 explain the effects of using an inappropriate work holding device when setting up a secondary processing machine	D1 justify the choice of a work holding device for a given component when setting up a secondary processing machine
P2 explain how work holding devices and tools are used on four different secondary processing machines to manufacture a different given component for each machine		
P3 explain how a range of machine parameters are set up to produce required features on components machined on four different secondary processing machines	M2 explain the importance of setting machine parameters correctly to produce accurate features on a component produced by a secondary processing machine	
P4 set up a secondary processing machine to safely produce a given component		
P5 carry out checks for accuracy of a given component during the setup of a secondary processing machine		

<table>
<tr><td>P6 explain how to produce trial components on a secondary processing machine</td><td rowspan="2">M3 explain the impact of producing trial components and correct hand over procedures on the operator being able to continuously produce accurate components.</td><td rowspan="2">D2 evaluate the impact that aspects of working safely have on the effectiveness and accuracy of setting up a secondary processing machine.</td></tr>
<tr><td>P7 explain how to hand over a secondary processing machine to an operator including a description of the hand over procedures used.</td></tr>
</table>

Essential guidance for tutors

Assessment

Assessment evidence for this unit is likely to be gained from a mixture of written tasks and practical process evidence (witness statements/observation records).

To achieve a pass grade, learners must demonstrate knowledge of a range of different secondary processing machines and their techniques when carrying out set up procedures. Both traditional and specialist techniques need to be covered. This means that learners need to know set up procedures for at least one technique from each range and an overall total of four.

Assessment of the procedure of actually setting up a machine, the knowledge required to prove the process by making trial components and handing over to an operator is restricted to one secondary processing machine, which can be either traditional or specialist. Centres and learners should pick the one most suitable for individual needs, considering any work-based learning expectations.

To achieve a merit grade, learners will need to demonstrate that they can explain some of the effects of using an inappropriate work holding device when setting up a secondary processing machine. This could be achieved through the selection of appropriate work holding devices for P2 together with learners demonstrating an appreciation of the possible effects of an inappropriate device. In addition, learners are required to explain the importance to producing accurate features on components produced by a secondary processing machine of setting machine parameters correctly. For example, if the depth of cut and/or feed rate in a turning operation is not set correctly, then the component is likely to have an out of tolerance surface finish and not be free from false tool cuts.

Finally, learners need to explain the impact of producing trial components and correct handover procedures on the operator being able to continuously produce accurate components. For example, if trial components are meeting the correct accuracy checks then the 'setter' will be confident when demonstrating to the operator the procedures to follow and the correct tolerance and finish requirements explained more easily to the operator. The required evidence for these criteria is likely to be in the form of a written response to tasks set for the learner.

To achieve a distinction grade, learners will need to justify their choice of a work holding device for a given component when setting up a secondary processing machine. This machine is likely to be one from their chosen skill route. Judgement needs to be made as to whether the device used would succeed and whether it is likely to meet the needs and features of the component, alignment and use of the tooling and tool-component interface.

They also need to be able to evaluate the impact of working safely on the effectiveness and accuracy of setting up a secondary processing machine. They need to consider whether the use of the safety equipment hampers the set up process. Again, the required evidence for these criteria is likely to be in the form of a written response to tasks set for the learner.

Wherever possible it is important to maximise the opportunities for assessment through practical tasks. A possible scenario would be to use a total of three assignments. It may be best to set a practical assignment as the first of these. This could be to set up a secondary processing machine (P4) and carry out checks for accuracy (P5). Evidence for these criteria could be in the form of annotated photographs, observation record/witness statement(s), notes and sketches produced by learners that capture the processes carried out.

Learners will also need to maintain a record of all measurements taken and the action taken to correct any errors in the set up to complete the requirements of P5.

Following the practical, learners could then prepare a written report on how this secondary machining process functions and is set up. This could then be used to cover one of the four different machines required for P1, P2 and P3. It may also be the best opportunity to work towards the merit and distinction criteria M1, M2 and D1.

The second assignment could follow on from the practical activities, and involve learners preparing a report on the machining process used in assignment 1. They would also need to research and report on three more machines to generate the evidence required for P1, P2 and P3. The tasks undertaken should make it clear what secondary processing machines are to be covered (this could be set by the tutor or could be decided through learner choice).

To meet the requirements of the unit content for outcomes 1 and 2, both traditional and specialist techniques need to be covered. However, as long as at least one of each type is covered then the other two can be either traditional or specialist machines. When choosing from the examples listed in the unit content, e.g. turning (centre lathe, capstan, turret, single-spindle automatic, multi-spindle automatic), it would be sufficient to select from any one of the machines listed e.g. for a turning machine – use of a single-spindle automatic. This applies equally to the other aspects of unit content where examples are given.

The choice from these lists will be solely determined by the component being machined. For example, work holding devices for turning lists drive plate and centres, faceplates, magnetic or pneumatic devices, fixed steadies or travelling steadies. If the component only requires mounting on a faceplate then this would be sufficient. However, when choosing components centres need to take care to ensure the use of a reasonable range of techniques. For example, if all the components, for all four machines selected could be simply held in a three-jaw chuck to complete all operations, then this would be considered insufficient.

The last assignment could ask learners to explain how trial components are produced (P6) and how to handover a secondary processing machine to an operator (P7). The assignment could also provide an opportunity to explain the impact of producing trial components and the impact of correct handover procedures on the operator being able to continuously produce accurate components (M3). It could also evaluate the impact of working safely on the effectiveness and accuracy of setting up a secondary processing machine (D2). See earlier examples of what is expected for criteria M3 and D2; remember that the explanation and evaluation are likely to be a consideration of the experience of the practical work carried out in the first assignment.

Although simulated or practical activities would be the preferred means of capturing evidence for P6 and P7, it is accepted that this might not always be possible or realistic for a number of reasons. If a simulation is possible then for P7 it may be best if the tutor takes the role of the operator. For both P6 and P7 process evidence (records of observation and oral questioning) could be used. This process evidence could then be supplemented/supported by the product evidence that will be available from the activities e.g. the trial components, the learners' own preparation notes before handover and their own records of the actual handover process.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5	Producing Components Using Secondary Processing Techniques	Learners are required to produce a component using a secondary processing machine and check it for accuracy.	A practical assignment evidenced through photographs, tutor observation records and learners' notes.
P1, P2, P3, M1, M2, D1	Investigating Secondary Processing Machines	Learners need to prepare an information leaflet giving details of four different secondary processing machines.	A written report detailing how each functions, the holding devices, tools and machine parameters associated with each.
P6, P7, M3, D2	Producing Trial Components and Handing Over Secondary Processing Machines	Learners explain to a new member of staff how to produce a trial component and correctly hand over a secondary processing machine.	A written report detailing how to produce trial components and the correct hand over procedures for a secondary processing machine.

Essential resources

To meet the needs of this unit it is essential that the centre has, or has access to some if not all of the range of machines specified in the unit content. This should include at least one specialist secondary processing machine. All auxiliary equipment such as that required for measuring accuracy should also be made available.

Indicative reading for learners

Textbooks

Edwards J – *Lathe Operation and Maintenance* (Hanser, 2003) ISBN 9781569903407

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Kalpakjian, Serope - *Studyguide for Manufacturing Engineering &* Technology (Cram101 Textbook Reviews) ISBN 978-9810694067

Unit 36: Business Operations in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Engineers are employed in a range of businesses within the primary, secondary and tertiary sectors. Their knowledge and skills are used to carry out a variety of specific functions that solve the needs of businesses and contribute to their commercial success. By making effective use of their engineers' expertise, organisations can secure competitive advantage, whether they be a small owner-managed company or a large limited company with many shareholders.

For anyone considering a career in engineering, it is important to have an understanding of how an engineering business operates and its position within society. This unit will develop learners' understanding of business, the engineering industry and the effect of engineering on the environment. It will help give learners a firm foundation for employment in the engineering sector and an understanding of the organisational, financial, legal, social and environmental constraints within which an engineering company operates.

The unit will enable learners to examine an engineering company in detail. This could be either the one in which they are employed or one in an engineering sector in which they may look for employment. Learners will understand how the company operates, the factors that impact upon the business and the importance of a cost-effective output. This will include an examination of the engineering functions of the company and the importance of communication and information flow within the business. This is set within a study of how external factors and the economic environment impact on the company.

Learners will examine relevant legislation and how it can place considerable constraints on the way that a typical engineering company is required to operate. A company cannot survive if it is not profitable and the unit allows learners to consider the use and implication of costing techniques on the sustainability of a particular engineering activity.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand how an engineering company operates

2 Understand how external factors and the economic environment can affect the operation of an engineering company

3 Know how legislation, regulation and other constraints impact on the operation of engineering businesses

4 Be able to apply costing techniques to determine the cost effectiveness of an engineering activity.

Unit content

- 1 **Understand how an engineering company operates**

  Sectors: primary e.g. oil, gas, agriculture; secondary e.g. chemical, manufacturing, automotive, aerospace, marine, sports; tertiary e.g. energy distribution, nuclear technologies, waste management, water services, building services, civil, construction, structural, health, telecommunications

  Engineering functions: e.g. research and development (R&D), design, manufacture, materials supply and control, production planning and control, installation, commissioning, maintenance, technical support, technical sales, project planning and management, quality assurance

  Organisational types: size e.g. micro, small, medium, large; status e.g. sole trader, partnership, public (plc), private (ltd), new, established, charitable, not for profit; structure e.g. owner-manager, boards, committees, governors, hierarchical, flat, matrix

  Information flow: internal systems e.g. lines of communication, working procedures, e-systems, integrated systems; people involved e.g. supervisor, other employees, customers, suppliers; types of information e.g. work instructions (such as operation sheets, engineering drawings, circuit diagrams), work in progress records, stock/orders/sales; work ethics of communication e.g. confidentiality, integrity, respect

- 2 **Understand how external factors and the economic environment can affect the operation of an engineering company**

  External factors: factors to consider e.g. markets, consumers, demographic and social trends, competitive products/services/organisations, customer/client relationships, innovation and technological change, availability of sustainable resources

  Economic environment: measures e.g. gross national product (GNP), gross domestic product (GDP), balance of payments; location e.g. local economy, regional and national economy (such as Regional Development Agency, local/regional skills targets); economic variables e.g. interest rates, exchange rates

- 3 **Know how legislation, regulation and other constraints impact on the operation of engineering businesses**

  Legislation: legislation e.g. Health and Safety at Work Act 1974, Employment Act 2008, Factories Act 1961, Fire Precautions Act 1971, Data Protection Act 1998, Companies Act 2014 Regulation: e.g. Employment Equality (Age) Regulations 2006, Management of Health and Safety at Work Regulations 1999, Provision and use of Work Equipment Regulations 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Reportable Injuries Diseases and Dangerous Occurrences Regulations 2013, Working Time Regulations 1998, Workplace (Health, Safety and Welfare) Regulations 1992, Health and Safety (First Aid) Regulations 1981

Environmental constraints: e.g. sustainability, environmental impact, use of renewable energy resources, carbon footprint, recycling, product end of life strategy

Social constraints: e.g. employment levels, workforce skill levels and training requirements, opportunities for self-improvement and progression, motivation, impact of outsourcing

- 4 **Be able to apply costing techniques to determine the cost effectiveness of an engineering activity**

  Costing techniques: income; expenditure; profit/loss; cost control e.g. direct cost, indirect cost, fixed cost, variable cost, contribution, marginal costing; assets e.g. investment and value of fixed assets, depreciation of fixed assets

  Make-or-buy decisions: e.g. break-even point, investment appraisal, return on investment, pay-back time, financial risk, development costs

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the functions carried out by different engineering companies in the sectors in which they operate	M1 discuss how improvements in information flow could enhance the functional activities of an engineering company	D1 evaluate the information flow through an engineering company in relation to an engineering activity
P2 explain the organisational types of three given engineering companies		
P3 outline how information flows through an engineering company in relation to an engineering activity		
P4 explain how external factors and the economic environment affect the way in which an engineering company operates	M2 discuss the impact of relevant legislation on a specific operation within a typical engineering company in terms of benefits and limitations	D2 evaluate the importance and possible effect of the external factors that directly impact on an engineering company.
P5 describe the legislation and regulations that impact on the way an engineering business operates		
P6 describe the environmental and social constraints that impact on the way an engineering business operates		

P7 carry out costing techniques to determine the cost effectiveness of an engineering activity	M3 demonstrate how the cost effectiveness of an engineering activity could be improved.	
P8 carry out costing techniques to reach a make-or-buy decision for a given product.		

Essential guidance for tutors

Assessment

It is likely that the assessment evidence for pass criteria P1 and P2 could be produced through the study of three separate engineering companies. One of these could be the company in which the learner is employed, with the others through case study or relevant research of companies chosen either by the learner or the tutor. It is important to ensure an opportunity for activity in all three sectors is given collectively across the three companies studied. Evidence for criteria P3, P4, P5 and P6 could be produced through the study of a single engineering company, again likely to be one chosen by the learner. The remaining pass criteria (P7 and P8) lend themselves to a controlled and time-constrained activity. Although opportunities to carry out costing exercises in a real environment may be used, it may be that issues of business confidentiality will prevent this.

This unit could be assessed using three assignments. The first assignment could assess criteria P1, P2 and P3 together with M1 and D1. Information should be given about three separate engineering companies, real or fictitious, ideally one from each sector (primary, secondary and tertiary). The functions that the companies carry out can be simplified, such as designing a solution to an engineering problem or installing a machine. Other information should be given about the size and structure of the organisations.

Work-based learners may wish to use their own company to satisfy part of each criteria, although they will need data on a further two organisations to fulfil the criteria. Written tasks could be given and the evidence is also likely to be in written format.

For P2, sketches may also help to explain organisational structures. For P3, learners need to be able to explain how functions within a business are able to communicate effectively to support business strategies in relation to an engineering activity (for example the link between design and technical sales, manufacturing and material/component supply). This will link to the content section on information flow, where learners need to explain the internal systems, people involved, types of information and work ethics of communication relevant to a specific activity within an engineering company.

A second assignment should require learners to investigate how external factors and the economic environment (P4); legislation and regulations (P5); environmental and social constraints (P6) impact on the overall operation of an engineering business. It is sensible to also include criteria M2 and D2 in this assignment.

The evidence for the last two pass criteria (P7 and P8) could be gathered through a third assignment involving a costing exercise based on the engineering activity considered in P3. For example, this could involve the use of costing techniques to determine the cost effectiveness of the product/service and then looking at a make or buy decision for part of or the whole product/service. If this is not realistic or appropriate then separate tasks may be necessary. The engineering activity considered in the criteria P3 and P7 could, for example, be the manufacture of a product or the provision of a service. In either case, centres need to ensure that the relevant data is available to cover all aspects of the content, although the product or service itself does not need to be overly complex. A task could then be set to complete a make or buy decision (P8). Criterion M3 is also best linked to this assignment.

To achieve a merit grade, learners will need to apply evaluative skills to discuss how improvements in information flow could enhance the functional activities of an engineering company (M1). This could be a natural extension to work carried out for P1, P2 and P3. Learners should also be able to discuss the impact of legislation on a specific operation within a typical engineering company (M2). This has a link with the criterion P5, which considers legislation in a broader context for the company. For merit, learners need to be able to analytically apply the understanding they have gained at pass level to consider the impact of legislation in terms of benefit (for example reduced risk to employees and therefore improved safety record) and limitations (for example increase in production cycle times and therefore increased costs) for the operation considered. Finally, to achieve the last merit criterion M3, learners should be able to consider the costing exercise carried out for P7 and P8 and explain how the cost effectiveness of the engineering activity could be improved or the make-or-buy decision made more conclusive or even amended.

To achieve a distinction grade, learners should be able to focus on a specific activity and evaluate the information flow through an engineering company in support of it (D1). This links to P2 and P3, where learners described organisational types and explained the information flow for an activity and with M1 their ability to consider improvements. The evaluation for D1 should consider the key aspects of the information flow, how it impacts upon the specific activity and other functional activities of the company, plus any issues in terms of problems encountered or opportunities for improvement. As such this could be within the first assignment. To achieve D2 learners should be able to evaluate the importance and possible effects of the external factors that directly impact on an engineering company. Learners will need to be able to use their general understanding of external factors from P4 but at this level begin to take an analytical view of the relative importance and the direct effects on the business.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Types and Operation of Engineering Businesses	An activity requiring learners to carry out research based on actual engineering companies. These companies will be involved in a range of business activities, and have different management structures and operating methods.	A portfolio containing written responses and flow diagrams based on primary and secondary research data. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.
P4, P5, P6, M2, D2	External Factors and Legislation Which Affect The Operation of an Engineering Company	An activity to investigate the external factors and pressures which can affect the profitability of businesses. It involves finding out about economic, legislative and environmental constraints in the context of a given engineering company.	A portfolio containing written responses to a number of defined activities. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation. This assessment could be delivered in two parts – small group research activity followed by a summative test.
P7, P8, M3	Assessing The Cost and Viability of an Engineering Activity	An investigative activity involving calculation and decision making supported by reflective writing and, where appropriate, verbal presentation.	A portfolio containing spreadsheets and written commentary carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.

Essential resources

Learners require access to sufficient data on engineering companies. This can be in the form of case studies, industry visits or data available through learners' employers.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Chelsom J, Reavill L and Payne A – *Management for Engineers, Scientists and Technologists, Second Edition* (John Wiley and Sons Ltd, 2004) ISBN 9780470021262

Nicholas J and Steyn M – *Project Management for Business and Engineering and Technology* (Routledge, 2011) ISBN 9780080967042

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 37: Industrial Plant and Process Control

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Modern industrial plant would fail to operate effectively without appropriate process control systems and methods. Engineers play a vital role in designing, installing and operating such systems.

The aim of this unit is to introduce learners to the principles and techniques involved in the control of industrial process plants. The methods of process control are investigated, along with the industrial techniques that are employed to ensure that plant is controlled to meet given specifications.

The unit starts by considering the basic principles of control in terms of open and closed loop systems and the elements that are required as part of the loop. Further areas of closed loop control are discussed and simple analysis techniques are considered.

Having identified a control system the unit then considers the main controller types that are available. Emphasis is placed on the widely used two step and three term controllers. These controllers are examined in some depth with opportunities to extend knowledge of controllers through standard tuning methods.

Modern large industrial process plants are controlled using hierarchical control systems. This unit allows learners to consider hierarchical control strategies such as supervisory control and distributed control systems. The philosophies of these systems are discussed and reference to the physical structure is covered.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the characteristics of process control systems

2 Know about common modes of control and their effect on control system performance

3 Be able to apply tuning methods to three-term controllers to improve control system performance

4 Understand hierarchical and advanced process control systems.

Unit content

- 1 **Understand the characteristics of process control systems**

  System components: block diagrams; control loops e.g. open, closed; accuracy and stability; elements e.g. detecting, measuring, comparing, controlling, correcting

  Transfer functions: block diagrams; transfer functions for simple closed loop systems derived; closed loop gain determined using derived transfer function; block diagram reduction techniques

  System characteristics: inherent regulation; time constant; initial reaction rate; exponential growth and decay e.g. equations (simple first order) for process systems, curves; lags e.g. transfer, distance velocity, dead time; measurement of process dead time

- 2 **Know about common modes of control and their effect on control system performance**

  Two-step control and terminology: applications of two-step control e.g. temperature control, level control; definition of two-step control; functional attributes e.g. effect of process lag, overlap, effect of the degree of overlap on process response

  Three-term control and terminology: applications of three-term control e.g. flow rate control, positional control; types of control (proportional (P), integral (I), derivative (D), proportional-integral-derivative (PID))

  Three-term control parameters and system response: responses e.g. under P control, under PI control, under PID control; parameters e.g. proportional band, proportional gain, integral gain, integral action time, derivative gain, derivative action time

- 3 **Be able to apply tuning methods to three-term controllers to improve control system performance**

  Tuning methods: methods (process reaction curve, ultimate cycle, frequency response); plant under three-term control e.g. flow rate control, positional control

- 4 **Understand hierarchical and advanced process control systems**

  Hierarchical control: pyramid of control, process instrumentation layer, supervisory layer, management layer

  Types of hierarchical control systems: applications of distributed control systems (DCS) e.g. petrochemical, nuclear, paper mill; architecture of DCS; multi-loop structure e.g. plant interfaces, process managers, operator stations, history modules, control networks, management networks; applications of supervisory control and data acquisition (SCADA) e.g. machine control, assembly line production, sequential manufacture; architecture of SCADA e.g. remote terminal units, programmable logic controllers, control networks, remote input/output, supervisor stations

  Advanced control: cascade control; feed-forward control (applications and improvement of response time)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the main system components of a given process control system	M1 design a block diagram of a single closed-loop process control system to meet a given specification in terms of transfer function and system characteristics	D1 evaluate the extent to which the design meets the given specification
P2 explain the operation of a given process control system using block diagrams and transfer functions		
P3 explain process control system characteristics		
P4 describe the functional attributes of a two-step controller, using controller terminology for a given application		
P5 describe an application of a three-term controller and the meaning of the four types of control		
P6 record the control system output responses relating to various values of three-term parameters		
P7 use three tuning methods to improve the performance of plant under three-term control		

P8 explain the pyramid of control for hierarchical control systems	M2 design a structure for a hierarchical control system explaining how it meets a given requirement.	D1 evaluate the performance of a given process control system.
P9 describe two types of hierarchical control system		
P10 explain how two types of advanced control can improve plant performance.		

Essential guidance for tutors

Assessment

Assessment evidence for pass criteria P1, P2 and P3 could be produced through a written assignment. After describing the main components (P1) learners would then need to consider a single closed-loop process control system and explain its operation. Block diagrams and transfer function calculations should be used to aid the explanation (P2). The use of simulation software within the assignment should also be encouraged to identify the system characteristics of the single control loop. Hard copy printouts using the simulation software could form part of the evidence for P3 within the assignment.

Assessment evidence for pass criteria P4, P5 and P6 could be produced through a combination of a practical assignment and written tasks that will enable learners to describe the functional attributes of a two-step controller (P4) through a practical application (e.g. the control of liquid level within a tank). The assessment could then require learners to control liquid flow or shaft position (P5) and record the responses of the system under three term control.

Various three-term controller parameters should be used within the practical activity and context given, and a report produced concluding on the various response results (P6). The practical activity could be extended to include the tuning of a three-term controller to improve the performance of the plant (P7). All three tuning methods should be used and conclusions clearly stated identifying the most suitable technique in terms of final system improvement.

Assessment evidence for pass criteria P8 and P9 could be produced through a written assignment relating to case studies of hierarchical control systems. The assignment could require learners to explain and describe the operation of given schematics of an industrial SCADA and a DCS. Evidence for pass criteria P10 could also be considered within the same assignment. Learners could be asked to consider a single loop within one of the given hierarchical systems and provide a written explanation of how both feed forward and cascade control can improve the performance of the loop.

Assessment evidence for M1 is likely to be an extension to the assignment that covers P1, P2 and P3. Learners could be asked to design a new control loop in block diagram form to meet a given control specification. This specification can be addressed through the design and identification of control system elements whose transfer functions will contribute to an overall system transfer function. This type of activity could be supported through the use of simulation software to confirm that the specification has been met.

Assessment evidence for criterion M2 could be achieved through the assignment covering P8, P9 and P10. Learners could be asked to design a hierarchical control structure to meet a given specification, in terms of plant size and plant operation. This design may be in the form of a block diagram supported by an explanation for the choice of system and constituent elements.

Assessment evidence for criteria D1 will be an extension of M1, requiring an evaluation of the design in relation to the given specification. D2 is likely to be achieved through an extension of the assignment covering criteria P8, P9, P10 and M2. Learners could be asked to evaluate the performance of a system that is controlling a given industrial process plant. This evaluation will consider the operation and performance of the system and learners could be requested to suggest improvements to both the structure and the selection of control method.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Characteristics of Process Control	Learners need to describe the operation of a control system.	Written report
P4, P5, P6, P7	Modes of Control	Learners describe the use of controllers and use tuning methods.	Written report and logbook from practical activities supported by witness statements
P8, P9, P10, M2, D2	Hierarchical and Advanced Process Control	Learners explain process control systems.	Written report

Essential resources

Learners should have access to a relevant workshop or laboratory facilities including:

- industrial plant, rigs or system simulators
- control system simulation software
- data books and manufacturers' specifications
- process rig schematics
- appropriate tools.

Indicative reading for learners

Textbook

Bolton W – *Instrumentation and Control Systems* (Elsevier, 2004) ISBN 9780750664325

Unit 38: Industrial Process Controllers

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Control engineering plays an important role in ensuring that process plant and machine controlled systems function correctly and with optimum performance. This unit provides learners with an opportunity to gain knowledge and experience of the industrial process controllers that are the main elements within a controlled system.

The unit starts with basic control and the comparison of common control technologies and applications. It then proceeds to examine the traditional three-term controllers that are still widely used in industry and the principles required to tune and set up these controllers.

The unit then develops the knowledge and practical skills that are essential to configure and program a programmable logic controller (PLC). Various instruction types are described and learners will be required to write programs to perform a range of control applications.

Learners will also gain a knowledge of fault-finding techniques and tools and will be able to write and fault-find programmable logic controllers.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know about control system types and their applications

2 Know about the operating principles and tuning of three-term controllers

3 Know about the types and operation of programmable logic controllers

4 Be able to write and fault-find programmable logic controller programs.

Unit content

- 1 **Know about control system types and their applications**

  Control loops: open loop systems; elements of closed loop control (controller, error, correction, process, measurement, comparator); signal flow diagrams (transfer function, calculation of steady state error)

  Control system types and applications: sequential control e.g. component sorting, product assembly; continuous control e.g. flow, level, temperature, displacement, velocity; batch control e.g. chemical mixing, bottling plant, manufacturing

- 2 **Know about the operating principles and tuning of three-term controllers**

  Operating principles: proportional controller (proportional band, gain, steady state error, rise time, overshoot); proportional-integral (PI) controller (Kp, integral action time, integral gain, responses); proportional-integral-derivative (PID) controller (Kp, Ki, derivative action time, responses)

  Controller tuning methods: process reaction curve e.g. level, velocity; ultimate cycle e.g. flow, displacement; lambda e.g. paper mill, large holding tanks; adaptive; auto tuning

- 3 **Know about the types and operation of programmable logic controllers (PLCs)**

  Programmable controller types: unitary; modular; rack-mounted; selection to meet specification e.g. application, cost, versatility

  Operational characteristics: central processing unit (CPU); Arithmetic Logic Unit (ALU), flags, registers); input/output (I/O); memory organisation; scanning

  System hardware and software: specification of I/O units e.g. digital, analogue; power supply; operating system; configuration of I/O; number systems e.g. binary, octal, hexadecimal, binary-coded decimal (BCD)

  External input and output devices: mechanical switches; relays e.g. electromechanical, solid state; input transducers e.g. temperature, pressure, flow, smart sensors; output devices e.g. motors, pumps, valves, audio or visual display

- 4 **Be able to write and fault-find programmable logic controller programs**

  PLC programs: program applications e.g. on-off process control, washing machine, traffic lights, conveyor control with component sorting

  PLC instructions: ladder relay instructions; bit instructions; branches; timers; counters; logical instructions; arithmetic instructions

  Test and debug programs: software debug instructions; diagnostic indicators; data monitors; search and force facilities

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe control loops in terms of their individual elements		
P2 determine transfer functions and values for steady state error from closed loop signal flow diagrams		
P3 describe the three different control system types and identify an application for each type	M1 explain why the control system type is suitable for the particular application	
P4 describe the operating principles of a three-term controller in terms of its three constituent parts		
P5 describe an appropriate tuning method for three different applications	M2 apply an alternative to a given tuning method so as to improve the performance of a given process controller in terms of its system response	D1 compare the functionality of adaptive and auto tuning methods

P6 describe three types of PLC and select an appropriate type to meet a given specification		
P7 describe the four main components that identify the operating characteristics of a PLC		
P8 select system hardware and software elements that will be required to meet a given specification	M3 explain why the elements selected meet the requirements of the specification	
P9 describe the four different types of external input and output devices that can be connected to a PLC for plant control or monitoring		
P10 write and document a PLC program using the seven different instruction types that will control a given application		
P11 carry out fault-finding on a PLC program using common debugging tools.	M4 explain the methods and tools used to carry out fault-finding.	D2 analyse a given PLC control program and identify improvements that can be made to improve control system performance.

Essential guidance for tutors

Assessment

Assessment evidence for pass criteria P1, P2, P3 and M1 could be produced through a written assignment. The first part of the assessment could ask learners to describe, with the aid of signal flow diagrams, the difference between an open loop and a closed loop system (P1). The second part of this assessment could ask learners to calculate the overall system transfer function of a given closed loop system (e.g. velocity control) and then calculate the steady error using the transfer function result (P2). The final part of the assessment could look at types of control systems in terms of application (P3). For example a computer controlled washing machine could be given and learners asked to identify and describe the type of control system and the control processes that will occur. The same example could be used develop an explanation for its suitability (M1).

Pass criteria P4 and P5 could be assessed through a written assignment, supported by practical formative tasks. This could ask learners to consider a given control system and determine and describe the operating principles of the controller using practical investigations (P4). As a second part of the assessment learners could be provided with three different control systems. They could then be asked to select a tuning method for each system (P5).

Evidence for pass criteria P6-P9 could be produced through a short research project. Learners could be asked to research the types of PLC (P6), PLC operating characteristics (P7) and PLC hardware/software (P8) that would be required to meet a given specification. This specification could include information regarding system type, I/O requirement, interface, software requirements and communication system. The project report should include a description of the three types of PLC (unitary, modular and rack mounted) and identify the most appropriate for the given specification (P6).

The response for P7 should include a description of the four component parts listed in the unit content of the operational characteristics (CPU, I/O, memory organisation and scanning). The last part of the report should include the hardware and software requirements to meet the given specification (P8) and include an explanation of the suitability of the elements selected (M3).

A final task within the research project could ask learners to describe a mechanical switch, a relay, an input transducer and an output device (P9) that could be part of the selected solution for the given specification. The given specification needs to be carefully thought through before it is given to learners to ensure that all pass criteria can be evidenced.

A final assignment covering pass criteria P10 and P11 could be in the form of a practical PLC workshop. Learners could be given access to a process rig and be asked to identify the input and output devices found on the rig (e.g. sensors and motors) and connect the PLC to these devices. It is important that these devices include a mechanical switch, a relay, an input transducer and an output device as listed in the unit content. Once the PLC is connected to the rig, learners could be asked to write, document, debug and fault-find a PLC program that will provide rig control (P10 and P11). A witness statement/observation record may be the best way to record the evidence for criteria P10 and P11 supported by annotated photographs and the documented PLC program.

Assessment evidence for M2 is likely to be collected as an extension to the assignment covering criteria P4 and P5. Having selected a tuning method for three different systems, learners could be provided with a given tuned system with an identified tuning method. They could then be asked to select and apply an alternative tuning method that will improve the original system response. The final task of this assignment would involve a comparison of adaptive and auto tuning methods (D1).

Criterion M4 could be achieved through an extension to the assignment covering criteria P10 and P11. Having written a PLC program to meet a specification, learners could be asked to redesign the program to meet a new specification that identifies the maximum number of lines of code. This will require learners to produce an elegant program structure. The program would still be required to meet specification.

Assessment of D2 could be achieved through an extension of the assignment covering criteria P10, P11 and M4. Learners could be asked to analyse the performance of a given short PLC control program and identify improvements to the program operation in terms of operating speed and memory use. Learners could then be asked to alter the program and measure its performance against the original.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Control System Types and Applications	Learner to produce an information leaflet detailing control systems and their applications.	A written assignment
P4, P5, M1	Three-Term Controllers	Learner to produce a report describing three-term controllers and identifying the most appropriate tuning method for different applications.	A written assignment
P6, P7, P8, P9	Programmable Logic Controllers	Learner has been asked to research and produce a report on the different types of PLC.	A written assignment
P10, P11, M2, D1	PLC Programs	Learners to write and fault-find a PLC program.	A practical assignment supported by observation records and annotated photos

Essential resources

Centres will need to provide access to process controllers, process rigs, data books and manufacturers' specifications.

Indicative reading for learners

Textbooks

Bolton W – *Instrumentation and Control Systems* (Elsevier, 2004) ISBN 9780750664325

Bolton W – *Programmable Logic Controllers* (Newnes, 2015) ISBN 9780128029299

Unit 39: Principles and Operation of Three-phase Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Three-phase systems are used to deliver the great amounts of power required to supply industrial, commercial and domestic demand. These systems can be divided into three main categories – generation, transmission and distribution.

This unit will cover the principles of the basic circuit configurations which are common to all parts of the electricity supply system. Circuits are connected in either star or delta using three wire circuits wherever possible, as four wire circuits are normally only used where division into single-phase distribution is required. The unit also covers the equipment required to protect systems against faults and the procedures used to operate systems safely and legally.

On completion of this unit, learners will have a broad knowledge of the design and operation of three-phase circuits. This will include being able to read and produce simple circuit diagrams, make simple measurements and knowledge of the principles of system operation and maintenance.

This unit provides a foundation for anyone interested in taking up a career in the electricity supply, manufacturing or processing industries. In large factories and processing plants three-phase systems are used for internal distribution.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to use electrical relationships and determine current, voltage and power quantities for three-phase circuits

2 Know about the operation of three-phase supply systems

3 Be able to calculate parameters and carry out measurements in three-phase balanced and unbalanced loads

4 Know how three-phase power is protected and monitored and the safety requirements for working on high voltage equipment.

Unit content

- 1 **Be able to use electrical relationships and determine current, voltage and power quantities for three-phase circuits**

  Three-phase circuit relationships: systems of connection e.g. 3-wire star, 4-wire star, delta; phasor diagrams

  Current and voltage: star connection; delta connection; line and phase voltages; line and phase currents

  Power in balanced loads: the power triangle e.g. real, reactive and apparent power values, relationships; real power e.g. single-phase equation, phase angle, power factor (PF); three-phase power e.g. total power relationships from phase and line currents and voltages, calculations involving phase and total power, kW, kVAr and kVA values

- 2 **Know about the operation of three-phase supply systems**

  Three-phase supplies: diagrammatic representation; system generation, transmission and distribution e.g. National Grid, schematic diagrams, operating voltages (such as 400kV, 275 kV, 132 kV, 33 kV, 11 kV, 400 V, 110 V), transformer connections (such as star-delta, star-star, delta-star)

  Principle of operation of synchronous generators (alternators): calculations e.g. emf, voltage, leading/lagging power factor, power, efficiency; production of three-phase emfs e.g. distributed winding, salient pole, frequency, pole pairs, synchronous speed, phase sequence, effect of excitation; characteristics e.g. open circuit, v-curves

  Construction of alternators: rotor e.g. cylindrical, salient pole; stator e.g. distributed windings, single layer, double layer; excitation methods e.g. DC exciter, AC exciter, brushless; parallel operation of generators e.g. conditions for synchronising onto supply system, voltage control

- 3 **Be able to calculate parameters and carry out measurements in three-phase balanced and unbalanced loads**

  Circuits: calculations e.g. parameters (such as line and phase voltages, line and phase currents, real power, apparent power, reactive power, power factor, phase angles, 3 and 4-wire circuit currents, line, phase and neutral currents), phasor diagrams (such as sketches, scaled diagrams, determination of values); circuits e.g. balanced star and delta, unbalanced star and delta

  Measurement of three-phase power: parameters from practical measurements e.g. voltage, current, real power, line and phase voltages, line, phase and neutral currents; measurement methods e.g. single wattmeter for 4-wire balanced circuits, three wattmeter and two wattmeter methods for unbalanced loads; equipment for practical measurements e.g. voltmeter, ammeter, wattmeter

- 4 **Know how three-phase power is protected and monitored and the safety requirements for working on high voltage equipment**

  Faults and protection: protection equipment e.g. current transformers, voltage transformers, relays; protection of three-phase generators and transformers; common faults e.g. excess current, overvoltage, phase to phase, phase to earth; monitoring equipment e.g. voltmeter, ammeter, wattmeter, frequency meter, PF meter, kVAR meter, kVA meter

  Supply considerations: availability of supply e.g. single-phase, three-phase, voltage; tariff structures e.g. commercial, industrial, maximum demand, metering and recording arrangements, methods and connection of power factor improvement equipment (such as capacity banks, capacitors on individual machines, synchronous motors operating on leading PF)

  Safety: safety precautions when working e.g. warning notices, labelling, working space, earthing arrangements, interlocking arrangements, personal protective equipment, rubber mats, barriers, insulated tools, test equipment; documentation e.g. limitation of access, permit to work, sanction for test

  Equipment, machines and systems: equipment e.g. switchgear, protection apparatus, monitoring apparatus; machines e.g. generators, transformers; systems e.g. transmission networks, distribution networks

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 demonstrate current and voltage quantities for star and delta connections using three-phase circuit relationships	M1 explain the operation of the protection system on a three-phase transmission line in the event of a given common fault	D1 explain, using numerical examples, the need for different voltages for different parts of the generation, transmission and distribution systems
P2 determine real power and three-phase power for both star and delta connections, including the use of the power triangle		
P3 describe the system of three-phase generation, transmission and distribution		
P4 describe the principle of operation of a synchronous generator (alternator) with the aid of calculations	M2 using practical examples and/or characteristics, explain how the variation of excitation of an alternator can be used to control power factor	
P5 describe the function of the components within an alternator		

P6 carry out calculations relating to line and phase voltages and currents, in circuits with balanced and unbalanced three-phase loads		
P7 measure voltages, currents and real power in circuits with balanced and unbalanced three-phase loads	M3 explain why it is important to use the correct equipment when measuring three-phase power and the impact this would have on circuit calculations when using any of these measurements	
P8 describe the equipment required to protect three-phase generators and transformers against common faults and the equipment required to monitor supplies	M4 explain the different tariff structures and how this could lead to the connection of power factor improvement equipment.	D2 evaluate the benefits to commercial consumers and suppliers of installing power factor improvement equipment on consumers' equipment.
P9 describe the equipment and documentation required for safe working on high voltage equipment, machines and systems.		

Essential guidance for tutors

Assessment

The unit could be assessed using three assignments. The first assignment could be based on circuits throughout the supply system and the reasons for the choice of voltages. This could cover criteria P1, P2, P3, M1 and D1 and ensure diagrams are suitably detailed. Exercises on numerical and phase relationships could be used to achieve P1 and P2. It is important that both line and phase voltages and currents are covered. To ensure authenticity of evidence, data would need to be varied for each learner. Alternatively the tasks for P1 and P2 could be carried out first in a time-controlled environment and then the rest of the assignment carried out in learners' own time.

To achieve P3, diagrams of parts of the supply system for P3 could be coupled with explanations of the reasons for choosing different voltages at D1. At distinction level such an exercise would require numerical evidence to be analysed to support the principles applied in selecting a voltage. Realistic or measured values should be used at all times. The assignment could be completed with a task to explain the protection system (M1).

The second assignment could cover the major aspects of power in three-phase systems and enable achievement of criteria P4, P5, P6 and M2.

The generation of power and the control of all types of power and power factor throughout the system are the main features of this assignment to ensure the understanding of each component and their purpose. Results from practical tests could be used for part or all of the work, although in this assignment the practical element is not being assessed. Simulation packages and low voltage equipment could be used for the measurements if other methods are not available.

As with the first assignment, data could be varied for each learner or these tasks could be carried out first in a time-controlled environment to ensure authenticity. As well as the requirement for carrying out calculations, the task to achieve P4 should consider the production of three-phase emfs and characteristics.

A written task could then be given asking learners to describe the function of an alternator and in doing so should include rotor, stator and excitation aspects as well as parallel operation of generators.

A further task could be given to achieve M2. The tasks for P4 and P6 could be done under controlled conditions and P5 and M2 by the learner in their own time, clearly evidencing the components that make up an alternator.

The third assignment could focus on the protection of the system and the techniques of making work on high voltage systems safe. This would cover criteria P7, P8, P9, M3, M4 and D2.

To demonstrate an appreciation of the whole system learners would need to explain how and why it is important to operate at an economical power factor (D2). The consumer's equipment would be that found at the user end of the transmission and distribution networks. For this assignment a visit to a power station, sub-station or large industrial plant could provide the required background information.

A practical task needs to be set to measure voltages, current and real power (P7) and within the task there should be scope to cover measurement methods and equipment requirements. The evidence for this criterion is likely to be in the form of a witness statement/observation record supplemented by a table of results and annotated photographs.

A written task is required for P8 and P9 and further written tasks for M3 and M4. The task for P9 should ensure that equipment and documentation requirements are considered when working on all three aspects of high voltage. These should include a type of equipment, a type of machine and a type of system as listed in the content section of learning outcome 4.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Three-Phase Circuits	A technician has been asked to look at a range of circuits in the supply system and determine current, voltage and power quantities.	A controlled test to determine current, voltage and power quantities plus a written explanation/ diagrams of three-phase generation, transmission and distribution including reasons for choice of different voltages.
P4, P5, P6, M2	Power Generation and Control	A technician needs to determine the operation of three-phase supply systems and line and phase voltages and currents.	A controlled test to determine operation of a synchronous generator line and phase voltages and currents, plus a written description of an alternator.
P7, P8, P9, M3, M4, D2	Protection and Safety Requirements for Three-Phase Power	A technician must show a new learner how to measure voltages, current and real power and explain the use of relevant protection and safety equipment.	Results from practical measurement tasks supported by observation records, plus a written report.

Essential resources

Centres delivering this unit must have access to industrial standard three-phase equipment and systems. Appropriate and adequate testing instruments and measurement equipment should also be provided.

A range of relevant international and British Standards and health and safety publications should be available.

Indicative reading for learners

Textbooks

Bayliss C and Hardy B – *Transmission and Distribution Electrical Engineering* (Newnes, 2012) ISBN 9780080969121

Bird J – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9780415662864

Robertson C R – *Electrical and Electronic Principles and Technology by Bird John* (Routledge, 2013) ISBN 9780415662857

Unit 40: Industrial Robot Technology

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

This unit will give learners an understanding of the principles and operation of industrial robots used in modern manufacturing. The unit will cover robot control systems, the operating principles of different types of sensors used and their application within an industrial robot.

Learners will gain an understanding of the programming methods used and will be required to produce a working program for an industrial robot or robot work cell. The unit will also give learners an understanding of the health and safety and maintenance requirements associated with modern industrial robots.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operating, design and control principles of modern industrial robots and typical robot work cells

2 Understand the operating principles of industrial robot sensors and end effectors

3 Be able to produce a working program for an industrial robot or robot work cell

4 Know the hazards and health, safety and maintenance requirements associated with industrial robots and robot work cells.

Unit content

- 1 **Understand the operating, design and control principles of modern industrial robots and robot work cells**

  Principles of operation: operational characteristics and specifications; types of controller, manipulator, end effector/tooling e.g. pneumatic suction cup, hydraulic, electrical and mechanical grippers; work space organisation e.g. feed of work, robot-to-robot work, material flow and logistics

  Design principles: manipulator coordinate systems e.g. cylindrical spherical, jointed, spherical, Cartesian and Selective Compliant Assembly Robot Arm (SCARA) with associated working envelope; wrist articulations e.g. yaw, pitch and roll, degrees of freedom in terms of translations and rotations; drive mechanisms: mechanical (ball screws, chain/belt, gears), pneumatic, hydraulic, electrical; speed reducers/gearheads e.g. harmonic, cycloidal, parallel shaft spur gear, planetary

  Control systems: on/off and programmable-integral-derivative (PID) control; closed-loop servo controlled systems e.g. for driving one axis of a robot; input, output and feedback signals e.g. the sequence which takes place in order to perform a task; control of three axes of a robot

- 2 **Understand the operating principles of industrial robot sensors and end effectors**

  Sensors: sensor types e.g. tactile (micro switches/piezoelectric/strain gauge/pressure), non-tactile (capacitive/inductive/light/laser), vision (inspection, identification and navigation); sensor applications e.g. safety, work-cell control, component/part inspection

  End effectors: grippers and tools e.g. parts handling/transfer, assembly, welding, paint spraying, testing

3 **Be able to produce a working program for an industrial robot or robot work cell**

Operating program: program selection, start-up, test, alterations and operation; types of programming e.g. manual, walk through, teach pendant methods; off-line programming; planning robot efficient routes; writing programs using flowcharts; work-cell commands e.g. wait/signal/delay

4 **Know the hazards and health, safety and maintenance requirements associated with industrial robots and robot work cells**

Health and safety requirements: relevant regulations e.g. Health and Safety at Work Act, Electricity at Work Regulations, Health and Safety Executive publications, Machine Tool Technologies Association Codes of Practice (MTA Safeguarding Codes of Practice – Industrial Robots parts 1–3); human dangers e.g. during programming, maintenance and as a result of system faults; safety barriers e.g. 'dead man's handle', hold and emergency stop buttons, pressure pads/matting surrounding robot, infra-red curtains and electromagnetic field barriers

Maintenance: inspection routines e.g. mechanical condition of all parts, environmental conditions (particulate matter, temperature, ventilation, shock, vibration, electrical noise); spare parts required to sustain continuous operation; relevant maintenance tools and test equipment; set-up and maintenance schedules

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the operating principles of a given industrial robot or robot work cell	M1 explain how the design principles of a given industrial robot or robot work cell are reflected in its control and operation	D1 evaluate an industrial robot or robot work cell installation in terms of its design, operation and control
P2 explain the design principles of a given industrial robot or robot work cell		
P3 describe the control systems, including input, output and feedback signals, used to control the operation of an industrial robot or robot work cell to perform a specific task		
P4 explain the operating principles of three different types of sensors and their relevant application within an industrial robot or robot work cell	M2 justify the use of a specific sensor/end effector for a given industrial robot or robot work cell application	

P5 explain the relevant operating principles of two different industrial robot or robot work cell end effectors being used to perform a specific task		
P6 produce an operating program for an industrial robot or robot work cell to enable it to effectively carry out a specific function	M3 test that an industrial robot or robot work cell conforms to a specification and performs the programmed tasks correctly and safely	D2 compare two different methods used to program an industrial robot or robot work cell for a specific operation, and justify the choice of one over the other.
P7 describe the health and safety requirements for the safe operation of a given industrial robot or robot work cell	M4 justify the choice of a safety barrier for a given industrial robot or robot work cell operation.	
P8 describe maintenance procedures on a given industrial robot or robot work cell.		

Essential guidance for tutors

Assessment

One assignment could cover P1, P2, P3, M1 and D1.

For P1, learners will need to explain the principles of operation of robots, including types of controller, manipulator, end effector/tooler and work space organisation. This can be linked to P2, so that their explanation also includes robot design principles (manipulator coordinate systems, wrist articulations, drive mechanisms and speed reducers).

Learners will need to describe types and applications of control systems suitable for robots (P3). A separate task could be used to combine M1 and D1, which essentially synthesises P1, P2 and P3 and requires an evaluation of a given industrial robot or robot work cell in terms of its design, operation and control.

A second assignment could cover P4, P5 and M2. For P4, learners will need to explain the operation of three different sensors and their different applications. This can be linked to P5 where they will need to provide details of robot end effectors.

M2 combines P4 and P5. Learners could select one example used in P4 to justify sensor use and one example from P5 for end effector use or use one example to combine the two.

A third assignment could be used to cover P6, M3 and D2. For P6, a robot must be programmed and the program produced should be tested in order to achieve M3. It is suggested that the program should be centred on industrially relevant tasks. The ability to have used two programming methods and subsequently to evaluate and compare them is also necessary to achieve D2.

A fourth assignment could be used to cover P7, P8 and M4. A clear awareness of health and safety (P7) and maintenance issues (P8) associated with robots should be shown through the assessment tasks.

To achieve M4, learners must be aware of safety and choose and justify the choice of a safety barrier in an industrially relevant situation.

Learners must be able to select and interpret from a range of sources of information, such as manufacturers' literature, textbooks and the internet. Learners should require significantly less tutor help or guidance when carrying out assessable practical activities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Robot Operation, Design and Control Principles	A technician needs to evaluate the operation, design and control of a robot to see if improvements can be made	A written report
P4, P5, M2	Sensors and End Effectors	A technician needs to explain to a new learner the operating principles of robot sensors and end effectors	A written report
P6, M3, D2	Producing and Testing Operating Programs for Industrial Robots	A technician needs to produce and test an operating program for an industrial robot	A practical task supported by learners' written records and records of tutor observation
P7, P8, M4	Health, Safety and Maintenance With Industrial Robots	A H&S manager requires a report on health and safety requirements for an industrial robot along with maintenance procedures. operate	A written report

Essential resources

Centres delivering this unit should be equipped with, or have access to, an industrial standard robot or smaller educational-standard robots. Learners are expected to undertake programming exercises and be encouraged to set up robot controlled systems/processes.

Indicative reading for learners

Textbooks

Appin Knowledge Solutions — *Robotics* (Infinity Science Press, 2006) ISBN 9781934015025

Niku S — *Introduction to Robotics* (John Wiley and Sons, 2010) ISBN 9780470604465

Unit 41: Vehicle Electronic Ancillary and Information Systems

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning: 60

Unit introduction

Significant technological developments within the motor vehicle industry have resulted in modern vehicles being equipped with a vast array of additional ancillary and information systems. From anti-lock braking systems (ABS) and stability control, to condition monitoring computers and satellite navigation and information, these systems contribute to the overall safety and comfort of the vehicle's occupants.

Through practical investigation, learners will gain an understanding of the function of these systems and their key components. The unit will also focus on how ancillary and information systems interrelate with each other and how they interact with a vehicle's driver or passengers.

Learners will carry out inspections on different vehicle ancillary and information systems to confirm their correct operation and system integrity.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operating principles and characteristics of vehicle electronic ancillary and information systems

2 Know about the function of key units and components of vehicle electronic ancillary and information systems

3 Know the interrelationships and interaction of vehicle electronic ancillary and information systems

4 Be able to inspect vehicle electronic ancillary and information systems.

Unit content

1 **Understand the operating principles and characteristics of vehicle electronic ancillary and information systems**

Systems model: use of systems model (input – process – output); characteristics of control strategies employed e.g. open-loop, closed-loop

Operating principles and characteristics: control systems e.g. analogue, digital, programmable, non-programmable; main elements of a digital processing system and principal functions e.g. central processing unit (CPU), memory devices (such as volatile, non-volatile), buses, input/output ports, multiplexing, controller area network (CAN) systems; characteristics e.g. purpose and applications of the system, operating conditions (such as conditions in which the system is operative or inoperative, 'fail-safe' features), system evaluation to identify benefits, comparative cost, performance, safety, convenience, efficiency

Vehicle electronic ancillary and information systems: electronic ancillary systems e.g. anti-lock braking systems (ABS), vehicle stability control systems, security and alarm systems, central body electronic systems (such as seat positioning, seatbelt tensioning, secondary restraint systems, cargo/cabin compartment climate control); information systems e.g. driver information (condition monitoring and trip computers), navigation – global positioning system (GPS), communication systems, entertainment systems, proximity (reversing) sensors and road positioning

Operating principles of sensors and actuators: transducers used in vehicle ancillary and information systems e.g. electromagnetic, Hall-effect, photoelectric, resistive, inductive, capacitive; factors affecting performance and application e.g. sensitivity, accuracy, linearity and stability; influence of environmental factors e.g. heat, vibration, moisture, contaminants

2 **Know about the function of key units and components of vehicle electronic ancillary and information systems**

Key units and components of vehicle ancillary systems: input data e.g. temperature, speed, position; process data e.g. mapping to input; output data e.g. electronic/mechanical actuation; key units and components e.g. sensors (temperature, speed, position), processors (ABS, electronic climate control unit), actuators (switches, inductive, capacitive, direct current (DC) motors, stepper motors when used for throttle poisoning or ventilation control), solenoids when used on ABS, air conditioning or for multi-position; legal considerations e.g. modifications to vehicle specification that may affect sensor/system performance (fitment of larger wheels/tyres effect on speedometer accuracy, fitment of passenger airbag isolation switches)

Key units and components of vehicle information systems: input data e.g. temperature, speed, position, levels, electrical values; process data; visual output e.g. lights, display screen, gauges; audible output e.g. buzzer, speaker; key units and components e.g. sensors (temperature, fluid level, speed, GPS); processors e.g. satellite navigation, on-board diagnostics when used as comfort computing; output units e.g. display screen, speakers, buzzers, gauges, lights; legal considerations e.g. fitment of radar detectors

3 **Know the interrelationships and interaction of vehicle electronic ancillary and information systems**

Interfacing and signal processing: compatibility between components and systems; characteristics of devices which give rise to the need for signal processing (inductive pick-ups, analogue to digital (AD), digital to analogue (DA)); control of output devices e.g. energy transfer, power output stages, buffer circuits

Representational methods: diagrams e.g. circuit, flow, block, systems; circuit type e.g. electrical, electronic, hydraulic, pneumatic; connections

Functional interrelationships: location e.g. units and components within the vehicle, position/location of components relative to others in the system; functional relationships between the elements of the system; effects e.g. failures on other components within the system, the operation of the system and on external systems (such as effect of speed sensor failure)

System interaction: ways in which the system under consideration interacts with other vehicle systems and functions e.g. integration of anti-lock braking and stability control (anti-skid), systems, stability control system obtains information from the steering system, ABS system components interacts with the braking and engine control systems

Driver/passenger interaction: driver/passenger influence on the operation and characteristics of the system (such as seat pad recognition); effects of the system on the driver's/passengers' behaviour, comfort and safety (such as temperature effect on stress levels)

Vehicle interaction: ways in which the system affects the vehicle in relation to other vehicles e.g. proximity detection; external factors influencing the operation/function of the system e.g. satellite navigation, ground positioning systems

4 **Be able to inspect vehicle electronic ancillary and information systems**

Inspections: location of systems and key components; means of identification; testing and diagnostic procedures as appropriate to the system under consideration

Safety: relating to the operation, inspection, maintenance and testing of the system

Practical confirmation of system operation and characteristics: observation of the system in operation; examination of system responses to external conditions as appropriate to the system under consideration

Testing considerations: factors affecting performance/reliability and application e.g. sensitivity, accuracy, linearity and stability; influence of environmental factors e.g. heat, vibration, moisture, contaminants

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 with the aid of a systems model, explain the operating principles and characteristics associated with the vehicle electronic ancillary and information systems	M1 compare the characteristics of two vehicle electronic ancillary and information systems in terms of function, performance, safety and cost.	
P2 describe the operating principles of sensors and actuators	M2 compare two different sensors, with respect to position and environment control	D1 evaluate the factors that affect the performance and application of sensors and actuators
P3 describe the function of the key units and components of two vehicle ancillary systems		
P4 describe the function of the key units and components of two vehicle information systems	M3 explain how the malfunction of key units and components can influence the operation of a vehicle electronic ancillary and information system	
P5 describe interfacing and signal processing in ancillary and information systems	M4 explain the benefits of the interaction of vehicle ancillary and information systems for a chosen application.	

P6 use representational methods to help describe the functional interrelationship and interaction between systems		
P7 describe driver/passenger and vehicle interactions for one ancillary and one information system		
P8 safely inspect an electronic ancillary system to confirm system operation and integrity		
P9 safely inspect an information system to confirm system operation and integrity		
P10 identify the testing considerations to make when carrying out a practical investigation into inspecting vehicle electronic ancillary and information systems.	M5 explain the factors affecting performance and reliability of vehicle electronic ancillary and information systems	D2 evaluate the effect of environmental factors on vehicle electronic ancillary and information systems.

Essential guidance for tutors

Assessment

This unit could be assessed using three assignments.

Learners will need to generate evidence of using a systems model to explain the operating principles and characteristics (P1). This can be extended to make a comparison of the characteristics for M1. Learners can then describe the function of two ancillary systems (P3) and describe the operating principles of sensors and actuators (P2) relating to the two identified ancillary systems, comparing different sensors in respect of position and environment (M2). This can be expanded upon to evaluate the factors affecting performance and application of sensors and actuators (D1). All of the above criteria could be combined into one assignment which is likely to be in written form and may include diagrams and sketches.

A second assignment could cover P4, P5, P6, P7, M3 and M4. Learners would need to describe the function of key units and components of two vehicle information systems (P4). To meet P5 the description of interfacing and signal processing should include compatibility, inductive pick-ups, processing, and the control of output devices. The inclusion of an appropriate circuit diagram for each system would meet P6 and would need to include the description of the functional interrelationship and interaction of systems.

Learners could then be asked to describe driver/passenger and vehicle interactions (P7). Further tasks could be set to extend to the information system element of M3, and M4.

A third assignment will need to be based on practical sessions, with learners carrying out inspections on both ancillary (P8) and information systems (P9) to industry standards. A written task could ask learners to identify testing considerations for both types of system (P10). M5 requires factors affecting performance/reliability and application and could include sensitivity, accuracy, linearity and stability. This can be extended to D2 to include the influence of environmental factors such as heat, vibration, moisture and contaminants.

Evidence should include notes, diagrams, test data, and records of the maintenance and diagnostic procedures carried out. Witness statements/ observation records, supplemented by annotated photographs could also form part of the evidence for these practical elements.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Function and Operation of Ancillary and Information Systems and Components	A technician needs to investigate vehicle ancillary systems, sensors and actuators prior to system testing	A written report

P4, P5, P6, P7, M3 and M4	Interrelationship and Interaction of Ancillary and Information System Components	A technician needs to investigate the vehicle information systems, system interfacing and signal processing and the interaction between systems	A written report
P8, P9, P10, M5, D2	Inspecting and Testing Electronic Ancillary and Information Systems	A technician needs to inspect vehicle electronic ancillary and information systems to confirm their operation	A practical assignment evidenced through learners' portfolio and tutor observation records

Essential resources

A range of components, vehicles and equipment will be required for practical investigation, along with an accompanying variety of data sources.

Indicative reading for learners

Textbooks

Denton T — *Automobile Electrical and Electronic Systems* (Routledge, 2012) ISBN 9780080969428

Hillier V — *Hillier's Fundamentals of Automotive Electronics Book 2*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515372

Unit 42: Light Vehicle Suspension, Steering and Braking Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Advances in engine and transmission design mean that modern vehicles have an increased need for suspension, steering and braking technology that can cope with the forces associated with modern vehicle performance.

Some suspension systems have different modes for the driver to select according to personal demands or those of the terrain. The most sophisticated suspension systems can self-level, have yaw control and adjust to the type of terrain being encountered.

Steering systems are now mostly power-assisted, in some cases to counter the effects of wider tyres and suspension that have been set to enhance the vehicle's road holding. Most tyres are now low profile in order to ensure that performance, control and stability are maximised.

Sports vehicles, family saloons, multi-purpose vehicles, off-road vehicles, passenger service vehicles and haulage vehicles all require different things from these systems in order to perform well in the environment for which they are intended. It is vital that these systems interrelate with, and complement, each other to ensure maximum comfort and safety of the driver and passengers.

This unit will develop learners' knowledge of the function and operation of the main suspension, steering and braking system components and their relationship to the efficient operation of the vehicle. Learners will then carry out a range of practical inspection and fault-finding techniques on these systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Know the function and operation of different types of suspension system

2 Know the function and operation of steering system components

3 Know the function and operation of braking system components

4 Be able to carry out fault-finding procedures on steering, braking and suspension systems.

Unit content

1 **Know the function and operation of different types of suspension system**

Suspension systems: types of independent front suspension e.g. unequal length wishbones, transverse link and strut; types of independent rear suspension e.g. trailing arm, pure and semi, unequal transverse links, transverse link and strut, air suspension; dampers (construction, operation and typical faults); suspension requirements e.g. sprung weight, unsprung weight; impact of chassis design on suspension type e.g. ladder, monocoque, space frame, welded shell constructions

Adaptive suspension system main components: Electronic Control Unit (ECU); regulator; solenoid valve; sensors; dampers; system operation

2 **Know the function and operation of steering system components**

Power-assisted steering main components: hydraulic pump; control valve; power cylinder; reservoir; filter; pressure relief valve; pipes; steering gear; types e.g. integral, semi-integral, rack and pinion, worm and follower, speed sensitive

Steering characteristics: understeer; oversteer; neutral steer; roll axis; roll centre; centre of gravity

Road wheels: wheel type e.g. alloy (cast or forged), steel, well based, specialist (such as wire spoke, flat-edge, double hump, divided, detachable flange); rim codes; wheel retention methods

Tyres: types e.g. belt and brace construction, ply construction; tyre profile and tyre markings e.g. width, aspect ratio, type of construction, load index, speed index, ply ratings, direction indicators; applications e.g. high performance, light/heavy vehicles, motorcycle, agriculture, industrial; valve types

3 **Know the function and operation of braking system components**

Main components: types of system e.g. single piston disc brakes, multi-piston disc brakes; brake fluid characteristics; brake bleeding componentry; brake pad warning systems; types of brake circuits (construction and operation) e.g. tandem master cylinders, vacuum servo units, pressure apportioning valves

Anti-lock braking system (ABS) components: wheel speed sensors; ECU; system modulator; reservoir; electronic control system

4 **Be able to carry out fault-finding procedures on steering, braking and suspension systems**

Fault-finding: identification of typical faults and corrective action to be taken for each system; adjustment and servicing of the main components for each of the systems; protection of units against the usual hazards during use or fault-finding; safe working practice

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 describe the function and operation of two independent front and two independent rear vehicle suspension systems, including suspension requirements and the impact of chassis design	M1 compare the relative advantages and disadvantages of an adaptive suspension system with one other type of suspension system	D1 evaluate an adaptive suspension system for performance and safety
P2 describe the function and operation of the main components of an adaptive suspension system		
P3 describe the function and operation of the main components of power assisted steering	M2 explain the suitability of using these systems in different types of vehicle	
P4 distinguish the range of steering characteristics	M3 explain the effect of understeer, oversteer and neutral steering characteristics, vehicle roll axis, roll centre and centre of gravity on wheel/tyre function and operation	
P5 describe the functional differences between two different wheel and tyre combinations		

P6 describe the function and operation of the components found in a given type of braking system	M4 compare the function and operation of the braking system selected with an anti-lock braking system.	D2 evaluate two different braking system applications for efficiency and safety.
P7 describe the function and operation of the components found in an anti-lock braking system		
P8 carry out fault-finding on a suspension system to check for satisfactory operation		
P9 carry out fault-finding on a steering system to check for satisfactory operation		
P10 carry out fault-finding on a braking system to check for satisfactory operation		
P11 state the corrective action to be taken for each of the faults found.		

Essential guidance for tutors

Assessment

This unit could be assessed through three written assignments and one practical assignment.

The first written assignment could give learners opportunities to meet the requirements of P1, P2, M1 and D2. A task could be set asking learners to describe the function and operation of two main types of independent front and two types of independent rear vehicle suspension design (P1). Different types of rear suspension could be given to different learners from the range listed within the unit content. The task should ensure that learners cover dampers, the suspension requirements and the impact of chassis design.

For P2, a task should be given asking learners to describe the function and operation of the main components of an adaptive suspension system. The main components that need to be covered are listed within the unit content. A further written task could be set asking learners to compare the relative advantages and disadvantages of an adaptive suspension system and one other suspension system (M1). This could be extended to incorporate an evaluation of an adaptive suspension system using performance and safety as the criteria (D1).

A second assignment could be given to meet the requirements of P3, P4, P5, M2 and M3. An initial task, covering P3, could require learners to describe the function and operations of the main components in a power-assisted steering system. Tutors can give different types of steering system to different learners.

A second task in this assignment could ask learners to distinguish between understeer, oversteer and neutral steering characteristics, vehicle roll axis, roll centre and centre of gravity, to achieve P4.

A third task, covering P5, would again give tutors the opportunity to give different wheel and tyre combinations to different learners. Consideration should be given to wheel types, rim codes and retention methods, valve and tyre types including profile and markings and applications. A further task could be set asking learners to explain the effect of steering characteristics on wheel/tyre function and operation (M3).

A third written assignment could be used to meet the requirements of P6, P7, M4 and D2. Initially, learners could describe the function and operation of the components found in braking systems (P6) and anti-lock braking systems (P7). A further task could then be set asking them to compare the breaking system with an anti-lock system and extend this to evaluate two braking system applications for efficiency and safety (D2). Although the components used in the anti-lock braking system are clearly listed within the unit content tutors can vary what is given to each learner. It is important that the type of system is fully explored and that brake bleeding componentry and brake pad warning systems are considered in the descriptions.

A final practical assignment could be set to meet the requirements of P8, P9, P10 and P11. Learners would need to be given a particular vehicle to carry out a fault finding exercise on its suspension, steering and braking systems. In doing so learners will need to establish which components are operating satisfactorily and which are not. At least one fault in each system must be present to allow corrective action to be identified. A record of hazard protection and safe working needs to be made.

Depending on the resources available different learners could work on different vehicles. Evidence for this practical assignment is likely to be in the form of a witness statement/observation record, supplemented by annotated photographs and a list of the faults found and suggested corrective action for each.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, P5, M2, M3	Steering System Components	A vehicle technician needs to describe the function and operation of steering systems to a new learner	Written report
P6, P7, M4, D2	Braking System Components	A vehicle technician needs to describe the function and operation of braking system components to a new learner	Written report
P8, P9, P10, P11	Fault-finding of Steering, Braking and Suspension Systems	A vehicle technician needs to inspect a vehicle's steering, braking and suspension systems	Practical activities evidenced by learner record sheets and observation records.

Essential resources

A range of suspension, steering and braking components and equipment will be required for delivery of this unit. Learners will need access to vehicles in order to carry out fault-finding on the different systems.

Indicative reading for learners

Textbooks

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Killingsworth J, Godfrey E and Haynes J — *Suspension, Steering and Driveline Manual* (Haynes, 1998) ISBN 9781563922930

Nunney, M — *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 43: Mechanical Measurement and Inspection Techniques

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

In order to produce components that meet the design criteria, manufacturing companies have to know whether the components they make are to the required dimensional and accuracy standards. Companies carrying out maintenance activities also need to know that the components they are working with, repairing or servicing are to the required size and accuracy.

Measurement and inspection play an important role in establishing these needs and support other areas of assuring quality in the products produced. The process of finding out whether a product is accurate and to dimensional standards also needs to be done in an efficient and effective way.

The aim of this unit is to provide a broad understanding of mechanical measurement and inspection techniques that apply to a range of engineering activities within different companies. The unit will give learners an understanding of a range of techniques and equipment commonly used in mechanical measurement and inspection.

Learners will be introduced to principles of measurement and the use of comparators and gauges, along with sampling and statistical process control (SPC). Learners will develop the skills needed to select and use standards, measuring equipment, comparators and gauges. They will be able to appreciate the fundamental requirements of measurement and inspection techniques and be able to apply standards to these.

Learners will have an opportunity to carry out practical measurements using linear measuring equipment and techniques and comparators and gauges. They will also be able to prepare a process control chart for a given process.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand principles and applications of mechanical measurement

2 Be able to use measurement equipment and techniques

3 Be able to use comparators and design a gauging system for inspection

4 Be able to apply sampling and statistical process control (SPC) during inspection.

Unit content

1 **Understand principles and applications of mechanical measurement**

Limits and fits: e.g. concepts of limits and fits, definitions of the types of fits (clearance, transition, interference)

Tolerances: principles e.g. standard symbols and interpretation, maximum material condition, maximum variation of form, grades of tolerance; hole tolerances, shaft tolerances

Principles of measurement: units; standards e.g. BS969, BS1134, BS2634, BS4500; calibration e.g. national standards, traceability; errors and instruments; kinematics of equipment

2 **Be able to use measurement equipment and techniques**

Linear measurement equipment: range (verniers, callipers, micrometers); principles involved; scales; types; use in dimensional measurement; specific calibration issues

Further measurement techniques: determining surface texture e.g. significance to component function, surface texture symbols, roughness average, waviness, finish, amplitude parameters, spacing parameters, instrumentation used for surface texture measurement; determining alignment e.g. principles of straight edges, measurement of straightness, squareness, flatness and parallelism; determining angular measurements e.g. concepts of geometry, divided circles, principles of angular measurement, angular scales, methods for angular measurement, taper measurement

3 **Be able to use comparators and design a gauging system for inspection**

Comparators: types of comparator, magnification, cosine errors, use of angle dekkor, specific calibration issues

Gauge design: principles of gauge design (gauge types, gauge materials, Taylor's principle, principle of go/no-go gauging); slip gauges as references for length standards (classification of slip gauges, multiple slip gauge use, ancillary equipment, care and maintenance required, wringing); slip gauges for instrument calibration (use with dial gauges in dimensional measurement, specific calibration issues)

Simple application: measuring a component containing round (external or internal), linear and angled features, following the use of a high precision manufacturing method such as grinding e.g. the jaw of a toolmaker's clamp

4 **Be able to apply sampling and statistical process control (SPC) during inspection**

Sampling: acceptance sampling, 100% inspection

Statistical process control: charts (mean, range); process capability, conformance, cost, process variability; process e.g. grinding machine, high-volume lathe

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 explain the different types of limits and fits	M1 analyse the use of the concept of limits and fits	
P2 use tolerancing principles to calculate hole and shaft tolerances for a range of required component fits		
P3 explain the principles of measurement		
P4 use linear measurement equipment to carry out practical measurements for given products	M2 explain the use of linear measuring equipment when used on given products	D1 evaluate the use and accuracy of linear measuring equipment when used on given products
P5 use further measurement techniques on given products to establish surface texture, alignment and angular measurements		

P6 use comparators to measure dimensions and angles for a simple given product	M3 compare different uses of comparators when used to measure dimensional accuracy	D2 analyse the calibration requirements of comparators and measurement equipment.
P7 design a gauging system for a simple given application		
P8 explain the technique of acceptance sampling and state when 100% inspection is applicable	M4 explain process capability in relationship to statistical process control (SPC) for a given relevant process.	
P9 produce control charts for a given process.		

Essential guidance for tutors

Assessment

Four assignments could be developed for the assessment of this unit.

The first assignment could be a time-constrained assignment addressing criteria P1, P2, P3 and M1. A range of data for all three types of fit should be given allowing learners to apply their knowledge of tolerancing to develop suitable tolerances for each fit. Tasks need to be included that ensure the range of unit content – such as maximum material condition and tolerance grades – are covered (P2). Written tasks should be given for the other criteria, P3 and M1, targeted in this assignment.

For the second assignment, addressing criteria P4, P5, M2 and D1, a range of products need to be made available so that each learner is able to use a vernier, a calliper and a micrometer. It would be useful if the products had both internal and external features to be measured. Obviously the products need to be machined to allow the accuracy that demands the use of this equipment. The instructions should ensure that surface texture, alignment and angular measurements are taken.

Particular care needs to be taken with the choice of product to ensure it is large enough to allow alignment measurements to be taken as ranged in the content. At least two products are required to ensure the range of features and accuracy can be measured and the use of the equipment evaluated. A written task needs to follow the practical activity to address M2. A witness statement/observation record would support the evidence for the use of this equipment, along with a table of measurements taken. D1 will form an extension to the practical work and will require an evaluation of the range of instruments - vernier, a calliper and a micrometer.

The third assignment, addressing criteria P6, P7, M3 and D2, could also be based around a practical exercise. The choice of product for the use of comparators (P6) needs to ensure that there are both dimensions and angles to be measured. No more than two angles are required otherwise the product will be too complex.

Care will need to be taken when planning an assessment activity for the designing of a gauging system (P7). Data or a particular specification should be made available that ensures the principles of gauge design are applied and slip gauges are used. The unit content suggests as an example the jaw of a toolmaker's clamp, so in this case as long as there are external and internal features, linear and angled features the product is suitable. An overly complex product would not be suitable. A written task should be given to provide opportunities for criteria M3 and D2, and could be an extension of the practical work. Again, a witness statement/observation record would support evidence of the use of comparators, along with a table of measurements taken.

The last and fourth assignment could address criteria P8, P9 and M4. Data needs to be given for a process that allows learners to present control charts (P9) for both mean and range and link this to M4. A further written task needs to be set for P8.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3 and M1	Tolerances and Fits	A time-constrained assignment requiring learners to demonstrate their knowledge of tolerances and fits	A practical assignment requiring learners to calculate tolerances for component fits supported by written tasks
P4, P5, M2 and D1	Using Measurement Equipment and Techniques	An assignment requiring learners to use linear measuring equipment and further measuring techniques	A practical task in which learners use verniers, callipers and micrometers and determine surface texture, alignment and angular measurements on at least two products. A further written task can be used to give learners an opportunity to evaluate the use of linear measuring equipment
P6, P7, M3 and D2	Comparators and Gauges	A practical assignment requiring learners to use comparators and design a gauging system	Two practical tasks in which learners first measure dimensions and angles using comparators. Learners then need to design a gauging system. A further written task could build on the practical work so that learners can carry out a comparison and analysis for M3 and D2

P8, P9 and M4	Sampling and Statistical Process Control.	An assignment requiring learners to investigate sampling and inspection techniques.	A series of three written tasks in which learner provide an explanation of sampling and inspection techniques. Learners will then need to produce control charts from given data.

Essential resources

A range of measuring and inspection equipment as defined by the content is necessary, plus a range of products for learners to measure. Centres will need to provide access to engineering data handbooks, manufacturers' specifications and suitable current British Standards (e.g. BS969: Limits and Tolerances on Plain Limit Gauges, BS1134: Method for the Assessment of Surface Texture).

Indicative reading for learners

Textbooks

Drake P – *Dimensioning and Tolerancing Handbook* (McGraw-Hill, 1999) ISBN 9780070181311

Griffith G – Geometric Dimensioning and Tolerancing: Applications and Inspection (Prentice Hall, 2001) ISBN 9780130604637

Timings R L – *Fundamentals of Engineering* (Routledge, 2002) ISBN 9780750656092

Unit 44: Vehicle Engine Principles, Operation, Service and Repair

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Although the technology used in modern vehicles is under constant development, the basic principles of the internal combustion engine (ICE) have remained the same for many years. However, advances in design have produced engines that are more efficient, powerful, environmentally friendly and, with the aid of electronics, much more responsive to the needs of the user.

Developments in engine design and materials technology have significantly increased the reliability and durability of engine components and systems and, therefore, minimised failure and the need for subsequent repairs. However, the modern motor vehicle technician still needs to have a working knowledge and understanding of the engine, and associated sub-systems, to enable them to carry out the necessary care, fault diagnosis and repair.

This unit will enable learners to develop an understanding of a range of engines in terms of their operating principles and processes, applications and service/repair. Two and four-stroke cycle spark and compression ignition engines will be considered together with their related sub-systems — fuel, cooling and lubrication. The unit also examines current and future developments in engine design that make use of alternative fuel and power systems.

Finally, the unit will give learners an opportunity to apply their understanding of engine principles by carrying out engine service and repair work in a vehicle workshop environment. Learners will gain practical experience of using a range of tools and equipment and will work to industry standards relating to vehicle service and repair.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the principles of operation of an internal combustion engine

2 Understand the principles of operation of fuel supply systems
3 Understand the principles of operation of engine cooling and lubrication systems
4 Be able to carry out engine service and repair procedures.

Unit content

1 **Understand the principles of operation of an internal combustion engine**

Operating cycles: internal combustion engines (ICE) e.g. four-stroke spark ignition (SI) and compression ignition (CI) cycles, two-stroke cycle, Wankel (rotary); pressure-volume diagrams and engine performance diagrams (torque/power) e.g. the Otto cycle, identification of induction, compression, ignition, exhaust strokes, effects of bore, stroke, swept and clearance volume; engine efficiency e.g. engine timing, pressure charging, compression ratio

Engine configurations and layout: orientation (longitudinal/transverse); position of engine (front, mid and rear); cylinder arrangement e.g. single cylinder, multi cylinder; cylinder configuration e.g. in-line, vee, horizontally opposed arrangements; vehicle design and performance e.g. space saving, arrangements for power transmission, vehicle function (passenger, people carrier, off-road, motorsport), cost, environmental issues

Engine assemblies: engine types e.g. four-stroke SI and CI, two-stroke cycle, Wankel (rotary); components e.g. cylinder block (piston, connecting rod, crankshaft and bearings), cylinder head (camshaft, inlet/exhaust valves, valve operating mechanisms such as overhead valve (OHV), single overhead cam (SOHC), double overhead cam (DOHC), variable valve timing); flywheel; inlet and exhaust manifolds

2 **Understand the principles of operation of fuel supply systems**

Petrol combustion process: fuel principles e.g. composition of petrol, characteristics of petrol, composition of air, air/fuel ratio, lambda ratio; combustion process e.g. mixing of fuel/air, flame spread, exhaust emissions; effects of pollutants/causes of undesirable emissions e.g. weak mixture, rich mixture, oil control problems; symptoms of incorrect combustion process e.g. detonation, pre-ignition; fuel supply method e.g. fuel injection, mechanical, electrical; fuel system components e.g. tank, petrol filter, air filter, supply/pressure pump, pressure regulator, injectors

Diesel combustion process: fuel principles e.g. composition of diesel, characteristics of diesel, air/fuel ratio; combustion process e.g. phases, delay, combustion/flame spread, spontaneous/direct burning, pressure/crank angle diagrams, diesel knock; exhaust emissions e.g. normal, excess air, excess fuel, effects of pollutants; fuel supply method e.g. rotary, inline, unit injector; fuel system components e.g. low pressure (tank, filter(s), supply pump), high pressure (in-line pump, governor, injector, cold start arrangements)

Alternative fuel/power: systems e.g. electric, liquefied petroleum gas (LPG), natural gas, hydrogen, hybrid; adapted/additional components e.g. batteries, fuel tank, additional modifications, cooling system, management control system, performance; legislation e.g. emissions, tax, health and safety

3 **Understand the principles of operation of engine cooling and lubrication systems**

Engine cooling systems: types of system e.g. air-cooled (cylinder construction, fan, shutters, thermostat), water-cooled (radiator, radiator cap, expansion tank, water pump, viscous/electric/mechanical fans, thermostat, hoses, types of coolant, level indication, anti-freeze protection, effects and prevention of corrosion); cooling control systems e.g. engine temperature sensor, ambient air temperature sensor, thermostatic control valves (mechanical and electrical), cooling air flow control (air flow control via flap for warm up); engine management system e.g. overheating, fuel cut-off

Engine lubrication system: system components e.g. wet/dry sumps, oil pump, pressure relief valve; engine oil types and filtration methods e.g. viscosity, Society of Automotive Engineers (SAE) rating, multi-grade oil; filters e.g. full flow or bypass; lubrication control systems e.g. sensors, level indicator (mechanical, electrical); pressure sensors e.g. absolute and gauge or lamp; low pressure safety system e.g. engine management system fuel cut-off

4 **Be able to carry out engine service and repair procedures**

Routine engine service: procedures e.g. changing engine lubricant, filters (air, lubricant, fuel), checking and adjusting engine timing (ignition, camshaft); working to instructions e.g. manufacturer's service schedules/data, dealership work schedules/job cards; use of tools and equipment e.g. hand tools, vehicle lift equipment, oil drainer, on-board service indicators; safe working procedures e.g. personal and vehicle protection (personal protective equipment, vehicle covers, mats); Control of Substances Hazardous to Health (COSHH) Regulations; safe disposal of waste products

Major engine repair: procedures e.g. strip and inspect bore and crankshaft journals for wear, cylinder head for distortion, valves for seating and damage; working to instructions e.g. manufacturer's repair manuals, web-based information, dealership work schedules/job cards/supervisor's instructions; use of tools and equipment e.g. engine crane, chains, slings, torque wrenches, micrometers, dial test indicators (DTI), timing tools, locking devices, cleaning equipment; safe working procedures e.g. personal and vehicle protection (personal protective equipment, vehicle covers, mats), manual handling, use of lifting and support equipment, use of cleaning solvents; safe disposal of waste products

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 explain the operating cycles of two different internal combustion engines	M1 compare the advantages and disadvantages of the design and performance of two different engine configurations and layouts	D1 evaluate the suitability of an engine used for a current vehicle application, in terms of its layout, operation and performance
P2 explain the vehicle design and performance implications of an engine's configuration and layout		
P3 explain the function, operation and construction of the components/ assemblies of one type of engine		
P4 explain the effects of different air-fuel ratios on the petrol combustion process and exhaust emissions		
P5 explain the diesel combustion process		
P6 describe an application of an alternative fuel/power supply system	M2 compare a conventional fuel system with that of an alternative fuel/power source.	
P7 explain the principles of operation and difference between an	M3 compare the advantages and disadvantages of two	

air-cooled and a water-cooled engine	different engines in terms of their fuel, cooling and lubrication systems	
P8 explain the layout, system components and operation of two different engine lubrication systems		
P9 carry out a routine engine service by following given instructions		
P10 prepare a work schedule for a major engine repair procedure	M4 carry out the repair procedure in line with the schedule	D2 evaluate the effectiveness of the work schedule.

Essential guidance for tutors

Assessment

Tutors should design a varied assessment strategy that could include research and investigate tasks, set piece service/repair activities and technical reporting.

While assessment methods must reflect the unit content, they should also recognise the need to keep up to date with current components, systems, applications and working practices. The examples given in the unit content reflect current practice but could be replaced with more relevant and up-to-date examples as technology changes, without affecting content coverage. For example, the content for lubrication control systems has the examples 'sensors, level indicator (mechanical, electrical)' but advances in digital/computer-based engine management systems could make mechanical sensors obsolete in the not too distant future.

There are no fixed ways in which the unit should be assessed or the number of assessment instruments that might be used. The maximum number of assignments is likely to be five, one for each of the first three learning outcomes and two for the last. However, there are strong links between all the pass criteria and across the merit and distinction criteria. Tutors should endeavour to make the most of these links to keep the number of assessment instruments to a minimum.

One approach might be to design two project-style assignments that run in parallel to each other. Each project would focus on a particular engine and learners would study the engine's operating cycle, configuration and layout, combustion process, cooling and lubrication systems. They would then carry out a routine service on one engine and a major repair on the other.

To meet all the requirements of the criteria, one engine should use petrol combustion and the other diesel. One allowance on this would be to incorporate an alternative fuel such as LPG. Special considerations within the project brief would need to be applied to P2 and P3, which only need to be covered for one engine (although the configuration and layout of the second engine would need to be considered to achieve M1). Additional tasks would probably need to be included in the project brief to enable learners to achieve P6 (alternative fuel/power supply system), and P7 (differences in operation of an air- and a water-cooled engine). P6 could be achieved through a 'what if' scenario within one of the projects (for example consider an alternative fuel/power supply system for the vehicle being considered). P7 could be achieved by ensuring that one engine is air-cooled and the other water-cooled. However, as this situation is unlikely to occur, a 'what if' scenario could also be set within one of the projects (for example if the water-cooled engine had been air-cooled then explain the principles of operation and differences that would apply).

Running the two projects in parallel would ensure that assessment could follow delivery and also that the criteria would not need to be fragmented (i.e. visited twice at different times before they could be achieved). Opportunities to achieve the merit and distinction criteria could also be built into the projects with some imagination and careful planning.

Whatever form of assessment is used, the tasks set will need to ensure that for P1 learners are able to explain the operating cycles of two different internal combustion engines (i.e. selecting two from the list of examples in the unit content). For each engine, learners should explain the engine's operating cycle by using suitable diagrams to indicate pressure-volume within the cycle, engine performance (torque/power) and engine efficiencies (for example engine timing, pressure charging and applicable compression ratios).

For P2, learners must be able to explain the vehicle design and performance implications of an engine's configuration and layout. They need to take into account the orientation (longitudinal/transverse), position of engine (front, mid and rear), cylinder arrangement, cylinder configuration, the purpose for which the vehicle has been designed and its expected performance (see examples in the unit content). The key question for learners to address and consider is – why that engine for that vehicle?

To achieve P3 learners need to explain the function, operation and construction of the components/assemblies of one type of engine (for example a four-stroke SI engine or a four-stroke CI engine). Their explanation should include details of the engine's main components and assemblies (i.e. cylinder block, cylinder head, flywheel, inlet and exhaust manifolds).

Criteria P4, P5 and P6 focus on fuel systems. For P4, learners need to focus on a petrol engine and explain the effects of different air/fuel ratios on the petrol combustion process and exhaust emissions. This should include an introduction to fuel principles (for example composition of petrol, characteristics of petrol, composition of air, air/fuel ratio, lambda ratio) the combustion process, effects of pollutants and causes of undesirable symptoms. Learners should also consider the fuel supply method and fuel system components (for example tank, petrol filter, air filter). This could be set within the context of the particular petrol engine/vehicle being studied.

A similar approach is required for P5, but this time learners need to explain the diesel combustion process. Learners should explain diesel fuel principles, the combustion process, exhaust emissions, fuel supply method and fuel system components for either low pressure or high pressure diesel fuel systems.

For P6, learners must describe an application of an alternative fuel/power supply system. This can either be given by the tutor or chosen by the learner.

Learners should describe the system (for example LPG, natural gas, hydrogen, hybrid) and how traditional components have been adapted and/or any necessary additional components. They should also describe the relevant aspects of legislation that apply to these alternative fuel/power supplies. This should be set within the context of a particular vehicle.

P7 and P8 are closely linked and require learners to consider the fundamental differences between common cooling and lubrication systems. They can also be extended through to M3.

For P7, learners need to explain the principles of operation of and the differences between an air- and a water-cooled engine. Learners need to identify the types of system being considered (for example for an air cooled engine the cylinder construction, fan, shutters etc, for a water cooled engine the radiator, radiator cap, expansion tank etc). For each engine learners will need to consider the cooling control systems used and the relevant aspects of the engine management system with respect to engine cooling.

For P8, learners need to explain the system components, layout and operation of two different engine lubrication systems. This should include the respective system components (for example wet/dry sumps, oil pump, pressure relief valve), engine oil types and filtration methods, lubrication control systems, pressure sensors and low pressure safety system.

P9 and P10 form the focus of the practical assessment for this unit. Learners need to carry out a routine engine service and a major engine repair following given instructions. Examples of typical routine servicing and major repairs are given in the unit content, although these are not exclusive. Other service activities or repairs of an equivalent level of difficulty would be acceptable.

Assessment evidence for P9 and P10 is likely to be in the form of the learner's personal log/record of the work undertaken plus relevant tutor observation records. Learners may also wish to use suitably annotated photographic evidence to support both their log/record and tutor observation. The evidence must indicate the service and repair procedures carried out, the instructions followed, the tools and equipment used and the safe working procedures followed, including safe disposal of waste products.

To achieve M1, learners need to further consider the design and performance of two different engine configurations and layouts by comparing the advantages and disadvantages of each.

For M2, learners must compare a conventional fuel system with that of an alternative fuel/power source. This can be linked with the work undertaken for P4, P5 and P6. The comparison should be in terms of the same aspects covered for the pass criteria (for example the fuel/power principles, combustion process, adapted/additional components, effects of pollutants/causes of undesirable emissions, fuel/power supply methods, fuel/power system components, relevant legislation). Again, evidence for this criterion is likely to be in the form of a written report and learners may make use of suitable images, as detailed for D1 below.

To achieve M3, learners need to build on their understanding of fuel, cooling and lubrication systems (P4 to P8) to compare the advantages and disadvantages of two engines with respect to these systems.

For M4, learners need to prepare a work schedule for a major engine repair procedure, carry out the repair and evaluate the effectiveness of the work schedule. Learners are expected to carry out a second (and different) major engine repair to achieve the merit criterion. It is not sufficient for learners just to prepare the work schedule and carry out a single repair in order to achieve P10 and M4. The object of the assessment at pass level is to establish whether learners can competently complete a given major repair under supervision/guidance. However, at merit level they are expected to demonstrate independence and reflection. This can be extended to incorporate an evaluation of the effectiveness of the work schedule (D2).

For D1, learners need to evaluate the suitability of an engine for a current vehicle application. This should be done in terms of the engine's layout, operation and performance. It is expected that the evidence presented will include a detailed evaluation of the particular vehicle's engine (for example type, power, layout, main components, fuel, lubrication systems). Having evaluated the engine in this way learners should then arrive at a reasoned justification for the manufacturer's choice based on their own findings.

Evidence for D1 is most likely to be in a written format but learners could also include diagrams, photographs or other visual means to illustrate their work. Where images are not learners' own work credit must be given to the originator. Learners should suitably annotate these images to indicate how they support their report.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Principles and Operation of Engines	A technician needs to explain to a new learner the different internal combustion cycles, the design and performance implications of an engine layout and the operation and construction of the components and sub-assemblies	A written report supported by relevant annotated diagrams
P4, P5, P6, M2	Fuel Systems	A technician needs to explain the differences between diesel, petrol and alternative fuel systems to a learner	A written report/presentation supported by relevant annotated diagrams
P7, P8, M3	Cooling and Lubrication Systems	An learner needs to investigate a vehicle's cooling and lubrication systems	A written report supported by relevant annotated diagrams
P9	Routine Engine Servicing	A technician needs to carry out a routine engine service to give the opportunity of vocational tasks in employment	Workshop practical activity with associated documentary evidence to reflect industrial methods and standards. Observation Records and annotated photographs would also be suitable supporting evidence.

P10, M4, D2	Major Engine Repair Procedures	A technician needs to carry out a major engine repair	Workshop practical activity with associated documentary evidence and a written evaluation to include data collation aligned to full list of tools and equipment utilised. Observation Records and annotated photographs would also be suitable supporting evidence.

Essential resources

Centres will need to provide learners with access to a suitable workshop, equipped to modern standards with live vehicles, test rigs and components that reflect current technology and working practices.

Indicative reading for learners

Textbooks

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney, M — *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 45: Vehicle System Fault Diagnosis and Rectification

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Although technological advances have led to increasingly reliable mechanical, electrical and electronic vehicle systems, for a variety of reasons these systems still fail. When a fault develops it is more important than ever, from an operational, safety and often a legal standpoint, to carry out a quality repair.

Learners will be expected to diagnose and undertake work on faults in vehicle mechanical and electrical/electronic systems regardless of the manufacturer or vehicle type (for example light or heavy vehicle, passenger carrying vehicle, motorsport vehicles). Learners will identify, select and use a range of diagnostic tools and equipment, checking that they are in a safe and useable condition before use.

For the purpose of this unit, a fault may be considered to be a component failure or system malfunction relating to mechanical or electrical and electronic systems, individually or in combination.

When diagnosing faults, learners will need to work in a logical manner, working to instructions obtained from appropriate sources. Safe working practices and good housekeeping are a recurrent theme throughout the unit.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to identify vehicle system faults

2 Be able to prepare and use diagnostic equipment and procedures to identify and confirm faults

3 Know alternative rectification procedures

4 Be able to rectify faults and confirm system integrity.

Unit content

1 **Be able to identify vehicle system faults**

Mechanical system: systems e.g. engine (pistons, belts, chains, bearings, shafts), ancillary systems (fuel, lubrication, cooling), transmission (clutch, torque converter, gearbox, rear axle, differential), steering and suspension, braking; faults e.g. internal engine component failure, failed head gasket, failed seal, fuel blockage, contamination (oil, fuel, coolant, hydraulic and pneumatic fluid), non-starting, low/high oil pressure, faulty coolant system, clutch malfunction, damaged clutch linkages, bearing failure (engine, clutch, pump, rear axle/differential), selector mechanisms malfunction, gear selection difficult, faulty torque converter hydraulic components, worn gear, worn drive shaft/joint, misalignment (drive shafts, steering/suspension), defective steering/suspension components, inoperative braking system (faulty caliper, worn disc); symptoms e.g. unusual sounds, noisy bearings, leaks, smoke, metallic particles in lubricants, loss of power, exhaust gas contamination, misfire, engine overheating/overcooling, water contamination, clutch (slip, grab, judder, difficult selection), vibration, unusual tyre wear, poor brake efficiency, brake noise and judder, braking imbalance, excessive brake pedal travel, poor road handling, oversteer, understeer

Electrical/electronic system: systems e.g. starting, charging, ignition, lighting and auxiliary, control systems (electronic, instrumentation, engine); faults e.g. starting system sluggish or non-operational, battery faults, alternator malfunctioning, diode faults, electronic control not working, fuse problems, damaged or loose wire, inoperative ignition components, ignition timing faults, inoperative systems, headlamp misalignment, instrumentation malfunction, driver information malfunction, engine management malfunction, chassis control system malfunction (Anti-lock Braking System (ABS), stability control, transmission control), security and alarm systems failure; symptoms e.g. noisy operation, no charge, over charging, short circuit, open circuit, misfire, non-starting, incorrect information, inaccurate displays, confused control

2 **Be able to prepare and use diagnostic equipment and procedures to identify and confirm faults**

Preparation: adherence to regulations e.g. Provision and Use of Work Equipment Regulations (PUWER) 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013, Health and Safety (First Aid) Regulations 1981, motorsport specific; positioning e.g. use of ramps, jacks, stands; vehicle protection e.g. covers, sheeting; component/system access e.g. removal of bodywork, fairings and covers, removal of excessive oil, dust, grease and dirt, competition/road debris

Diagnostic equipment: mechanical equipment e.g. dial gauges, micrometers, feeler gauges, pressure gauges, specialist equipment e.g. auto transmission test equipment, steering geometry and suspension alignment equipment, wheel balancing and brake testing equipment; electrical and electronic equipment e.g. meters, multimeters, oscilloscopes, diagnostic analysers, data logging/self-diagnosis equipment, emissions testers, computer systems

Diagnostic procedures: reference to considerations of safety and vehicle/system protection; procedures e.g. visual, aural, performance monitoring, road and roller tests, procedures used with electrical, electronic and systems diagnostic equipment; assessing vehicle information systems and data in a variety of formats e.g. workshop manuals, diagnostic information, CD ROMs, IT-based data retrieval systems and fault code analysers

3 **Know alternative rectification procedures**

Rectification procedures: e.g.

- dismantling, inspection and assessment: comparison against specifications (manufacturer, vehicle data, auto data, computer-based systems), factors influencing rectification choice (operational, cost, safety and legal requirements)
- adjustments: associated with the range of vehicle systems, manufacturers' specifications (tolerances, operational limits), safety, performance and legal considerations
- replacement: using new, overhauled and factory or third party reconditioned components and units
- repair: in-house or third-party specialist repair options, comparison of cost of replacement/repair including consideration of service life expectancy, reliability and warranty status
- substitution/alteration: use of adapted, redesigned or re-engineered components and/or units and effects of substitution (based on comparisons of specifications, manufacturers' bulletins, safety and service recommendations)

4 **Be able to rectify faults and confirm system integrity**

Rectify faults associated with mechanical systems: e.g. engine and ancillary systems, transmission, steering, wheels and tyres, suspension and braking systems

Rectify typical faults associated with electrical/electronic systems: e.g. starting, charging, ignition, lighting and auxiliary systems, vehicle instrumentation, driver information, engine management, chassis control (ABS, stability control, transmission control), security, driver information and alarm

Equipment: hand tools; MOT equipment; product specific equipment; for mechanical systems e.g. measuring equipment, analysers, on-board diagnostics, alignment equipment, balancing equipment; for electrical/electronic systems e.g. scanning equipment meters

Documentation to confirm system integrity: manufacturers' specifications and data; legal requirements; performance test data

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 diagnose two mechanical system faults on two different vehicles from given symptoms	M1 justify the use of the equipment chosen to diagnose selected system faults with reference to the expected accuracy of the results obtained	D1 evaluate the use of diagnostic test equipment
P2 diagnose two electrical system faults on two different vehicles from given symptoms	M2 compare the advantages and disadvantages of two diagnostic procedures	
P3 prepare two vehicles for fault diagnosis		
P4 use appropriate diagnostic equipment and procedures to diagnose faults on two different mechanical systems on two different vehicles		

P5 use appropriate diagnostic equipment and procedures to diagnose faults on two different electrical systems on two different vehicles		
P6 describe an alternative rectification procedure for two faults on different mechanical systems		
P7 describe an alternative rectification procedure for two faults on different electrical/ electronic systems		
P8 carry out rectification procedures on two different faulty mechanical systems, conforming with manufacturers' specifications and safety and legal requirements	M3 justify the selection of a rectification procedure in terms of safety, cost, performance and legal considerations.	D2 evaluate one rectification procedure carried out and make recommendations for improvement.
P9 carry out rectification procedures on two different faulty electrical/electronic systems, conforming with manufacturers' specifications and safety and legal requirements		
P10 use appropriate equipment, procedures and documentation to confirm system integrity		

Essential guidance for tutors

Assessment

This unit is likely to be assessed through a combination of assignments and practical workshop investigations.

It is expected that learners will have carried out practical work on vehicles to support their underpinning knowledge. Evidence will include test data, printouts and records of diagnostic procedures carried out supported by witness statements/observation records supplemented by annotated photographs.

The emphasis of this unit is on developing practical fault diagnostic and rectification skills across a range of mechanical and electrical/electronic vehicle systems. Learners should be given opportunities to diagnose typical faults, recommend repair strategies and carry out fault rectification. This should be based on diagnostic information and other criteria such as safety, cost, operational and legal requirements. It is expected that learners will be given opportunities to use and compare alternative diagnostic procedures and equipment in practical situations.

To achieve the pass criteria associated with learning outcome 1 (P1 and P2) learners should diagnose faults on two mechanical and two electrical systems, on two different vehicles from given symptoms. This means there will be a total of eight faults to diagnose. It is likely that only one symptom for each fault will be sufficient. However it may be beneficial to learners if more symptoms can be given or arranged.

For P3, learners will need to prepare two vehicles for fault diagnostic checking. They will then need to diagnose faults on two mechanical systems (P4) and on two electrical systems (P5), on two different vehicles faults prior to rectification. Learners should be able to select and access sources of data to help with the fault diagnosis and also select, prepare and use the appropriate diagnostic equipment to carry out the tasks.

To achieve P6 and P7, learners need to describe an alternative rectification procedure for faults on two mechanical systems and two electrical/electronic systems. Although the rectification procedures described for the two electrical/electronic systems or two mechanical systems need to be different, procedures described for P6 can be used again in P7. The rectification strategies described could relate back to the different faults identified for P1 and P2.

For P8 and P9, learners will apply their knowledge by carrying out the rectification process, conforming to the manufacturer’s specifications, safety and legal requirements, for two different mechanical and two different electrical/electronic systems.

When confirming system integrity for P10, the equipment that could be used is listed within the unit content under learning outcome 4, although other equipment, such as that listed under learning outcome 2 as diagnostic equipment, is also appropriate. Confirmation of system integrity should include comparing results against manufacturers’ specifications and data, legal requirements and performance test data.

Throughout the assignments it is expected that the faults will be on different systems and may be on different vehicles at different times. The vehicles could, however, be of the same type (for example both goods vehicles and motorsports vehicles if this is appropriate) or different types. The intention is to give learners experience of a diverse range of vehicle system faults across different vehicles so that they have the opportunity to satisfy all the grading criteria with sufficient depth and rigour.

To achieve M1, learners should justify the use of the equipment selected to diagnose system faults, with reference to the expected accuracy of the results obtained.

This should demonstrate learners' ability to progress from knowing how to select and use the equipment to justifying the reasons for using the correct equipment and possible consequences of not doing so.

For M2, learners should compare the advantages and disadvantages of alternative diagnostic procedures, including the use of dedicated test equipment within the context of the fault diagnosis being carried out. Learners should also be able to justify the selection of a rectification procedure (M3) in terms of safety, cost, performance and legal considerations. All responses to tasks set for the merit criteria are likely to be in the form of written outcomes.

To achieve a distinction, learners should evaluate the use of diagnostic test equipment giving reasons for the advantages and disadvantages (D1). Learners will also need to evaluate a vehicle rectification procedure and make recommendations for improvement (D2).These criteria can be met through responses to written tasks after all pass criteria have been carried out and data obtained from the practical tasks for D1.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, P5, M1, M2, D1	Identifying and Diagnosing Faults	A vehicle technician needs to diagnose and diagnose vehicle system faults using diagnostic equipment	Practical work evidenced through records/log of work carried out and observation records
P6, P7	Alternative Rectification Procedures	A vehicle technician needs to propose alternative rectification procedures to be used for vehicle system faults	Written task
P8, P9, P10, M3, D2	Rectifying Faults	A vehicle technician has to rectify faults and confirm system integrity	Practical work evidenced through records/log of work carried out and observation records

Essential resources

A range of vehicle types and equipment is needed for delivery of this unit. This will include manufacturer/vehicle-specific equipment (e.g. for engine management, ABS, security and other advanced systems) and non-manufacturer/vehicle-specific equipment (e.g. meters, oscilloscopes). A variety of data sources will also be required to support the range of vehicles, systems, equipment and procedures used.

Indicative reading for learners

Textbooks

Bonnick A — *Vehicle Electronic Systems and Fault Diagnosis* (Routledge, 1998) ISBN 9780340706305

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney, M — *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 46: Applications of Vehicle Science and Mathematics

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

This unit will develop learner knowledge of mathematical and scientific principles and their application in the vehicle technology environment. This can be in a variety of vocational areas, such as the fine detail needed in the calculations in motorsport or the crucial calculations required when working with large commercial vehicles.

Learners will carry out data collection and manipulation in vehicle-related areas such as speed, acceleration and power. They will also complete a variety of practical activities including carrying out an engine performance test and comparing the outcomes to scientific calculations.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to apply mathematical and statistical methods to vehicle-related tasks

2 Be able to apply fundamental algebraic laws and trigonometric ratios to solve vehicle-related tasks

3 Be able to apply scientific principles related to heat, force and machines to solve vehicle-related tasks

4 Be able to carry out engine testing and apply scientific principles to determine vehicle and engine performance.

Unit content

1 **Be able to apply mathematical and statistical methods to vehicle-related tasks**

Data for vehicle-related tasks: data e.g. engine speed, stopping distance, miles per gallon, brake pad life, vehicle speed, acceleration, wheel bearing life; sources e.g. manufacturers, workshop experiments, publicly available figures,(such as media, internet); considerations e.g. types of error, accuracy, representation

Mathematical methods: methods e.g. addition, subtraction, multiplication, division, use of brackets, order, estimation techniques, use of calculators, expressing numbers using standard form and scientific notation e.g. 5.6×10^5, 12×10^3W, 12 kW; features e.g. ratio and proportion, percentage, real and integer numbers, binary systems, vulgar and decimal fractions, ratios, direct and inverse proportion, roots and powers (such as $v = \sqrt{2gh}$, $I = \sqrt{P/R}$, $s = ut + ½at^2$, $v^2 = u^2 + 2as$, if $½mv^2 = mgh$ find v)

Data manipulation and graphical representation: data represented in graphical format e.g. bar charts, pie charts, frequency distributions, class boundaries and class width, frequency table, variables (discrete and continuous); histogram (continuous and discrete variants); cumulative frequency curves

Statistical information: arithmetic mean; median; mode; discrete and grouped data

2 **Be able to apply fundamental algebraic laws and trigonometric ratios to solve vehicle-related tasks**

Linear equations and graphs: linear equations e.g. $y = mx + c$; straight line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line); quadratic graph y= a$ax^2 + bx + c$;

Factorisation and quadratics: multiply expressions in brackets by a number, symbol or by another expression in a bracket; by extraction of a common factor e.g. $ax + ay$, $a(x + 2) + b(x + 2)$; by grouping e.g. $ax - ay + bx - by$; quadratic expressions e.g. $a^2 + 2ab + b^2$; roots of an equation e.g. quadratic equations with real roots by factorisation, and by the use of formula;

Trigonometric ratios: basic ratios e.g. sine, cosine, tangent; $\text{Sin}\theta/\text{Cos}\theta = \text{Tan}\theta$

Vehicle-related tasks: algebraic application e.g. Ohm's law, pair of simultaneous linear equations in two unknowns (two linear or one linear and one quadratic), acceleration 30 to 50 mph, time taken to cover a given distance when subjected to constant acceleration, volume and area of combined shapes e.g. swept, clearance volume, loading capacity, workshop areas; trigonometric application e.g. steering and suspension angles, valve timing, wiper motion angles

3 **Be able to apply scientific principles related to heat, force and machines to solve vehicle-related tasks**

Force: laws of friction; friction in a clutch; stress and strain; Young's modulus; forces in tension/compression; vehicle component subjected to tension/compression e.g. tie rod, cylinder head bolt, push rod, valve stem, piston, connecting rod, braking components

Heat: gas laws e.g. Boyle's law, Charles' law, general gas equation $pV/T = C$, ideal gas equation $pV = mRT$; change of dimension e.g. linear, superficial, cubical, heat dissipation; pressure e.g. hydraulic, gas; gauge pressure, atmospheric pressure

Machines: ratios e.g. steering box, gear ratio, final drive ratio, compression ratio; vehicle mechanism e.g. alternator and power steering, pulleys, winches, levers, brake operation, cylinder, gearbox

4 **Be able to carry out engine testing and apply scientific principles to determine vehicle and engine performance**

Vehicle performance: equations of motion; Newton's laws; performance e.g. work, power, velocity, acceleration, retardation

Engine testing: safe use of equipment e.g. rolling road, dynamometer rig, engine analyser; collection of data e.g. torque, power (indicated and brake), fuel consumption

Engine performance: performance to report on e.g. torque, power (indicated and brake), mechanical efficiency, thermal efficiency, volumetric efficiency, specific fuel consumption, brake mean effective pressure, indicated mean effective pressure; presentation within report e.g. engine indicator diagrams, calculations using data (such as efficiency, frictional loss, temperature variations)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 explain what should be considered before using data gathered from different sources		
P2 use mathematical methods for different features to manipulate collected data and present statistical information in a graphical format		
P3 solve a linear equation by plotting a straight line graph, using given experimental data, and use it to deduce the gradient, intercept and equation of the line for a vehicle-related task	M1 solve a pair of simultaneous linear equations in two unknowns	D1 solve a pair of simultaneous equations, one linear and one quadratic, in two unknowns
P4 factorise by extraction and grouping of a common factor from expressions with two, three and four terms respectively	M2 solve a quadratic equation by factorisation and one by the formula method	
P5 use trigonometric ratios to solve two vehicle-related tasks		

P6 use the laws of friction to find the friction in a clutch		
P7 determine Young's modulus for a given tension/compression on a given vehicle component		
P8 use a gas law to determine the change in dimensions of the gas		
P9 describe how ratios help a given vehicle mechanism function properly		
P10 calculate vehicle performance using Newton's laws and the equations of motion	M3 explain, with examples, the importance of the accuracy of data that is used to solve a range of problems related to engine and vehicle performance.	D2 compare actual data and calculated data for engine or vehicle performance.
P11 carry out engine testing to obtain data and report on engine performance.		

Essential guidance for tutors

Assessment

For P1, the collation of data should be made vocationally relevant by using vehicle-related subject areas such as engine power to stroke or fuel consumption to capacity. A variety of sources should be used, for example manufacturers' or internet sites. An explanation of the considerations to be taken into account before using the data should be included.

For P2, the methods (for example add, subtract etc) and features (for example ratio or percentages etc) need to be completed prior to graphical presentation. This can be in a variety of formats (for example bar and pie charts, frequency distribution tables). This could be achieved by using computer-based software packages, although care must be taken to ensure authenticity of the evidence provided. Learners need to calculate mean, median and mode for discrete and grouped data. The graphical format used must include at least one from bar charts, pie charts, frequency distributions, and frequency table. It should also include a histogram (continuous and discrete variants) and a cumulative frequency curve.

The evidence for P3 could be generated using vehicle speed and timing and the task set should ensure that gradient, intercept and the equation of the line can be presented in the evidence. P4 should also use vehicle-related formulae where possible.

Assessment of M1 and M2 can be linked to that for P3 and P4. If a vehicle context is difficult to apply, then P4, M1 and M2 could be achieved through a purely mathematical context. However, P4 will require a range of tasks that allows expressions with two, three and four terms. Each task is therefore likely to have a different vehicle-related algebraic application or mathematical scenario.

For P5, the use of steering geometry or piston displacement could give vocational relevance when using one basic ratio and $\text{Sin}\theta/\text{Cos}\theta = \text{Tan}\theta$ to calculate angles and length of steering components. This could be integrated with other units that cover vehicle componentry applications.

The evidence for P6 and P7 would naturally link to clutch or brake linings and the use of components for applying loads, such as handbrake cables, to determine Young's modulus.

Assessment of P8 could be integrated with that of other units. The task used should focus on vocational gas applications, such as within engine technology, suspension or brake systems. The task should enable learners to use one of the gas laws outlined in the unit content and must include data on pressure.

Using a system application such as the handbrake, complete with its lever mechanism, would enable learners to generate evidence for P9. There needs to be clear direction to ensure that responses include a description of how mechanical ratios help the system function.

For P10, learners will need to produce evidence of calculating vehicle performance using Newton's laws and the equations of motion. This should be contextualised to their intended vocational area (for example light vehicle, heavy vehicle, motorsport).

For P11, learners will need to complete engine testing to obtain a range of performance data, as set out in the unit content. Assessment of P11 could be linked to that for M3 and D1 and would need to be completed after achievement of P1.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Mathematical and Statistical Methods	A vehicle technician needs to use mathematical methods and gather and manipulate data	Written responses to set tasks
P3, P4, P5, M1, M2	Algebraic Laws and Trigonometric Ratios	A vehicle technician needs to use algebraic laws and trigonometry	Written responses to set tasks
P6, P7, P8, P9	Heat, Force and Machines	A vehicle technician needs to use the laws of friction, gas laws and ratios	Written responses to set tasks
P10, P11, M3, D1	Vehicle and Engine Performance	A vehicle technician needs to calculate vehicle performance and carry out engine testing	Written responses to set tasks and a report of engine performance based on practical engine testing

Essential resources

As a minimum, centres will need to provide learners with access to workshop facilities to enable practical investigation and assessment of friction, Young's modulus, ratios, measuring bores and complete calculations linked to gas laws etc.

Indicative reading for learners

Bonnick A — *Automotive Science and Mathematics* (Routledge, 2008) ISBN 9780750685221

Greer A, Fuller A and Taylor GW — *BTEC National Mathematics for Technicians* (Nelson Thornes, 2004) ISBN 9780748779499

Twigg P — *Science for Motor Vehicle Engineers* (Elsevier, 1995) ISBN 9780340645277

Unit 47: Electrical and Electronic Principles for Vehicle Technology

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

In this unit learners will gain an understanding of electrical and electronic principles through the analysis of direct current (DC) motor vehicle electrical circuits. Learners will also be introduced to the principles and properties of magnetism as applied to motor vehicle circuit devices.

Learners will then examine the concepts of digital electronic principles and microprocessor applications in motor vehicles. Finally, learners will be introduced to single-phase alternating current (AC) theory as applied to vehicle alternators. They will consider waveform characteristics and determine the values (using phasor and algebraic representation and actual waveform measurements using an oscilloscope) of alternating quantities.

This unit has been designed to encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) motor vehicle circuits

2 Understand the principles, properties and applications of magnetism in motor vehicle technology

3 Know the concepts of digital principles and applications of microprocessors in motor vehicles

4 Be able to use single-phase alternating current (AC) theory to determine vehicle alternator performance.

Unit content

1 **Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) motor vehicle circuits**

DC circuit theory: voltage e.g. potential difference, electromotive force (emf); resistance e.g. conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source e.g. battery, stabilised power supply; resistors e.g. function, types, values, colour coding; diodes e.g. types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae e.g. V = IR, P = IV, W = Pt; application of Kirchoff's voltage and current laws

DC motor vehicle circuits: circuits to include a DC power source, four components including circuit protection and switching arrangement; vehicle applications e.g. lighting circuits (side and rear lamp, main and dip headlamp, front and rear fog lamps, stop lamp, reverse lamp, indicator and hazard warning system), auxiliary circuits (horn, window winding, central locking, interior heater, rear screen heater), vehicle security systems, air-conditioning, use of relays, circuit protection devices (DC power source circuit protection fuse and resistors (series/parallel)), operating component(s) such as motor assembly; diode resistor circuit with DC power source, series resistors and diodes e.g. bulb failure circuit, low oil pressure circuits, alternator rectifier

Measurements in DC motor vehicle circuits: safe use of a multimeter e.g. setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source); testing a diode's forward and reverse bias

2 **Understand the principles, properties and applications of magnetism in motor vehicle technology**

Characteristics of magnetic field: field patterns (flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops); ferromagnetic materials; reluctance; magnetic screening; hysteresis

Electromagnetic induction: principles e.g. induced emf, eddy currents, self and mutual inductance; motor vehicle applications (electric motor/generator e.g. series and shunt motor/generator, transformer e.g. primary and secondary current and voltage ratios); motor vehicle applications of Faraday and Lenz's laws e.g. electrical induction in an alternator, electromagnetic coil

3 **Know the concepts of digital principles and applications of microprocessors in motor vehicles**

Digital principles: binary system e.g. binary notation and algebra, bits and bytes, input/output (I/O) voltage levels; logic system e.g. AND, OR, NOT NAND and NOR gates; truth tables, memory circuits, sequential and clocked circuits, flip flops, read only memory (ROM)/random access memory (RAM) structures and organisation; timers; digital to analogue (D/A) and analogue to digital (A/D) converters; types of integrated circuits e.g. classification, operation, performance characteristics and identification; vehicle applications e.g. fault diagnosis, code readers, data logging, visual/audio output, speed sensor processing, engine timing control, satellite navigation

Microprocessors: microprocessor system e.g. programmes, language, I/O interface, memory; construction of microprocessor e.g. control section, arithmetic and logic sections, register section, memory, I/O section buses, fetch and execute cycle, control by clock pulses; motor vehicle application of microprocessors e.g. engine management, antilock braking systems (ABS), climate control, suspension settings, transmission modes

4 **Be able to use single-phase alternating current (AC) theory to determine vehicle alternator performance**

Single-phase AC circuit theory: waveform characteristics e.g. sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities e.g. graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure resistor (R), inductor (L) and capacitor (C) components

Alternator performance: safe use of an oscilloscope e.g. setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 use DC circuit theory to calculate current, voltage and resistance in three different motor vehicle circuits	M1 use Kirchoff's laws to determine voltage and current in a motor vehicle circuit that has at least five nodes and the power dissipated in a load resistor containing two voltage sources	
P2 use a multimeter to carry out circuit measurements in three different DC motor vehicle circuits		
P3 describe the forward and reverse characteristics of two different types of semi-conductor diode		
P4 describe the characteristics of a magnetic field		
P5 explain the relationship between flux density (B) and field strength (H)		
P6 describe how the principles of electromagnetic induction apply to a given motor vehicle application	M2 explain the application of electromagnetic induction in vehicle motors and generators	D1 evaluate the performance of a motor and a generator used within a motor vehicle system by reference to electrical and electronic theory.

P7 describe two different vehicle system applications of digital principles		
P8 describe the function and operation of two different vehicle system integrated circuits		
P9 describe the function and operation of a vehicle system microprocessor	M3 compare the function and principles of operation of two different vehicle applications of microprocessors	
P10 use single-phase AC circuit theory to explain and determine the characteristics of a sinusoidal AC waveform	M4 compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram.	D2 analyse the operation and the effects of varying component parameters of a motor vehicle power supply circuit that includes at least a transformer, diode and resistor
P11 use an oscilloscope to measure and determine the performance of a vehicle alternator		

Essential guidance for tutors

Assessment

Much of the evidence for the pass criteria could be generated through practical experimentation and investigation with real components and circuits and computer-based software packages.

It is likely that at least five assessment instruments will be needed for this unit. If practical work and tests are also used then the total number of pieces of assessed work could be more. This should be considered carefully so as to not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. Alternatively, practical work could be observed by the tutor/witness and a record of observation used for assessment evidence. Both of these methods will help in ensuring authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Evidence of the use of DC circuit theory to calculate current, voltage and resistance in three different motor vehicle circuits (P1) could be produced by using paper- or computer-based methods. Between them, the three motor vehicle circuits need to be chosen to cover the required aspects of the unit content. However, it is essential that centres combine any testing of this sort with practical hands-on experience of real circuits and components. This could be achieved by prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement. Whichever method is used, tutors need to ensure that there is sufficient product evidence of the circuit being used/developed and the formulae selected to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where printouts do not show sufficient detail to meet the criterion.

The ability to use a multimeter to carry out circuit measurements in three different DC motor vehicle circuits (P2) will require process evidence (i.e. it will need to be observed by the tutor or assessor during relevant practical activities on motor vehicle applications). This could be the end product measurement of circuits being assessed for P1.Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The description of the forward and reverse characteristics of two different types of semiconductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box. This could be a progression from P1/P2 and could be set up on a vehicle for learners to build, test and compare against data and detail provided.

The characteristics of magnetic fields (P4) could be demonstrated on an OHP by using magnets and iron filings. Learners could sketch or be provided with a handout of the results and then make appropriate comparisons with expected theoretical results. The relationship between flux density and field strength (P5), may be set within the context and use of different materials such as silicon, iron and mild steel use in vehicles examples could include coil, relay and starter operation.

Evidence for P6 will be descriptive and learners will need to consider the movement of a conductor within a magnetic field in vehicle examples such as alternators, starters and solenoids.

For P7, learners need to describe two different vehicle system applications of digital principles. It is expected that one of these will involve the application of a binary system and the other a logic system including D/A and A/D converters, as appropriate to the particular vehicle application. There is a strong link between P7 and P8, which could be used to good effect if the vehicle system applications of digital principles (P7) enables learners to describe the function and operation of two different vehicle system integrated circuits (P8).

For P9, a practical investigation of a microprocessor application for a selected vehicle system, combined with a descriptive task, could be used. The investigation and report needs to focus on the microprocessor system being applied and its construction. Typical motor vehicle applications of microprocessors could be engine management, anti-lock braking systems, climate control, suspension settings or transmission modes.

P10 requires learners to use single phase AC circuit theory to explain and determine the characteristics of a sinusoidal AC waveform. This should include waveform characteristics and the determination of values using phasor and algebraic representation of alternating quantities. There is a useful link here with P11 and an assignment could be structured to provide a relevant link between the theory and application of AC to a vehicle.

All the merit and distinction criteria have close links with the pass criteria and tutors should try to design their assignments around these links.

M1 relates to the use of Kirchoff's laws and naturally follows on from learners' use of DC circuit theory to calculate current, voltage and resistance in P1. To achieve M1, learners need to be able use Kirchoff's laws to determine voltage and current in a motor vehicle circuit that has at least five nodes, and the power dissipated in a load resistor containing two voltage sources. Learners should be encouraged to use computer-based simulation to check their calculations.

M2 is an extension of P6 requiring an explanation of the application of electromagnetic induction in vehicle motors and generators.

M3 links to P9 and is designed to encourage learners to taker a wider and deeper look at the application of microprocessors in motor vehicles. It is important to keep in mind that the comparison should be based on the original findings for P8 (i.e. the microprocessor system being applied and its construction).

M4 is an extension of P10 and P11, for which learners will have demonstrated an ability to work with a single sinusoidal AC waveform. To achieve M4 learners need to compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram. There are possible links outside of this unit, for example to *Unit 46: Applications of Vehicle Science and Mathematics*.

D1 requires learners to evaluate the performance of a motor and a generator used within a motor vehicle system by reference to electrical and electronic theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines for example alternator output, motor applications such as door or window operating systems.

For D2, learners must analyse the operation and the effects of varying component parameters of a motor vehicle power supply circuit that includes at least a transformer, diode and a resistor. To achieve this, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of damaging a vehicle's system. This could be achieved using a function generator, alternating voltage or variable power source, along with a small isolating transformer, diode rectifiers (half wave and bridge) and load resistors in circuits such as alternator applications, bulb failure warning systems or data input devices.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P2, P3	DC Circuit Theory, Measurement and Diodes	A technician needs to complete measurements using a multimeter in a DC network and compare the characteristics of two different types of semi-conductor diode	Practical assignment evidenced by learner records and tutor observation records
P4, P5, P6, M2, D2	Magnetism, Transformers and Motor/Generators	A technician needs to explain to a new learner the characteristics of magnetism and help them evaluate the performance of a motor and generator	A written report containing diagrams, graphs and calculations
P7, P8, P9, M3	Digital Principles and Microprocessors	A technician needs to describe the vehicle system applications of digital principles, integrated circuits and microprocessors	Written responses to set tasks, carried out under controlled conditions
P10, P11, M4, D2	Single-Phase AC Theory	A technician needs to consider the characteristics of a sinusoidal AC waveform and use an oscilloscope to determine the performance of an alternator	A written report based on practical investigations

Essential resources

It is essential that learners have access to a vehicle workshop equipped with test rigs, vehicles and current electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content, together with the means to physically construct circuits. With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software for computer-based circuit simulation and analysis.

Indicative reading for learners

Textbooks

Bird J O — *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O — *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9780415662864

Denton T — *Automobile Electrical and Electronic Systems* (Routledge, 2012) ISBN 9780080969428

Unit 48: Vehicle Electrical Charging and Starting Systems

Level: 3
Unit type: Optional
Assessment type: Internal
Guided learning: 60

Unit introduction

The application of electrical technology in modern motor vehicle systems is under constant development. This has resulted in an ever-increasing electrical load being placed on a vehicle's charging and starting systems. The unit will give learners the opportunity to determine faults in a vehicle's battery, charging and starting systems, identify and confirm the specific component that has failed and undertake suitable rectification procedures.

Learners will investigate the chemical process within a battery and understand how to specify a battery for a particular vehicle. They will also gain an understanding of the operation and conversion of energy within the charging and starting systems of a modern motor vehicle. The unit will enable them to apply this knowledge to both charging and starting systems and undertake diagnostic and rectification work on a range of vehicles.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learners should:

1 Be able to specify a battery for a given motor vehicle application
2 Understand a vehicle's starting system
3 Understand a vehicle's electrical charging system
4 Be able to diagnose and rectify electrical system faults on a vehicle's charging and starting systems.

Unit content

1 **Be able to specify a battery for a given motor vehicle application**

Different battery types: Wet/Flooded - consists of all but freely suspended plates that are insulated from each other usually with the negative plate being sealed in a small polythene separator bag; Maintenance Free battery (MF) - normally a wet battery where the design keeps gassing to a minimum and includes a battery box that is sealed to keep the gases in place; Calcium-Calcium – where the antimony on both the negative and positive plates being replaced by calcium alloy; Valve Regulated Lead Acid battery (VRLA) - the battery box is designed as a small pressure vessel with safety valves; Gel - A Gel battery has some elements, usually silicon compounds, added to the acid to ensure it gelatinises and thereby guarantee that no flooded acid can leak out; Absorbed Glass Mat (AGM (Vlies)) - keeps the acid in place by the separator paper that consists of a fibreglass mat operating like a sponge

Chemical processes of lead acid batteries: chemical to electrical conversion, water to electrolyte process e.g. charge and discharge cycles, use of chemical symbols, changes to specific gravity and components chemical state; health and safety e.g. gases produced, acid content

Battery performance and construction: performance e.g. cold cranking amperage, amp/hour rating (10/20 rating); construction e.g. casing, plates (lead dioxide and spongy lead), separators; connections e.g. series/parallel, vehicle earthing, corrosion protection; electrolyte e.g. sulphuric acid, distilled water; battery calculations e.g. amp/hour system requirement, cold cranking usage, plate area, maximum load; battery specification e.g. manufacturer's recommendations, type, make, performance; specify battery by comparing system calculations/performance tests to battery capabilities

2 **Understand a vehicle's starting system**

Starting system: energy conversion e.g. electrical to mechanical rotation, rotational to linear translation; starter solenoid e.g. provide mechanical movement by use of Electromagnetic application; ignition key/push button switch e.g. provide timely electrical supply to starting system; principles of starter motor e.g. conversion of electrical energy to mechanical movement, creation and use of magnetic effect to create mechanical movement (Fleming's left hand rule)

Starting system components: electrical supply (battery); circuit protection methods e.g. fuse, immobiliser, key recognition, relay; ignition switch e.g. key or manual operation; wiring looms; warning system e.g. visual and audible; solenoid; starter motor assembly e.g. casing, magnets, armature, brush box, gear, roller clutch drive

Circuit diagrams: switched supply system; permanent feed system; recognition of circuit components/circuit symbols; types of circuit diagrams e.g. use of workshop manuals, manufacturer's diagrams, wiring diagrams and schematics

3 **Understand a vehicle's electrical charging system**

Voltage generation, rectification and regulation: function of generator e.g. alternator to create electro-motive-force using Fleming's right hand rule; system components e.g. stator, rotor, rectifier, voltage regulator, slip ring, brushes, bearings, cooling fan; warning device; bridge rectifier; drive belts e.g. single- or multi- 'V' design

Multi-phase electrical output: principles of three-phase electricity e.g. excitation, magnetic inductance, sinusoidal pattern, full wave rectification; use of oscilloscope to observe wave patterns; AC-DC voltage conversion

4 **Be able to diagnose and rectify electrical system faults on a vehicle's charging and starting systems**

Battery tests and faults: testing e.g. relative density, battery capacity, condition testing; equipment e.g. hydrometer, multimeter, dedicated test equipment, inductive amp clamp; typical battery faults e.g. dead cell, shorting out, low specific density, failing under heavy discharge, physical damage (overcharged causing heat distortion, corrosion/degradation, mechanical damage/defects)

Starting system tests and faults: system operation; circuit testing e.g. continuity, feed, voltage drop; component test e.g. ignition switch, solenoid operation, starter motor operation and internal components (armature, brushes, windings, circuit protection e.g. relays, overload relay, immobiliser); use of test equipment e.g. multimeter, dedicated test equipment, oscilloscope, inductive amp clamp; typical starting system faults e.g. internal short on armature, failed solenoid operation, inhibitor switch failed

Charging system tests and faults: system operation; circuit testing e.g. continuity, feed, voltage drop; component test e.g. diodes, bearings, rotor, windings; output test e.g. voltage, current, waveform; typical charging system faults e.g. diode failure (indicator light on), faulty voltage control (overcharging), bearing fault (noisy or excessive free play), faulty brush box/rotor (no charge); use of test equipment e.g. multimeter, dedicated test equipment, oscilloscope, inductive amp clamp

Assessment and grading criteria

In order to pass this unit, the evidence that the learners presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 describe the composition of at least three types of battery used on vehicle starting systems	M1 compare the performance characteristics of two different batteries	
P2 explain the chemical processes of a lead acid battery		
P3 perform calculations to select a battery, based on performance and construction, for a given motor vehicle application		
P4 explain the operation of a vehicle's starting system and the function of its components		
P5 use a circuit diagram to identify the electrical components of a vehicle's starting system		

P6 explain the process of voltage generation and regulation for a given vehicle application		
P7 explain the application of multi-phase electrical output in relationship to a vehicle’s charging system		
P8 carry out diagnostic tests to identify two different vehicle battery faults	M2 justify the choice of starting system diagnostic tests and rectification methods	D1 evaluate the engine electrical systems of two different vehicles in terms of the ease of carrying out diagnostic and rectification procedures.
P9 diagnose and rectify two different vehicle starting system faults	M3 justify the choice of charging system diagnostic tests and rectification methods.	
P10 diagnose and rectify two different vehicle charging system faults		

Essential guidance for tutors

Assessment

Assessment evidence is most likely to be gathered from practical work on vehicles and test rigs. Tutors will need to provide or simulate a range of system faults on vehicles to ensure authenticity of individual evidence for large groups of learners. Work-based evidence of the application of theory and fault-finding skills would also be acceptable.

P1 and P2 are linked and should be assessed together. For P1, learners will need to explain the chemical processes of a lead acid battery. In particular they should consider the chemical to electrical conversion, water to electrolyte process and relevant health and safety issues when working with a battery.

P2 requires learners to be able to consider the performance and construction of a battery for a given or chosen vehicle application. When considering performance, learners should typically look at the impact of cold cranking, other draws on the power of the battery (for example the demand from modern computer and security systems when the vehicle is idle) and issues such as amp/hour rating. When looking at construction, learners should be considering the battery's casing, plates and separators. They will also need to include how connections are achieved and electrolyte is used. The essential aspect of this criterion will be the learners's ability to perform the required battery calculations and establish the required battery specification for the application. It is expected that learners will draw from and make suitable references (for example manufacturer's recommendations, types, makes and performance capabilities) when specifying the battery and use their system calculations/performance tests to determine battery capabilities.

The assignment used for P1 and P2 could be extended to cover M1. This will require learners to compare the performance characteristics of two different batteries. One of the batteries used could be the one already dealt with for P2 and compared against another (completely different) battery.

A second assignment could be used to cover P3 and P4. This will require learners to explain the function of the components and operating principles of a vehicle's starting system (P3). The components to be covered include the battery, circuit protection methods, ignition switch, wiring looms, warning system, solenoid, starter and motor assembly. The explanation should consider the relevant energy conversion methods (for example electrical to mechanical rotation, rotational to linear translation), the operation of the starter solenoid and ignition key/push button switch and the operating principles of the starter motor. In explaining the function of components learners could also identify them using a circuit diagram in order to achieve P4.

P5 and P6 can also be linked, with learners covering the processes involved in voltage generation, rectification and regulation and the application of multi-phase output. For P5, learners will need to provide suitable explanations of the function of a generator, relevant system components and the related drive belts. P6 requires learners to explain the application of multi-phase electrical output in relationship to a vehicle's charging system. This should include the general principles of multiphase electrical output, the use of an oscilloscope to observe wave patterns (screenshots or sketches may be used to evidence the patterns observed under specific conditions), and the application of AC-DC voltage conversion in a vehicle setting.

P7, P8 and P9 will require learners to demonstrate their practical skills with respect to diagnostic tests and rectification for batteries, starter and charging systems. P7 requires learners to carry out diagnostic tests to identify two different vehicle battery faults. Assessment of rectification is not required as this would simply mean replacing the faulty battery. However P8 and P9 will require learners to carry out both diagnostic tests and rectification of two different vehicle starting system faults and two different vehicle charging systems.

The assessment of P7 could be linked back to P1 and P2. Typical battery faults might include dead cell(s), shorting out, low specific density, failing under heavy discharge or physical damage. Learners will need to select and use suitable equipment when carrying out the diagnostic tests.

For P8 and P9, the diagnostics tests should consider the respective system operation, appropriate circuit testing and component tests. The rectification procedures should be completed and systems checked to confirm integrity. Appropriate work records should also be completed.

It is likely that relevant observation records/witness statements will form the evidence of learners using a range of equipment for each system to confirm diagnosis before undertaking rectification. A short report (or logbook entry) outlining the details of the diagnostic procedures carried out would also be expected. The report does not have to be a full technical report but should reflect industry practice of reporting back to supervisor/customer. To ensure authenticity centres will need to provide a variety of faults so that each learners is able to carry out a series of diagnostic and rectification procedures unique to them.

The practical activities carried out for P8 and P9 will link directly with M2, M3 and D1.

To achieve M2 and M3, learners must be able to justify the choice of starting and charging system diagnostic tests and rectification methods used (on each of the two different vehicle system faults for each criterion), respectively.

For D1, learners should be able to evaluate the engine electrical systems of two different vehicles in terms of the ease of carrying out diagnostic and rectification procedures. The systems considered could be the same ones used for P8 and P9.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4	Vehicle Starting Systems	A vehicle technician needs to explain to an learners the function and operation of a vehicle’s starting system	Written report
P5, P6	Vehicle Electrical Charging Systems	A vehicle technician needs to explain to an	Written report

		learners the operation of a vehicle's electrical charging system	
P7, P8, P9, M2, M3, D1	Diagnosing and Rectifying Faults	A vehicle technician needs to diagnose and rectify faults on a vehicle's battery, charging and starting system	Practical activities evidenced by record sheets and observation records.

Essential resources

Learners will need access to suitable motor vehicle workshop facilities. This should include equipment for working with dangerous acids, voltage generation equipment and test equipment including oscilloscopes. A range of components and vehicles should be provided as well as a variety of data sources and technical information.

Indicative reading for learners

Textbooks

Denton T — *Automobile Electrical and Electronic Systems* (Routledge, 2012) ISBN 9780080969428

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Unit 49: Function and Operation of Vehicle Petrol Injection Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Most modern vehicles are fitted with fuel injection systems that enable the engine to work more efficiently and usually result in greater power and cleaner exhaust emissions. These systems work by forcing pressurised fuel through a tiny nozzle that atomises the fuel, allowing it to burn more quickly when mixed with air.

In this unit learners will study a variety of fuel injection systems in order to understand their operation and the differences between systems. Learners will develop an understanding of the air and fuel supply systems and will gain knowledge of the operation of the engine control systems and components. Learners will also develop knowledge of the equipment and methods used to test, maintain and repair petrol fuel injection systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operational differences of petrol injection systems

2 Understand the function and operation of air and fuel supply components and systems

3 Understand the operation of electronic control systems and components

4 Know the methods used to test, maintain and repair petrol fuel injection systems.

Unit content

1 **Understand the operational differences of petrol injection systems**

Petrol injection system: principles of fuel combustion e.g. composition of atmospheric air, calorific value of fuel, mixture strength and the range of combustibility, influence of air/fuel ratio on engine power output; vaporisation of fuel and cooling effects on charge density; injector layout (single point, multi-point, phased and continuous injection); mechanical and electronic control (open and closed loop systems); specification e.g. technical improvements relative to performance, emissions and costs

Fuel injector positioning: single/multi-point/common rail/direct injectors; positioning of injector within the induction manifold e.g. up-stream, down-stream or direct into the cylinder; quality of the homogeny of the charge and volumetric efficiency e.g. requirements for compensatory enrichment, effects of fuel condensation on manifolds walls

Stoichiometric and lean burn technology: phasing of injection e.g. induction cycle injection (stoichiometric cycle), compression stroke injection (direct injection, stratified engine operation); fuel injection strategies e.g. continuous injection, intermittent injection, semi sequential and sequential injection, asynchronous and grouped injection; operational conditions e.g. cold starting, idling, maximum power; thermal efficiency and the formation of pollutants; exhaust gas composition e.g. composition of the exhaust gases under rich, lean and stoichiometric conditions, legal requirements

2 **Understand the function and operation of air and fuel supply components and systems**

Air supply system components: air intake tract; air cleaner; air throttle valve (butterfly valve); throttle body; use of an electric throttle; induction manifold and plenum chamber; variable geometry induction manifolds

Fuel supply components: fuel tank construction e.g. steel with soldered joints, welded joints, moulded plastic, use of internal baffles and swirl pots; electric fuel pump e.g. vane, roller gear, plunger; valves e.g. pressure relief, non-return; fuel lines e.g. accumulator, pipelines, fuel pipe connections, fuel filter; continuous injection mechanical systems; pressure regulator with induction manifold pressure correction; common fuel rail injection (direct injection) e.g. low pressure supply pump, low pressure sensor, high pressure pump, high pressure injectors, high pressure sensor; methods employed to reduce fuel vapour escape e.g. charcoal canister, purge control valve

3 **Understand the operation of electronic control systems and components**

Sensors, switches and actuators: sensors e.g. crankshaft position, camshaft position, coolant temperature, ambient air temperature, fuel temperature, mass air flow (vane type, thermal type (hot wire and hot chip), manifold pressure sensors (manifold absolute pressure (MAP) sensor, exhaust gas oxygen sensor (step response lambda, broad band lambda), engine speed and throttle position sensor; switches e.g. thermo-time switch, idle speed switch, inertia switch; actuators e.g. solenoid injectors, variable manifold butterfly actuators, electrical throttle valve actuator

Electronic control unit (ECU): input and output processes; injector driver circuits; fuel mapping; basic programming theory e.g. use of input parameters to enable the software to calculate correct fuel quantity for injection; software updating e.g. use of specialised software to change fuel map setting at varying engine/operational conditions; software self- diagnostics; controller area network (CAN) data bus e.g. single wire, twin wire, fibre optic

Emission control principles and components: exhaust gas oxygen sensing; catalytic converter e.g. reduction, oxidising, nitrogen oxides (NOx); exhaust gas recirculation (EGR) and components e.g. outline of the process to reduce NOx formation, operation strategies, EGR valve, vacuum modulator, vacuum sensing valve; air injection and components e.g. air pump, air injector, pulse air injection, electronic control of EGR and air injection systems; effect of engine operating conditions e.g. cranking, cold start enrichment, hot start enrichment, cold idle, hot idle, light load, full load, acceleration, deceleration, engine speed limitation

4 **Know the methods used to test, maintain and repair petrol fuel injection systems**

Diagnostic equipment and tests: exhaust gas analysis e.g. use of exhaust gas analysers, lambda values, air/fuel ratio, idle speed adjustments; on-board diagnostics (OBD) e.g. fault code reading, data logging, use of break out box to locate faults, data link connection to dedicated code readers; vacuum pump e.g. induction system leakage, simulation of manifold depression to check fuel pressure regulator; multimeter e.g. system voltage and circuit tests, circuit resistance, circuit integrity; pressure gauge e.g. fuel line pressure and regulator settings; injector delivery and spray pattern e.g. injection quantity, spray pattern and leakage; oscilloscope e.g. engine/camshaft speed sensor patterns, injection duration, lambda sensor output

Injection systems faults and symptoms: e.g. throttle position sensor, mass air flow sensor, coolant sensor, crankshaft/camshaft speed/position sensor, exhaust oxygen sensor, idle speed control valve

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

<table>
<tr><th colspan="3">Assessment and grading criteria</th></tr>
<tr><th>To achieve a pass grade the evidence must show that the learner is able to:</th><th>To achieve a pass grade the evidence must show that the learner is able to:</th><th>To achieve a pass grade the evidence must show that the learner is able to:</th></tr>
<tr><td>P1 explain the operation of two different petrol injection systems used on modern fuel injected engines</td><td rowspan="2">M1 compare the relative advantages and disadvantages of port injection and direct injection with reference to timing of the injection process</td><td rowspan="4">D1 evaluate two typical modern petrol injection systems in terms of their legal, environmental and operational requirements</td></tr>
<tr><td>P2 describe the methods used to position the fuel injector for an induction port injection and a direct injection into the cylinder</td></tr>
<tr><td>P3 describe the principles of stoichiometric and lean burn technology with reference to petrol injection engines</td><td rowspan="2">M2 compare the injection, combustion cycle and exhaust emissions within a stoichiometric air fuel ratio engine and a lean burn stratified charge engine</td></tr>
<tr><td>P4 explain the function and operation of the air and fuel supply components of a given fuel injection system</td></tr>
</table>

P5 describe the function and operation of four major input sensors, their related switches and actuators and how the electronic control unit uses feedback from these devices to calculate quantity of fuel injected		
P6 explain the emission control measures and associated components used for a given fuel injected engine system		
P7 describe the diagnostic equipment required and tests that need to be carried out to check the satisfactory operation of two different fuel injection systems	M3 compare the diagnostic tests and repair strategies that can be performed on two different modern petrol injection systems, including the equipment that may be used.	D2 evaluate the use of diagnostic tests using standard workshop equipment in comparison to dedicated on board diagnostic facilities, equipment and software used with modern petrol injection systems.
P8 describe the symptoms associated with three different injection system faults found in modern engines and the repair strategy for each.		

Essential guidance for tutors

Assessment

A variety of evidence could be used to support assessment. For example, a mixture of written tests and practical investigative assignments could be used requiring learners to explain, describe, identify, compare and evaluate as required by the criteria.

For P1, learners need to explain the operation of two different petrol injection systems used on modern fuel injected engines. A task could be developed requiring learners to inspect two different types of system (selected from those outlined in the unit content) in a practical environment. The task should ensure the learner explains principles of combustion, vaporisation of fuel and cooling effects on charge density, injector layout, mechanical and electronic control and consider the specifications of each where appropriate. P2 requires learners to describe the methods used to position the fuel injector for an induction port injection and a direct injection into the cylinder. The task should ensure the learner considers the quality of the homogeny of the charge and volumetric efficiency. P1 and P2 are closely linked and could be assessed together. The same vehicles could then be used for both criteria.

There are similar close links between P3 and P4. For P3, learners need to explain the principles of stoichiometric and lean burn technology with reference to petrol injection engines. This should include phasing of injection, fuel injection strategies, operational conditions, thermal efficiency and the formation of pollutants including exhaust gas composition. It is expected that learners will refer to more than one type of petrol injected engine to cover the requirements of the unit content. They will need to demonstrate an understanding of the combustion of fuel within an engine and the differences between the homogenous/stoichiometric charge and the stratified, overall lean mixtures associated with modern direct injected engines. To achieve P4, learners need to explain the function and operation of the air and fuel supply components of a given fuel injection system. The operation and function of all components listed in the content under "Air Supply System components" should be explained. The fuel supply components should include the tank, pump, valves, fuel lines etc where applicable in the given system. Learners will, by necessity, need to refer to open and closed loop control methods and their relevance to the function, operation and fundamental principles affecting fuel delivery.

For P5, learners need to describe the function and operation of four major input sensors, their related switches and actuators and how the electronic control unit uses feedback from these devices to calculate quantity of fuel injected. This criterion should not be fragmented into sensors, switches, actuators and ECU. One activity should be designed to enable the whole criterion to be covered at the same time. Learners should include, for each major input sensor considered, suitable references to the interrelationships between each of the components within the systems.

P6 requires learners to explain the emission control measures and associated components used for a given fuel injected engine system. Learners should consider exhaust gas sensing, catalytic converter, EGR and associated components and the effect of engine operating conditions on emissions.

P7 and P8 focus on system defects, symptoms and the necessary testing procedures used in maintenance and repair processes. It is likely, although not essential, that the three faults in P8 will be associated with the two systems considered for P7. It is expected that faults associated with more than one system will be considered.

Wherever possible the descriptions associated with P7 and P8 should be the product of a practical investigation undertaken by the learner and should give consideration to exhaust gas analysis, OBD, vacuum pump, multimeter, pressure guage, injection delivery and oscilloscope. Where centres do not have the equipment to do this they may wish to consider work-based evidence if practicable.

For M1, learners will need to compare the relative attributes of port injection and direct cylinder injection. They should also clearly define the point at which injection commences relative to the engine cycle.

M2 is linked to P3, P4, P5 and P6 in as much as learners need to explore in more detail the differences in combustion strategy to meet the close limits set by environmental legislation. It is expected that learners will refer to the use of closed loop control and the use of step response and/or broadband (or both) oxygen sensors to enable accurate reduction and oxidation to occur within the catalytic converter.

M3 is linked to P7 and P8. Learners need to compare the effectiveness of the tests that can be used to locate faults and the appropriate repair strategies. This should draw on and bring together the understanding gained at pass level enabling them to demonstrate a coherent understanding of testing and fault finding methods.

For D1, learners need to evaluate two typical modern petrol injection systems in terms of their legal, environmental and operational requirements. For D2, they will need to evaluate the use of diagnostic tests. Emphasis should be placed on the comparison with diagnostic algorithms using standard workshop test equipment and on-board diagnosis (OBD) which require dedicated test equipment. Learners should cite examples of actual testing.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6	Electronic Control Systems	A vehicle technician needs to describe the function and operation of sensors, switches and actuators and emission control measures	Written responses to set tasks
P7, P8, M3, D2	Maintenance and Repair of Petrol Fuel Injection Systems	A vehicle technician needs to describe the methods used to test, maintain and repair petrol fuel injection systems	A written report based on practical investigations

Essential resources

Learners will need access to a range of components, assemblies and rigs and, wherever possible, access to the diagnostic equipment identified in the unit content. Access to suitable vehicles and tools will need to be provided along with a range of relevant information sources and operational manuals.

Indicative reading for learners

Textbooks

Bonnick A — *Vehicle Electronic Systems and Fault Diagnosis* (Routledge, 1998) ISBN 9780340706305

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Hillier V — *Hillier's Fundamentals of Automotive Electronics Book 2*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515372

Unit 50: Diesel Fuel Injection Systems for Compression Ignition Engines

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

Advances in technology and a tightening of exhaust emissions requirements have led to a considerable improvement in the performance of diesel engines. Once exclusively used in large heavy vehicles, plant or marine applications, diesel engines are now an acceptable alternative to petrol engines in light vehicles. To compete effectively as an alternative, the light diesel engine must have similar attributes to the petrol engine. Modern fuel injection systems in diesel engines enable improved engine performance and economy and control of emissions, enabling parity with the petrol engine.

In this unit learners will study a variety of fuel injection systems in order to appreciate their function, their operation and the differences between systems. The unit will develop learner understanding of air and fuel supply systems and the operation of the engine control systems and components. Learners will also develop their knowledge of the equipment and methods used to test, maintain and repair diesel fuel injection systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operational differences of diesel fuel injection systems

2 Understand the function and operation of air and diesel fuel supply components and systems

3 Understand the operation of diesel engine control systems and components

4 Know the methods used to test, maintain and repair diesel fuel injection systems.

Unit content

1 **Understand the operational differences of diesel fuel injection systems**

Diesel injection system: principles of diesel fuel combustion, combustion phases, turbulence and the compression of induced air, composition of fuels used in diesel engines, abnormal combustion and its causes; conventional diesel fuel injection systems e.g. in line, rotary fuel injection pump, high pressure common rail injection system using electronic injector control, low pressure common rail injection system using combined pump and injector, electronic diesel control using conventional fuel injection pump; operational factors e.g. technical improvements relative to performance and emissions

Diesel fuel supply: fuel supply pumps e.g. types (diaphragm, gear vane and plunger), multi-stage pressure development, provision for hand priming, single and double pumping action; means of operation e.g. fuel pump camshaft, engine camshaft auxiliary drives, electrical drives; fuel supply pressure regulating valves (control of fuel flow rates in high-pressure systems); fuel heaters and coolers e.g. waxing prevention methods, cooling of returned fuel before entering fuel tank; procedures for venting diesel fuel injection systems e.g. requirements to bleed air from the system, self- venting systems, faults associated with entrapment of air in the fuel injection system; fuel injection system settings requirements to set maximum fuel and maximum speed(mechanical or electronic), methods used to identify injection timing marks/position for refitting to engine, adjustment of plunger travel or torque methods on combined pump and injector types

2 **Understand the function and operation of air and diesel fuel supply components and systems**

Air supply system components: air cleaners; induction manifold design; use of resonance chambers to improve engine volumetric efficiency; variable geometry induction manifolds and variable geometry turbo chargers

Diesel fuel supply components: fuel tank e.g. construction, methods used to minimise aeration of the fuel; filtration of the fuel e.g. requirements to filter the fuel, effects of low temperature wax formation on fine filters, filter placement, effects of water ingress, methods used to trap and remove water, construction and position of primary and secondary filters, effect of blocked filtration system (loss of power, misfire, engine shut down); control valves e.g. delivery valves with anti-dribble control, manual shut down, solenoid shut down valves and reverse flow valves (used on electronically governed inline pumps to ensure engine shut down), application of electronic control; injector nozzles e.g. single hole, multi-hole, pintle, pintaux; fuel injection pump e.g. in-line fuel injection pumps, single and multi-cylinder, drive couplings, mechanical advance/retard system, electronic control of injection timing, firing order control, anti-reverse cams, methods used to meter quantity of fuel injected; high and low pressure pipes e.g. high pressure injection pipes, factors that govern internal and external diameter, length of high pressure pipes, factors that affect injection timing, size and effects on volume flow rates (low pressure pipes), need for adequate clamping of pipes

3 **Understand the operation of diesel engine control systems and components**

Sensors and actuators: sensors e.g. engine speed, air mass, coolant temperature, throttle position, fuel pressure intake manifold pressure, intake manifold temperature, governor control rod position, throttle position; actuators e.g. electrical/hydraulic servo units, glow plugs (methods to reduce diesel knock), injectors, fuel pressure regulating valve, rotary injection pumps (distributor type injection pumps, drive methods and engine timing), method to ensure correct firing order

Control systems: common rail, electronically controlled, low pressure systems e.g. combined pump and injector, drive mechanism for injector, control strategies, operation of the injector on its cycle, fuel supply pump operation pump drive and timing arrangements; common rail electronically controlled high-pressure system e.g. fuel supply circuitry, operation of the supply pump, fuel rail pressure sensors, pressure limiting valve, construction and operation of the injector, pre-injection phase, main injection phase; diesel fuel injection cold start devices e.g. retardation of injection timing, excess fuel device (including the legal implications of its use), manifold combustion heaters, heater plugs, ether injection, decompression devices; single, two and variable speed governing e.g. governor cut in/cut out, maximum speed over-run, hysteresis, over-shoot, speed droop; hydraulic and electronic governors e.g. components and operation under idling, maximum speed (legal requirement), over-run and variable speed

Electronic control unit (ECU): input and output processes; injector driver circuits; fuel mapping; basic programming theory e.g. use of input parameters to enable the software to calculate correct fuel quantity for injection; software updating e.g. use of specialised software to change fuel map setting at varying engine/operational conditions; software self- diagnostics; controller area network (CAN) data bus e.g. single wire, twin wire, fibre optic

Emission control measures and components: exhaust gas emissions under normal and abnormal running conditions e.g. methods employed to reduce emissions (exhaust gas recirculation (EGR), urea injection into exhaust using selective catalytic reduction); legal requirements for emissions (EURO specification); effect of diesel engine operating conditions e.g. cranking, cold/hot start, cold idle, hot idle, light load, full load, acceleration, deceleration, engine speed limitation

4 **Know the methods used to test, maintain and repair diesel fuel injection systems**

Diagnostic equipment and tests: exhaust gas analysis e.g. use of smoke meters for exhaust gas opacity, idle speed adjustments and maximum speed settings; on-board diagnostics (OBD) e.g. fault code reading, data logging, use of break out box to locate faults, data link connection to dedicated code readers; checking common rail operational pressures, effects of low rail pressure on starting and performance; induction system leakage, effects of changes in boost pressure on turbocharged engines, effects of fuel injection quantities of changes in boost pressure; use of multimeter e.g. system voltage and circuit tests on injector control solenoids, circuit resistance, circuit integrity; pressure gauge e.g. fuel line pressure and regulator settings; oscilloscope e.g. engine/camshaft speed sensor patterns and injection duration

Injection system faults and symptoms: removal and refitting of main fuel injection system components e.g. removal and refitting of injectors including common rail, removal and refitting of a fuel injection pump; servicing of fuel system e.g. fuel filters, bleeding and rectification of leaks; checking the operation of the fuel injection system e.g. in situ adjustments of fuel quantities injected and speed, checking of injection timing, producing fault finding algorithms; testing of injectors e.g. safety factors associated with high pressure fluids and vapour, spray patterns, setting pressures, nozzle back leakage, nozzle tip leakage, specialised equipment to test combined pump and injector types; maintenance of fuel systems e.g. fuel filter condition, condition of pipes and securing clamps, leaks, checking the condition and security of fuel injection pumps and drive couplings, security of maximum fuel and speed seals, check indication of visible vapour from the exhaust; test rectification techniques e.g. location of misfire on conventional injection system and/or on common rail using dedicated software, poor performance through lack of power, excess exhaust gas opacity, fuel leaks, air ingress, probable causes of black, blue and white smoke; legal implications of defects on diesel fuel injection systems e.g. excessive smoke, loss of power weight ratio and fuel leaks onto the road surface

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 explain the operation of two different diesel fuel injection systems used on modern diesel engines	M1 compare the relative advantages and disadvantages of a conventional fuel injection system with a high pressure common rail system	D1 evaluate two typical modern diesel injection systems in terms of their legal, environmental and operational requirements
P2 describe two different types of diesel fuel supply methods		
P3 explain the function and operation of the air and diesel fuel supply components of a given diesel fuel injection system	M2 compare two governor types used on modern automotive diesel engines in terms of their modes of operation and levels of sensitivity	
P4 describe the function and operation of four major diesel injection system input sensors, the related actuators and their relationship with the engine electronic control unit		
P5 explain the emission control measures and associated components used for a given diesel fuel injected engine system		
P6 describe the diagnostic equipment required and the tests that need to be carried out to check the satisfactory operation of two different diesel fuel injection systems	M3 compare the diagnostic tests and repair strategies that can be performed on two different modern diesel injection systems, including the equipment that may be used.	D2 evaluate the use of diagnostic tests using standard workshop equipment in comparison to dedicated on board diagnostic facilities, equipment and software used with modern diesel injection systems.
P7 describe the symptoms associated with three		

different diesel fuel injection system faults found in modern engines and the repair strategy for each.		

Essential guidance for tutors

Assessment

Assessment of this unit could be through a mixture of written tests and practical investigative assignments.

P1 and P2 are closely linked and could be assessed together, using the same vehicles for both criteria. For P1, learners need to explain the operation of two different diesel fuel injection systems used on modern diesel engines. A task could be developed requiring learners to inspect two different types of systems (selected from those outlined in the unit content) in a practical environment. P2 requires learners to describe two different types of diesel fuel supply methods. Ideally, one will be a conventional fuel lift pump with hand priming and the other a two-stage high-pressure pump and flow control valve for a common rail system.

For P3, learners need to explain the function and operation of the air and diesel fuel supply components of a given diesel fuel injection system. This should include an explanation of the principles of induction system design used to improve engine volumetric efficiency. Specifically this should be the use of acoustic design on normally aspirated engines to aid the induction ram effect and the use of geometrical variable manifolds and turbochargers to improve engine performance characteristics. Learners should also consider the effects of turbo charger boost pressure on fuel quantities injected and emissions which would enable learners to appreciate the control strategies involved.

For P4, learners need to describe the function and operation of four major diesel injection system input sensors and related actuators used to monitor engine parameters and enable the fuel and timing of injection to be controlled with accuracy through the ECU. P5, for which learners need to explain emission control measures and associated components can be linked with P3 and P4.

P6 and P7 can be linked through a practical assessment during a workshop session or at the learner’s own place of work. If work-based evidence is used care must be taken to ensure may its validity and authenticity.

For M1, learners need to compare the relative advantages and disadvantages of a conventional fuel injection system and the high-pressure common rail system. This is closely linked to P1, P2, P4 and P5.

For M2, the learner is required to compare two different engine governing systems such as speed for heavy goods vehicle against performance limitations/ expectations for light vehicles. It is important that the related operational characteristics of these governors are analysed and compared in relation to their operation and levels of sensitivity.

M3 requires learners to compare the diagnostic tests and repair strategies performed on two different diesel injection systems. This builds on the knowledge gained through P6 and P7 and could be built in to the same practical assignment.

For D1, learners need to evaluate two modern diesel injection systems in terms of their legal, environmental and operational requirements.

D2 requires them to evaluate the use of diagnostic tests using standard workshop equipment in comparison to dedicated on board diagnostic facilities, equipment and software used with modern diesel injection systems. Emphasis should be placed on the comparisons with diagnostic algorithms using standard workshop test equipment and on-board diagnosis (OBD), which require dedicated test equipment. Learners will need to give examples of actual testing.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, P5, M2	Air and Diesel Fuel Supply and Engine Control Systems	A vehicle technician needs to explain the function and operation of air and diesel fuel supply and diesel engine control systems to a new learner	A written report
P6, P7, M3, D2	Testing and Maintenance of Diesel Fuel Injection Systems	A technician needs to explain to an learner how to carry out testing and maintenance of a diesel fuel injection system	A written report

Essential resources

Learners will need access to a range of components, assemblies and rigs and, wherever possible, access to the diagnostic equipment identified in the unit content. Access to suitable vehicles and tools will need to be provided along with a range of relevant information sources and operational manuals.

Indicative reading for learners

Textbooks

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney, M — *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 51: Operation and Testing of Vehicle Electronic Ignition Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Electronic ignition systems have developed in line with the advancement of engine technology and engine management systems. Modern electronic ignition systems have improved vehicle reliability, performance and efficiency of operation. Recent advances in spark plug design, manufacture, operation and longer working life have also improved electronic ignition systems.

It is important that all motor vehicle technicians are aware of these systems and are able to recognise and confirm faults. This unit will enable learners to understand the fundamental operating principles of electronic ignition systems and will give them the knowledge and understanding needed to carry out accurate diagnosis and repair. Learners will develop an understanding of the main components of vehicle electronic ignition systems and their relationship to the efficient operation of the engine unit and sub-systems.

Note that the use of 'e.g. ' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g. ' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the function and operation of conventional ignition systems and their components

2 Understand the operation of programmed electronic ignition and distributorless ignition systems

3 Know about the function and operation of pulse generators and control modules

4 Be able to undertake tests on electronic ignition system to verify system faults.

Unit content

1 **Understand the function and operation of conventional ignition systems and their components**

Ignition system operation: ignition timing (static and dynamic); dwell (angle, time, variation); ignition scope patterns e.g. spark kV, primary circuit, secondary circuit, dwell, coil output

Ignition system components: circuits (diagrams, primary, secondary); contact breaker; coil; leads; distributor and cap; rotor arm; spark plugs; mechanisms (mechanical advance, retard, vacuum advance)

2 **Understand the operation of programmed electronic ignition and distributorless ignition systems**

Programmed electronic ignition: components, functions and operation; electronic control unit; sensors e.g. manifold absolute pressure, crankshaft, camshaft, engine temperature, knock, air temperature; ignition coil; distributor; ignition switch; reluctor disc; discharge e.g. capacitor, inductive

Distributorless ignition system: components, functions and operation; transformer; capacitor; ignition coil(s) e.g. waste spark, direct acting; spark plug; sensor e.g. manifold pressure, crankshaft, camshaft, knock; primary current switching modules, waste spark, direct acting

3 **Know about the function and operation of pulse generators and control modules**

Generators: Hall effect e.g. Hall voltage, Hall integrated circuit (IC), vanes, magnet, control module; inductive pick-up e.g. permanent magnet, inductive windings, trigger wheel; optical pulse e.g. light emitting diode, phototransistor

Transistor assisted contacts: transistor operation; Darlington pair; advantages of breakerless systems

Control modules: e.g. pulse shaping, dwell period control, voltage stabilisation, primary switching, pulse processing, secondary output control, ignition amplifier, air gap, electronic spark advance, spark advance map, read-only memory (ROM), erasable programmable read-only memory (EPROM), knock control

4 **Be able to undertake tests on electronic ignition system to verify system faults**

Testing: equipment e.g. on-board diagnostics, test instruments, voltage drop tester, electronic control unit tester; spark advance and retard tester; safe working practice; components and circuits e.g. fuses, wiring, connectors, coil, spark plug, leads, rotor arm, distributor cap, pulse generator, sensors (such as crankshaft, camshaft, knock), break out box, ignition switch, reluctor air gap; checking for faults e.g. moisture, dirt, corrosion, fault code reading, gap, data link connection, output and resistance, spark plug leads condition and resistance, rotor arm condition and leakage, distributor cap condition and leakage, dwell angle, spark plug condition, pulse generator module resistance, ignition timing, sensor output, sensor operation

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 explain, with the aid of appropriate diagrams, the operation of a typical conventional ignition system and the function of its main components		
P2 distinguish between dwell angle, dwell time and dwell variation		
P3 explain the operation of a programmed electronic ignition system and the function of its main components	M1 compare the relative advantages and disadvantages of a typical conventional ignition system, a programmed electronic ignition and a distributor less ignition system	D1 explain how the conventional ignition system, programmed electronic ignition system and distributor less ignition system operate in a variety of cold start and acceleration situations
P4 explain the operation of a distributor less ignition system and the function of its main components		
P5 describe the function and operation of a pulse generator		
P6 describe the advantages of transistor assisted contacts		

P7 describe the use of two different control modules		
P8 use appropriate equipment to carry out tests on five components/circuits to verify faults in an electronic ignition system	M2 suggest methods for dealing with typical faults on the electronic ignition system.	D2 analyse test results to diagnose defects, wear and maladjustment in the ignition system from given data and symptoms.

Essential guidance for tutors

Assessment

Assessment of this unit will normally be carried out through a combination of assignments, projects, and practical investigations. The unit can be linked to other units such as *Unit 46: Applications of Vehicle Science and Mathematics* and *Unit 47: Electrical and Electronic Principles for Vehicle Technology* and it would be appropriate, where possible, to combine assessment. Alternatively, this unit could be assessed using four assignments.

The first assignment could assess P1 and P2, with written tasks for each criterion. For P1 the use of diagrams is essential in the assessment process, and learners should explain both the function and operation of the main components of a typical conventional ignition system. This should include the type of circuit, contact breaker, coil, leads, distributor and cap and rotor arm. For P2, a simple description including the differences between the indicated elements could be assessed at the same time.

A second assignment could cover P3, P4, P5, P6 and M1. This could also provide an opportunity to direct learners to D1. Separate written tasks could be given for each criterion and learner responses are likely to be in the form of a report.

P7 could be assessed independently in a third assignment, or could be linked to the second assignment.

A final assignment covering P8, M2 and D2 could be assessed with the aid of task sheets that track authenticated, reliable and current practical activities on five components/circuits. The structure of this assignment is critical and tutors should ensure that learners have opportunities to diagnose faults (P8), suggest methods for dealing with faults (M2), and analyse test results on defects, wear and maladjustment (D2). The data and symptoms should be given to each learner. The evidence provided must include the test results involved and would typically incorporate printouts from test equipment. A witness statement/observation record would be a suitable form of evidence to show what the learner did and the equipment they used when carrying out tests.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Conventional Ignition Systems	A vehicle technician working on historic racing cars needs to report on the operation of a conventional ignition system	A written report supported by relevant diagrams

P3, P4, P5, P6, M1, D1	Programmed Electronic Ignition, Distributor less Ignition Systems and Pulse Generators	A technician needs to explain the function and operation of programmed and distributor less ignition systems and pulse generators to a new learner	A written report
P7	Control Modules	A vehicle technician needs to describe the use of different control modules to a mature technician	A written report
P8, M2, D2	Testing Electronic Ignition Systems	A technician needs to carry out tests on an electronic ignition system components and circuits as part of professional development	Practical activities evidenced by record sheets and observation records.

Essential resources

Learners will need access to vehicle workshops equipped with modern vehicles, rigs, components and appropriate test equipment.

Indicative reading for learners

Textbooks

Bosch R — *Automotive Electrics/Automotive Electronics* (Wiley-Blackwell, 2007) ISBN 9780470519370

Hillier V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Unit 52: Vehicle Engine Management Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

Modern motor vehicles continue to make use of the rapid advances in electronics technology in a wide range of vehicle applications. This unit considers how electronics are used in engine management systems (EMS) and, in particular, the use of engine control units (ECU) which control different aspects of an engine's operation.

As a minimum, a simple ECU may just control the quantity of fuel injected into each cylinder during each engine cycle. However, advanced ECUs also control the ignition timing, variable valve timing, the level of boost maintained by a turbocharger and may also control a range of other engine system peripherals. Increasingly, the EMS also plays an important part in maintaining environmental controls, fuel economy and safety and in ensuring compliance with the various legislative requirements placed on modern engines.

This unit will enable learners to gain an understanding of the systems and operating principles of an engine management system. Learners will also consider the interaction between the engine management system and the functions and performance of a modern motor vehicle engine. They will also carry out a series of engine management system tests and will select and use equipment to carry out a diagnostic test to determine EMS faults.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operating principles and characteristics of an engine management system

2 Understand the operating principles of engine management system sensors and actuators

3 Understand the interrelationships and interaction of engine management systems and components

4 Be able to carry out tests on an engine management system to locate a system fault.

Unit content

1 **Understand the operating principles and characteristics of an engine management system**

Operating principles and characteristics: systems modelling e.g. diagrammatic representation of system input/process/output, characteristics of open and closed-loop system control strategies used in engine management systems; control systems e.g. analogue, digital, programmable, non-programmable; main elements of a digital processing system e.g. central processing unit (CPU), memory devices (such as volatile, non-volatile), buses, input/output ports; principal functions of a digital processing system e.g. multiplexing, controller area network (CAN) systems; characteristics e.g. purpose and applications of the system, operating conditions (conditions in which the system is operative or inoperative, 'fail-safe' features), system features (benefits, cost, performance, safety, convenience, efficiency)

Engine management systems: integration developments e.g. fuel, mechanical to full electronic; interaction between other vehicle systems e.g. sport mode on gearbox selection; fuel management (spark and combustion ignition) systems; ignition control and combined fuel/ignition control; emission control e.g. active to reactive such as use of lambda system and knock sensor control; vehicle performance monitoring e.g. throttle position, driver selection

2 **Understand the operating principles of engine management system sensors and actuators**

Operating principles of sensors: types e.g. Electromagnetic , Hall effect, photo-electric, resistive, inductive, piezo-electric element effect, capacitive; factors affecting performance and application e.g. sensitivity, accuracy, linearity and stability; influence of environmental factors e.g. heat, vibration, moisture, contaminants

Operating principles of actuators: e.g. ignition components such as coils, high tension (HT) components (individual coils, spark generators), fuel components (idle control valves, cold start devices, electronic injectors), variable valve timing control

3 **Understand the interrelationships and interaction of engine management systems and components**

Interfacing and signal processing: compatibility between components and systems e.g. temperature and speed sensors, throttle position/drive by wire actuators; characteristics of devices which give rise to the need for signal processing (inductive pick-ups, analogue to digital (AD) and digital to analogue (DA) conversion); control of output devices e.g. energy transfer, power output stages, buffer circuits

Functional interrelationships: location e.g. units and components within the vehicle, position/location of components relative to others in the system; functional relationships between the elements of the system e.g. data input from sensors and electronic control unit (ECU) process to affect actuation; impact of a component's failure on other components within the system, the operation of the system and on external systems e.g. the effect of speed sensor failure, Lambda sensor fault

System interactions: e.g. integration fuel and emission control and/or vehicle performance control, achieved by common data sources and actuator responses

4 **Be able to carry out tests on an engine management system to locate a system fault**

Test components/circuits for satisfactory operation: test equipment e.g. onboard diagnostics, test instruments, voltage drop tester, ECU tester, spark advance and retard tester; safe working practice e.g. common rail fuel pressures, working with ECU, HT voltage; components and circuits e.g. fuses, wiring, connectors, injector, coil, ECU, pulse generator, sensors/transducers (such as crankshaft, camshaft, knock), actuators, pressure check (fuel pump), break out box; checking for faults e.g. moisture, dirt, corrosion, fault code reading, gap, data link connection, output and resistance, condition, ignition timing, sensor output, sensor operation

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 explain the operating principles and characteristics associated with an engine management system	M1 compare the relative advantages and disadvantages of two different engine management systems	D1 justify the use of a specific engine management system
P2 explain the operating principles and application of three different types of engine management system sensor	M2 compare the performance of three engine management system sensors in terms of their sensitivity, accuracy, linearity and stability	
P3 explain the operating principles and application of three different types of engine management system actuator		
P4 describe the interfacing and signal processing requirements of two engine management system components		
P5 explain the functional interrelationships and system interactions of engine management system units and components		

P6 explain the effect of different engine management functions during fuel, emission and performance control	M3 explain the benefits of an integrated management control system on engine performance.	
P7 use appropriate equipment to carry out tests on five different engine management system components/circuits to establish their serviceability		
P8 carry out a diagnostic procedure to locate an engine management system fault.	M4 explain the benefits of dedicated diagnostic equipment and procedures employed with engine management systems	D2 evaluate an engine management system diagnostic procedure and suggest possible improvements.

Essential guidance for tutors

Assessment

This unit could be assessed using three assignments and evidence is likely to be in the form of written work and tutor observation of practical work.

The first assignment could be designed to cover the requirements of P1, P2, P3, M1, M2 and D1. Evidence should show that learners can explain both the operating principles and characteristics associated with an engine management system. The task should ensure inclusion of systems modelling, the control system used and their principle functions and characteristics. The evidence should also show that learners have understood the relevant aspects of the engine management system being considered. This should include integration developments, the interaction between other vehicle systems, fuel management systems, ignition control and combined fuel/ignition control, emission control and vehicle performance monitoring. The assessment task could also include a natural link to M1, by asking learners to consider two different engine management systems. Having compared two systems in M1 learners could come up with reasons for justifying the use of one specific system (D1).

Learners could then consider relevant engine management system sensors to cover P2 (engine sensors/transducers such as engine temperature, speed and position) and actuators to cover P3 (such as idle control or ignition components). It would be natural to put the sensors/transducers (input) and actuators (output) within three different vehicle contexts (possibly across the two different engine management systems). Learner evidence should identify, for each specific application, the type of sensor/transducer being used (for example Electromagnetic, Hall-effect, photoelectric, resistive, inductive, piezoelectric element effect, capacitive), the factors that may affect its performance and application and the influence of environmental factors. It would be possible to generate evidence for P2 and P3 through a practical investigation of the outputs and inputs from sensors/transducers and actuators using scanner/oscilloscopes or other dedicated equipment. For the actuators, learners must show an understanding of the principles of how individual actuators operate, such as spark generation and idle control valve (for example, include how the electromagnetic effect is used to create linear movement). Learners should be given opportunities to link the work carried out for P2 with the requirements of M2.

A second assignment could be used to cover P4, P5, P6 and M3. This will need to include a task requiring learners to describe the interfacing and signal processing requirements of two engine management systems (P4) and explain the functional interrelationship and system interaction of one of these (P5). A separate task could then require learners to explain the effect of different engine management functions during fuel, emission and performance control (P6). A task to explain the benefits of an integrated control system on engine performance would cover M3. Finally a task to substantiate the comparative benefits of dedicated diagnostic equipment and procedures employed with engine management systems (M4) could also incorporate an evaluation of an engine management system diagnostic procedure (D2)

The third assignment will require learners to carry out practical activities to cover P7 and P8. It would also provide the best opportunity to cover M4 and D2.

For P7, learners will need to use appropriate equipment to carry out tests on five different engine management system components/circuits to establish their serviceability. The evidence for this criterion should be gathered over time and collected together in a portfolio/report, including results of the tests, relevant descriptive work and tutor observation/oral questioning records. The evidence should include the results of tests on both components and circuits, and clearly identify which system(s) and components are affected and are serviceable.

The evidence for P8 may also be used for some (or all if appropriate) of the testing carried out for P7. Although this would be ideal in terms of integration, it would need to be managed carefully to ensure full coverage of both criteria.

It is expected that all the tests and procedures are completed to relevant standards and within health and safety guidelines.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P4, P5, P6, M3	Interrelationships and Interaction of Engine Management Systems	A vehicle technician has been asked to explain the interrelationships and interaction of engine management systems and components, and substantiate comparative benefits of dedicated diagnostic equipment and procedures employed with engine management systems to a new learner.	A written report
P7, P8, M3, D2	Engine Management System Testing and Fault Location	A vehicle technician needs to locate an engine management system fault to aid work-based development	A practical assignment evidenced through learners' portfolio and tutor observation records

Essential resources

A range of components, vehicles, diagnostic equipment and software will be required for delivery of this unit. This will need to include manufacturer/vehicle specific maintenance and test equipment and non-specific equipment such as measuring instruments, meters and pressure gauges. A variety of data sources will also be required for the vehicles, systems and procedures used.

Indicative reading for learners

Textbooks

Bonnick A — *Automotive Computer Controlled Systems* (Routledge, 2001) ISBN 9780750650892

Bonnick A — *Vehicle Electronic Systems and Fault Diagnosis* (Routledge, 1998) ISBN 9780340706305

Denton T — *Advanced Automotive Fault Diagnosis* (Routledge, 2011) ISBN 9780080969558

Unit 53: Operation and Maintenance of Light Vehicle Transmission Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

This unit covers the conventional aspects of light vehicle transmission systems, their function, principal components and operating principles. This will include a detailed examination of the three major systems — a vehicle's clutch mechanism, gearbox and the driveline and final drive systems.

Learners will be introduced to the most recent developments in the use of electronics for the control and operation of transmissions systems in both standard production vehicles and motorsport applications. These developments are now frequently integrated into the overall electronic management of the vehicle and can provide significant improvements in terms of driveability, economy and performance. Learners will appreciate the fundamental operating principles of these developments, their integration within transmission systems and their significance in the maintenance of a vehicle's transmission system.

Finally, learners will carry out specific tests and checks to identify transmission system faults such as clutch slip, gearbox linkage problems and failing constant velocity joints. Learners will use these tests and checks, together with on-board diagnostic equipment, to maintain a vehicle's transmission system. This will include the maintenance requirements relating to driver/passenger safety and component reliability.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the operation of a vehicle clutch mechanism and the function of its principal components

2 Understand the operation of a vehicle gearbox and the function of its principal components

3 Understand the operation of a vehicle driveline system and final drive and the function of its principal components

4 Be able to maintain a vehicle's transmission system.

Unit content

1 **Understand the operation of a vehicle clutch mechanism and the function of its principal components**

Principal clutch components: pressure plate, disc, flywheel (including bearings and bushes); release bearings; release systems e.g. production vehicles (hydraulic, mechanical and cable), motorsport vehicles (push/pull and electrohydraulic actuating mechanisms)

Types of clutch mechanisms: e.g. production clutches (coil and diaphragm spring, single plate, wet and dry types), automatic clutches (torque converter, fluid flywheel, one way clutch), motorsport clutches (paddle, slipper and multiplate)

Operating principles of clutch: constructional design and use of materials (linings, drive plates and friction surfaces, springs); engagement and disengagement of clutch (single and multiplate, one way clutches and automatic clutches); provision for adjustment/self-adjustment; torque calculations and coefficient of friction; power flow; common faults e.g. wear, misalignment; fault symptoms (slip, drag, judder, overheating); fluid flywheels

2 **Understand the operation of a vehicle gearbox and the function of its principal components**

Principal gearbox components: gear design (spur and helical); bearings, shafts, casing, selector and sealing arrangements; gear locking and interlock mechanisms; gear speed synchronisation and engagement mechanisms e.g. sliding mesh, synchromesh and dog type

Types of gearboxes: e.g. manual (single stage, double stage, sliding mesh, constant mesh), automatic (epicyclic gear train, hydraulic control systems); layout e.g. transverse, longitudinal and transaxle

Operating principles of gearbox: manual gearbox - gear ratios, power flow e.g. constant mesh single and double stage; torque and speed calculations; gear ratio characteristics and number of available gears; selection and engagement methods e.g. synchromesh and dog type, selector forks, interlocks and linkages, remote control mechanisms, motorsport (sequential, electro-hydraulic); automatic gearbox - torque converters (lock-up mechanism); epicyclic gear trains (simple and compound); brake bands; multi-plate and unidirectional clutches; power flow paths; function of key hydraulic components (pump, governor, actuators, servos, regulator and shift valves); electronic control system including mode selection; electronic selection of conventional gear arrangements; lubrication e.g. method (splash and pump assisted); oil requirements and types (mineral, synthetic); seals and sealing arrangements (static and dynamic types)

3 **Understand the operation of a vehicle driveline system and final drive and the function of its principal components**

Principal components of driveline system: propeller shaft arrangement e.g. single, divided; driveline arrangements e.g. front, rear and four wheel; universal joints e.g. Hooke type and rubber; constant velocity joints, sliding joints; drive systems e.g. two-wheel, four-wheel (transfer box, centre differentials, viscous couplings, differential locks, automatic and manual)

Principal components of final drive: axle types and support arrangements e.g. transaxles, live and independent; final drives e.g. bevel, spiral and hypoid; differentials e.g. sun and planetary gears, crown wheel and pinion, limited slip systems; axle types e.g. semi, three quarter and fully floating; bearings

Operating principles of driveline: universal joints (Hooke type and rubber); constant velocity joints (angular limitations and conditions required to achieve constant velocity, basic consideration of balance requirements, alignment and torque capacity of hollow and solid shafts); suspension and transmission characteristics giving rise to the requirement for sliding joints and centre propshaft bearings

Operating principles of final drive: gear ratio, speed reduction and torque multiplication in the final drive; final drive arrangements for transaxles; driving thrust and torque reaction; differential (effects on torque/speed at the driven wheels, limited-slip differentials); lubrication methods (final drive and rear axles); oil requirements and types (mineral, synthetic); oil seals and sealing arrangements (static and dynamic)

4 **Be able to maintain a vehicle's transmission system**

Transmission system faults: e.g. clutch (slip, drag, judder, loss of drive, excessive noise, wear, misalignment, operating mechanism faults), gearbox (gear selection, oil leaks, linkages and fittings), driveline and finals drives (prop/drive shafts, universal and CV joints, bearings, gaiters and seals), use of on-board diagnostic (OBD) equipment, reporting methods (inspection records, oral report to supervisor)

Maintenance operations: working to manufacturers' maintenance and service procedures e.g. manuals, job cards, direct supervision; maintenance operations e.g. clutch adjustments/alignment, gearbox oil change, gear selection linkage repair, driveshaft gaiter condition check/replacement, security of mountings and fittings; context of the maintenance operations e.g. routine maintenance, repair or adjustment due to a system failure, alternative service procedures for adverse condition (vehicles operating in dry, dusty environments, race/rally vehicles and vehicles working in extreme temperature environments)

Critical safety considerations: procedures relating to maintenance operations carried out e.g. materials handling (protection against dust, oil and chemical exposure), vehicle and system protection (application of four-wheel drive diff locks, lifting and supporting vehicles), personal protective equipment (PPE), Control of Substances Hazardous to Health (COSHH) Regulations, component and environmental waste disposal.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a pass grade the evidence must show that the learner is able to:**	**To achieve a pass grade the evidence must show that the learner is able to:**
P1 describe the function of the principal components of two different types of clutch mechanism	M1 compare two different vehicle clutch types in terms of their principal components and operating principles	D1 justify the use of a specific clutch type for two different vehicle applications in terms of purpose, function and performance
P2 explain the operating principles of one type of clutch		
P3 describe the function of the principal components of one type of gearbox	M2 explain the advantages and disadvantages of increasing the number of available gears in a gearbox	
P4 explain the operating principles of two different types of vehicle gearbox		
P5 describe the function of the principal components in a vehicle driveline and final drive	M3 compare two different vehicle driveline and final drive arrangements.	D2 justify the use of a specific type of driveline and final drive arrangement for two different vehicle applications in terms of purpose, function and performance.
P6 explain the operating principles of a vehicle's driveline and final drive arrangement		
P7 inspect a vehicle's transmission system		
P8 report faults and attribute symptoms to the faults identified		
P9 carry out a maintenance operation on a vehicle's transmission system		

P10 follow relevant safety procedures when inspecting and maintaining a vehicle's transmission system.		

Essential guidance for tutors

Assessment

This unit provides opportunities for assessment evidence to be generated from a combination of assignments, projects and practical work. Although most of the pass criteria require descriptive evidence it is not expected that tutors only use tests to achieve this. The unit lends itself to an investigative, practical approach and this should be reflected in the assessment strategy wherever possible. The range of evidence presented could include notes, diagrams, investigative test data and the records of the maintenance and diagnostic procedures carried out.

To achieve a pass, learners will need to describe the function of the principal components of two types of clutch mechanism (P1), one gearbox (P3) and a vehicle's driveline and final drive (P5). In addition, learners need to explain the operating principles of one of the clutches (P2), two types of gearbox (P4) and one vehicle's driveline and final drive arrangement (P6). The unit content for each of these areas provides a range of choices through the examples listed. For clutches, this includes production, automatic and motorsport, and within these groupings there are further examples. Tutors are expected to cover as wide a range of these as possible during delivery but need only select one or two of these, as indicated by the criteria, for assessment purposes. This will enable tutors to concentrate on a specific specialisation as the main focus of assessment (for example motorsport paddle clutch).

Where a criterion requires learners to consider two types this is to ensure that coverage is sufficiently varied so as not to limit learners' employment potential. For example, whilst a centre may specialise in motorsport it is important that learners are equally aware of a production vehicle's clutch or vice-versa. The range of choices available could mean that each learner could be considering the function of the principle components for a different type of vehicle and clutch. This can be beneficial when considering the authenticity of learner evidence.

At pass level, learners should also be able to inspect a vehicle's transmission system (P7), identify and report faults aligned to the symptoms that are attributed to the findings (P8), and carry out a routine maintenance operation (P9) whilst following relevant safety procedures (P10). P7, P8, P9 and P10 would be best assessed through investigation and practical examination of a live vehicle layout and configuration. P10 should be an integral part of the assessment for P7 and P9.

A suitable transmission system fault may need to be simulated for P7 and P8 and learners given the typical symptoms of the fault, as would be reported by a driver of the faulty vehicle. Assessment is likely to consist of a written inspection record completed by learners at the time of the inspection, a verbal report back to the supervisor/customer (tutor record of oral questioning/observation) and tutor observation of the process (for example use of logical and efficient diagnostic techniques, safe working).

The main assessment evidence for P9 would be the final product - the completed maintenance task. However, tutor observation will also be necessary to cover the process aspects of the task (for example working to the manufacturer's procedures, correct and safe working). The final link is with P10 and the safety procedures relating to the maintenance operation being carried out. For example, tutors will need to observe learners handling materials correctly, using relevant system protection, using appropriate PPE, working to COSHH regulations and correctly disposing of waste, as required by the task being undertaken.

To achieve a merit, learners need to compare the constructional differences of two different clutch types (for example production diaphragm spring versus motorsport paddle or production wet versus production dry types). The two clutches could be the same as those considered for P1, or if tutors wish to encourage learners to have wider experience then one or two completely different clutches could be used. The focus of the comparison should be based on the understanding developed through P1 and P2. Learners must also explain the advantages and disadvantages of multiple gear ratio applications (for example 3 speed versus 4 speed, 5 speed versus 6 speed). Finally, they need to compare two different vehicle driveline and final drive arrangements (for example longitudinal, in line versus transverse or rear engine, rear wheel drive versus rear engine four wheel-drive). Again, one of these could be the driveline and final drive considered for P5 and P6.

To achieve a distinction, learners need to justify the use of two different clutch types and two different types of driveline and final drive arrangements for differing applications (for example production, fast road, motorsport track, motorsport rally), in terms of purpose, function and performance. Once again, these could be the same clutches, driveline and final drives that learners have been working with through the pass and merit criteria.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	**Assignment title**	**Scenario**	**Assessment method**
P3, P4, M2	Vehicle Gearbox Operation	A vehicle technician has been asked to explain the operation of a vehicle gearbox to a new learner	A written task under controlled conditions or oral questioning
P5, P6, M3, D2	Vehicle Driveline and Final Drive Operation	A vehicle technician has been asked to explain the operation of a vehicle driveline and final drive to a new learner	A written task under controlled conditions or oral questioning

P7, P8, P9, P10	Maintaining Vehicle Transmission Systems	A vehicle technician has to safely inspect, diagnose and repair a transmission system	A practical maintenance task supported by observation records and a written inspection record.

Essential resources

Learners will need access to a range of transmission types (clutches, gearboxes and driveline/final drives) and their components. A variety of information and data sources specific to the transmission systems will also be required. The necessary special tools and equipment will be needed for investigation and routine maintenance of the selected transmission systems as defined in the unit content and grading criteria.

Indicative reading for learners

Textbooks

Denton T — *Advanced Automotive Fault Diagnosis* (Routledge, 2011) ISBN 9780080969558

Heisler H — *Advanced Vehicle Technology* (Elsevier, 2002) ISBN 9780750651318

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology Book 1*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Unit 54: Operation of Vehicle Chassis Systems

Level: **3**

Unit type: **Optional**

Assessment type: **Internal**

Guided learning: **60**

Unit introduction

Modern vehicles are highly developed machines that involve sophisticated and complex systems. Engines now provide more power, leading to higher torque and greater speeds than in the past, which drivers have to handle and control. This involves controlling power to the road wheels, stopping the vehicle when needed and directing it in a particular direction. In addition, the vehicle must be comfortable to travel in and be able to cope with the many forces that act on it.

This unit will introduce learners to the layout, function and operation of systems and components found in the main vehicle chassis systems. Learners will develop an understanding of the operating principles of a range of transmission, steering, suspension and braking systems.

The unit will also support further development of apprentice knowledge in areas such as fault diagnosis, specialised transmission systems, steering, suspension and brakes.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Understand the layout and operation of a transmission system and its components

2 Understand the layout and operation of a steering system and its components

3 Understand the layout and operation of a suspension system and its components

4 Understand the layout and operation of a braking system and its components.

Unit content

1 **Understand the layout and operation of a transmission system and its components**

Transmission layout: drive method e.g. front-wheel drive, rear-wheel drive, four-wheel drive; power path e.g. flywheel, clutch, gearbox, drive/prop shafts

Transmission operation: function (clutch, gearbox, prop shaft, drive shaft, universal joint, final drive, differential); factors affecting torque transmitted by clutch e.g. number of plates, diameter, friction; gearing arrangements e.g. ratios, simple and compound gear trains

Transmission components: clutch e.g. single plate spring, diaphragm; release mechanisms e.g. linkage, cable, hydraulic, pneumatic, electrical; gearbox (input shaft, lay shaft, main shaft, idler); types of gear (straight cut, helical); universal joints e.g. Hooke's type, constant velocity type; final drive–crown wheel and pinion (bevel, hypoid and helical gears), differential (sun and planet gears); drive shafts (hollow and solid); axles e.g. semi, three quarter, fully floating; wheel hubs e.g. taper, roller bearings; transmission lubricant e.g. hypoid, multi-grade

2 **Understand the layout and operation of a steering system and its components**

Steering system layout: steering method e.g. rack and pinion, recirculating ball; position adjustment

Steering operation: Ackerman layout, toe out on turns, wheel alignment, camber, castor, swivel pin inclination, negative offset; oversteer and understeer behaviour; steering arrangement e.g. two-wheel steering, four-wheel steering systems

Steering components: steering wheel and steering column (bearings, bushes, mounting); universal joint (mounting methods, gaiters); steering linkage and joints for single steer vehicles e.g. track rod, drag link, drag link ends; steering arm, tie rod (bushes, joints); steering box (seals, bearing)

3 **Understand the layout and operation of a suspension system and its components**

Suspension systems layout: suspension method e.g. beam axle, independent front suspension (IFS), independent rear suspension (IRS); vibration and damping methods e.g. metal, rubber, hydraulic, hydro-pneumatic

Suspension operation: interaction of components e.g. vehicle loaded/unloaded, cornering, 'bump' reaction

Suspension components: spring systems e.g. leaf, coil, rubber, hydraulic; fittings and mounting e.g. shackles, U-bolts, saddle, tie bar; hydraulic/hydro-pneumatic systems e.g. fluid supply, storage, actuation, control; suspension damping e.g. oil, gas, friction; tyres e.g. type (radial, cross-ply, markings) and impact on vehicle suspension system

4 **Understand the layout and operation of a braking system and its components**

Layout: braking methods e.g. disc brakes, drum brakes; braking circuit e.g. hydraulic circuit, split braking circuits

Braking system operation: application of mechanical forces e.g. pedal force, transmission of force (fluid pressure, piston sizes); brake shoes/pads; heat dissipation e.g. mechanical to heat energy, vented brake arrangement; brake efficiency e.g. vehicle testing, axle efficiencies, brake balance; leading and trailing brake shoe action

Components: hydraulic circuit components e.g. single/tandem circuit, master/slave cylinders (machined surfaces, seals, pistons, springs), brake lines (fixed and flexible piping); brake servo e.g. diaphragm, spring, valve; pressure limiting valve e.g. seal, actuation; brake adjuster e.g. manual, automatic; brake discs/drums e.g. machined surface, vented, solid; callipers/actuators e.g. piston(s), seals, mounting; brake shoes (leading, trailing, springs); brake drums (machined surface, mounting); handbrake mechanism (actuation) e.g. mechanical linkage, cables, electronic control systems

Assessment and grading criteria

In order to pass this unit, the evidence that the apprentice presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the apprentice is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the apprentice is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the apprentice is able to:**
P1 describe with the aid of sketches the layout of a vehicle's transmission	M1 compare two different types of transmission systems	D1 evaluate and justify the choice, in terms of layout and operation, of the transmission, steering, suspension and braking systems used for a current vehicle application
P2 explain the operation of a transmission system and its components		
P3 describe with the aid of sketches the layout of a vehicle's steering system	M2 compare two different types of steering systems	
P4 explain the operation of a steering system and its components		
P5 describe with the aid of sketches the layout of a vehicle's suspension system	M3 compare two different types of suspension systems	
P6 explain the operation of a suspension system and its components		
P7 describe with the aid of sketches the layout		

of a vehicle's braking system P8 explain the operation of a braking system and its components.	M4 compare two different types of braking systems.	

Essential guidance for tutors

Assessment

Assessment of this unit might be best achieved through four separate assignments supported by sketches, each covering one of the listed systems (i.e., transmission, steering, suspension and brakes).

The assignments need to be constructed in such a way as to ensure sufficient coverage of the grading criteria and related unit content. Opportunities to meet the pass and merit criteria that relate to each system should be provided, for example to be able to describe a vehicle's transmission layout (P1), explain its operation and components (P2) and compare it with another different type of transmission (M1). The comparison for the merit criterion should also cover the different system's layout, operation and components.

The assignment could direct learners to investigate a given or chosen system (for example transmission) and then prepare their descriptions. Learners should be encouraged to research and use a range of resource materials during their investigation. Tutors should provide guidance on how such material can be referenced and used as part of learners' own work so as not to infringe guidelines on authentic evidence, for example annotation of images, diagrams used to support/clarify own text. Development of these research and presentation skills may also provide suitable evidence for functional skills attainment.

Guidance should be provided, during the early formative assessment period, on the type of evidence and amount of detail required, to ensure that it is sufficiently concise, clear and relevant to the unit criteria and content.

To achieve a pass, learners will need to produce a suitable description of each system's layout. This could be achieved through the production of drawings or sketches that illustrate the relevant aspects of the content (for example for P1, a transmission's drive method and power path). The drawings should then be suitably labelled and/or annotated to provide a sufficient description of the layout (for example to clearly identify the path taken by the power between the flywheel and the driven road wheels). In addition, for each system a suitable explanation of its operation and components is needed. Again, drawings or sketches can be used to good effect to support any written evidence (for example for P6, drawings that show the interaction of components during a 'bump' reaction of a suspension system, together with suitable labelling of the key components that play a part in the suspension of the vehicle under such conditions).

These could also be supplemented with evidence from practical activities carried out in other units or from work experience (for example steering geometry test report, braking efficiency tests). The use of such practical work would provide a vocational context to what could be seen as an overly theoretical unit.

To achieve the merit criteria, learners will need to compare two different types of system for each of those covered by the pass criteria (ie transmission, steering, suspension and brakes). One could be the system already examined for pass. The second could be chosen by the apprentice or set by the tutor, but it should be sufficiently different to provide scope for comparison. The comparison should consider the differences and similarities in terms of each system's layout, operation and components. It should also consider the differences in terms of how the components of each system interrelate with one another.

To achieve the distinction criterion, learners will need to choose, or be given, a current vehicle to investigate and evaluate in terms of the layout and operation of the four systems considered at pass level.

It is expected that tutors will supervise the final choice of vehicle so that learners are exposed to systems different to those already covered through the pass and merit criteria (for example if two-wheel drives have been the main focus at pass/merit, then learners should consider a four-wheel drive vehicle for D1). This will give learners both variety in their study and exposure to a greater range of systems. The evaluation and justification should take into account the intended use and therefore design of the vehicle. It should also consider the interrelationships between the systems, for example the impact of the type of suspension on the steering and handling of the vehicle.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Transmission Systems	A vehicle technician needs to explain the layout and operation of a transmission system to a new apprentice	A written task supported by relevant drawings/sketches
P3, P4, M2	Steering Systems	A vehicle technician needs to explain the layout and operation of a steering system to a new apprentice	A written task supported by relevant drawings/sketches
P5, P6, M3	Suspension Systems	A vehicle technician needs to explain the layout and operation of a suspension system to a new apprentice	A written task supported by relevant drawings/sketches
P7, P8, M4	Braking Systems	A vehicle technician needs to explain the	A written task supported by relevant drawings/sketches

		layout and operation of a braking system to a new apprentice	
D1	Evaluating Vehicle System Applications	A vehicle fleet operator has asked a technician to evaluate the suitability of a possible new fleet vehicle	A written report

Essential resources

Centres need to provide learners with access to vehicle components (e.g. bevel, hypoid and helical gears), demonstration rigs (e.g. sectioned clutches, gearboxes, steering boxes) and vehicles. A range of suitable reference material (e.g. manuals and manufacturers' data) relating to the systems covered is also essential.

Employer engagement and vocational contexts

Indicative reading for apprentices

Textbooks

Hillier, V — *Hillier's Fundamentals of Motor Vehicle Technology*, 6th Edition (Nelson Thornes, 2012) ISBN 9781408515181

Nunney, M — *Light and Heavy Vehicle Technology* (Routledge, 2006) ISBN 9780750680370

Unit 55: Mechanical Principles of Engineering Systems

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

The use and application of mechanical systems is an essential part of modern life. The design, manufacture and maintenance of these systems are the concern of engineers and technicians who must be able to apply a blend of practical and theoretical knowledge to ensure that systems work safely and efficiently. Science underpins all aspects of engineering and a sound understanding of its principles is essential for anyone seeking to become an engineer.

Learners are introduced to the behaviour of loaded engineering materials and the analysis of a range of static engineering systems. They will gain an understanding of dynamic systems through the application of Newtonian mechanics. Finally, they will deal with the effects of heat transfer, the expansion and compression of gases and the characteristic behaviour of liquids at rest and in motion.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to determine the effects of loading in static engineering systems

2 Be able to determine work, power and energy transfer in dynamic engineering systems

3 Be able to determine the parameters of fluid systems

4 Be able to determine the effects of energy transfer in thermodynamic systems.

Unit content

1 **Be able to determine the effects of loading in static engineering systems**

Non-concurrent coplanar force systems: graphical representation e.g. space and free body diagrams; resolution of forces in perpendicular directions e.g. $F_x = F \cos\theta$, $F_y = F \sin\theta$; vector addition of forces, resultant, equilibrant, line of action; conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$)

Simply supported beams: conditions for static equilibrium; loading (concentrated loads, uniformly distributed loads, support reactions)

Loaded components: elastic constants (modulus of elasticity, shear modulus); loading (uniaxial loading, shear loading); effects e.g. direct stress and strain including dimensional change, shear stress and strain, factor of safety

2 **Be able to determine work, power and energy transfer in dynamic engineering systems**

Kinetic parameters: e.g. displacement *(s)*, initial velocity *(u)*, final velocity *(v)*, uniform linear acceleration *(a)*

Kinetic principles: equations for linear motion with uniform acceleration ($v = u + at$, $s = ut + ½at^2$, $v^2 = u^2 + 2as$, $s = ½(u + v)t$)

Dynamics parameters: e.g. tractive effort, braking force, inertia, frictional resistance, gravitational force, momentum, mechanical work ($W = Fs$), power dissipation (*Average Power* = W/t, *Instantaneous Power* = Fv), gravitational potential energy ($PE = mgh$), kinetic energy ($KE = ½mv^2$)

Dynamic principles: Newton's laws of motion, D'Alembert's principle, principle of conservation of momentum, principle of conservation of energy

3 **Be able to determine the parameters of fluid systems**

Thrust on a submerged surface: hydrostatic pressure, hydrostatic thrust on an immersed plane surface ($F = \rho\ g\ A\ x$); centre of pressure of a rectangular retaining surface with one edge in the free surface of a liquid

Immersed bodies: Archimedes' principle; fluid e.g. liquid, gas; immersion of a body e.g. fully immersed, partly immersed; determination of density e.g. using floatation, specific gravity bottle

Flow characteristics of a gradually tapering pipe: e.g. volume flow rate, mass flow rate, input and output flow velocities, input and output diameters, continuity of volume and mass for incompressible fluid flow

4 **Be able to determine the effects of energy transfer in thermodynamic systems**

Heat transfer: heat transfer parameters e.g. temperature, pressure, mass, linear dimensions, time, specific heat capacity, specific latent heat of fusion, specific latent heat of vaporisation, linear expansivity; phase e.g. solid, liquid, gas; heat transfer principles e.g. sensible and latent heat transfer, thermal efficiency and power rating of heat exchangers; linear expansion

Thermodynamic process equations: process parameters e.g. absolute temperature, absolute pressure, volume, mass, density; Boyle's law (pV = *constant*), Charles' law (V/T = *constant*), general gas equation (pV/T = *constant*), characteristic gas equation ($pV = mRT$)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 calculate the magnitude, direction and position of the line of action of the resultant and equilibrant of a non-concurrent coplanar force system containing a minimum of four forces acting in different directions		
P2 calculate the support reactions of a simply supported beam carrying at least two concentrated loads and a uniformly distributed load		
P3 calculate the induced direct stress, strain and dimensional change in a component subjected to direct uniaxial loading and the shear stress and strain in a component subjected to shear loading	M1 calculate the factor of safety in operation for a component subjected to combined direct and shear loading against given failure criteria	

P4 solve three or more problems that require the application of kinetic and dynamic principles to determine unknown system parameters	M2 determine the retarding force on a freely falling body when it impacts upon a stationary object and is brought to rest without rebound, in a given distance	D1 compare and contrast the use of D'Alembert's principle with the principle of conservation of energy to solve an engineering problem
P5 calculate the resultant thrust and overturning moment on a vertical rectangular retaining surface with one edge in the free surface of a liquid		
P6 explain Archimedes Principle	M3 determine the up-thrust on an immersed body	D2 evaluate the methods that might be used to determine the density of an irregular shaped solid material
P7 use the continuity of volume and mass flow for an incompressible fluid to determine the design characteristics of a gradually tapering pipe		
P8 calculate the dimensional change when a solid material undergoes a change in temperature and the heat transfer that accompanies a change of temperature and phase	M4 determine the thermal efficiency of a heat transfer process from given values of flow rate, temperature change and input power	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P9 solve two or more problems that require application of thermodynamic process equations for a perfect gas to determine the unknown parameters of the problems	M5 determine the force induced in a rigidly held component that undergoes a change in temperature	

Essential guidance for tutors

Assessment

The criterion P1 requires the solution of a single non-concurrent force system that contains a minimum of four active forces. It will be expected that two of these forces will be set to act in directions other than the horizontal and vertical. This will necessitate the resolution of forces in perpendicular directions, e.g. the use of $F_x = F \cos\theta$ and $F_y = F \sin\theta$, as the first step in the solution to the problem. A typical problem might be an engineering component under the action of at least four non-concurrent forces whose magnitudes and directions are given. One of the forces might be its own weight but at least two of them should act in directions other than the horizontal and vertical. Learners would be expected to produce space and free body diagrams, resolve forces horizontally and vertically and take moments of the forces about some suitable reference point. The magnitude and direction of the resultant force and the position of its line of action could then be found through vector addition, application of Pythagoras' theorem and consideration of the resultant turning moment.

P2 will use similar skills to those required for P1 but in this case they will be applied to a simply supported beam carrying two point loads, as a minimum, and a uniformly distributed load. These specifications will provide centres with a variety of loading possibilities that can be used for assessment purposes. During the delivery phase for this part of the unit a greater range of loading may be considered but centres need only work with the minimum for assessment purposes. Neither the content nor criteria stipulate that the point loads should be anything other than perpendicular to the beam. During delivery however, it may be useful to demonstrate the resolution of forces applied at an angle to the beam and calculation of the magnitude and directions of the support reactions.

The assessment for criterion P3 will require a task to calculate the direct stress, direct strain and the accompanying dimensional change in a directly loaded component. It will also require a task to calculate the shear stress and shear strain in a component or material subjected to shear loading. Centres should consider how the tasks set for P3 could be extended to incorporate an opportunity to achieve M1. This might involve consideration of the factor of safety in operation for an angled joint that is bolted or riveted such that the fastenings are subjected to both tensile and shearing forces.

It will require the setting of at least three dynamic system tasks to ensure that the range of kinetic and dynamic principles is applied to achieve P4. Centres should not fragment the application of kinetic and dynamic principles to the extent that they over simplify the problems. It is the interrelationships between the kinetic and dynamics principles that are as important as the use of any single equation. The principles applied in P4 can be directly linked to M2, although achievement of M2 will require a further task to be set to consider the impact of a freely falling body. Suitable examples of this type of problem are listed in the delivery section of these guidance notes. A final task to achieve the distinction criterion D1 will be required to enable learners to consider and solve an engineering problem using the two alternative approaches (i.e. D'Alembert's principle and the principle of conservation of energy), and compare the two methods.

P5 may be achieved by calculating resultant thrust and overturning moment on a rectangular retaining surface, examples of which are listed in the delivery section. P6 requires an explanation of Archimedes' Principle.

M3 may be achieved by calculating the up-thrust on a totally immersed body using Archimedes' principle. An understanding of fluid principles is needed to achieve D2, which requires learners to evaluate the methods used to determine the density of an irregular shaped solid object.

The criterion P7 examines the learner's basic understanding of fluid flow. It may be achieved by considering the design of a gradually tapering pipe to suit given dimensional and flow constraints.

The criteria P8 and P9 have been designed to assess the thermodynamics aspects of the unit. P8 will require tasks to determine the dimensional change in an engineering component that accompanying a change in temperature, and the sensible and latent heat transfer that accompanies a change of temperature and phase in a substance. P9 will require tasks involving the range of thermodynamic process equations applicable to the expansion and compression of an ideal gas. The area of work covered by P8 – the effects of heat transfer – is extended in the merit criteria M4 and M5.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Static Systems	Problems involving engineering components subjected to static force systems.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.
P4, M2, D1	Dynamic Systems	Problems involving force, work and power in dynamic engineering system.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.
P5, P6, P7, M3, D2	Fluid Systems	Problems involving hydrostatic thrust and fluid dynamics. Experimental methods used to determine density.	A written report containing an introductory explanation to each step in the sequence of calculations and findings, and an evaluation of the methods used to determine density.
P8, P9, M4, M5	Thermodynamic Systems	Problems involving heat transfer and dimensional change in thermodynamic systems and involving the expansion and compression of gases.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.

Essential resources

As this is a very practical based unit, centres should provide access to laboratory facilities with a sufficient range of investigation and demonstration equipment wherever possible. In particular, tensile testing equipment, dynamics trolleys, linear expansivity apparatus, apparatus to determine density and apparatus for verification of Boyle's and Charles' laws would be of significant value.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Darbyshire A – *Mechanical Engineering BTEC National Option Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 56: Electrical and Electronic Principles in Engineering

Level: 3

Unit type: Optional

Assessment type: Internal

Guided learning: 60

Unit introduction

The modern world relies on electrical and electronic devices – from mobile telephones to jet aeroplanes, these devices have had an enormous impact on the way we live today. Without early engineers such as Faraday and Lenz, who studied the then new concept of electricity, many of the inventions we now take for granted would not have been developed.

The unit starts by developing and extending learners' understanding of fundamental electrical and electronic principles through analysis of simple direct current (DC) circuits. Learners are then taken through the various properties and parameters associated with capacitance and inductance, before finally considering the application of single-phase alternating current (AC) theory. The unit will encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

For learners wishing to follow an electrical/electronic programme this unit is an essential building block that will provide the underpinning knowledge required for further study of electrical and electronic applications.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits

2 Be able to apply the concepts of capacitance in DC circuits

3 Know the principles and properties of magnetism

4 Be able to use single-phase alternating current (AC) theory

Unit content

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits

DC circuit theory: voltage e.g. potential difference, electromotive force (emf); resistance e.g. conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source e.g. cell, battery, stabilised power supply; resistors e.g. function, types, values, colour coding; diodes e.g. types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae e.g. $V = IR$, $P = IV$, $W = Pt$, application of Kirchhoff's voltage and current laws

DC networks: networks with one DC power source and at least five components e.g. DC power source with two series resistor and three parallel resistors connected in a series parallel arrangement; diode resistor circuit with DC power source, series resistors and diodes

Measurements in DC circuits: safe use of a multimeter e.g. setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source, testing a diode's forward and reverse bias)

2 Be able to apply the concepts of capacitance and determine in DC circuits

Capacitors: types (electrolytic, mica, plastic, paper, ceramic, fixed and variable capacitors); typical capacitance values and construction (plates, dielectric materials and strength, flux density, permittivity); function e.g. energy stored, circuits (series, parallel, combination); working voltage

Charging and discharging of a capacitor: measurement of voltage, current and time; tabulation of data and graphical representation of results; time constants

DC network that includes a capacitor: e.g. DC power source with two/three capacitors connected in series, DC power source

3 Know the principles and properties of magnetism

Magnetic field: magnetic field patterns e.g. flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops; ferromagnetic materials; reluctance; magnetic screening; hysteresis

Electromagnetic induction: principles e.g. induced electromotive force (emf), eddy currents, self and mutual inductance; applications (electric motor/generator e.g. series and shunt motor/generator; transformer e.g. primary and secondary current and voltage ratios); application of Faraday's and Lenz's laws

4 Be able to use single-phase alternating current (AC) theory

Single phase AC circuit theory: waveform characteristics e.g. sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities e.g. graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure R, L and C components

AC circuit measurements: safe use of an oscilloscope e.g. setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values); circuits e.g. half and full wave rectifiers

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

– Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 use DC circuit theory to calculate current, voltage and resistance in DC networks	M1 use Kirchhoff's laws to determine the current in various parts of a network having four nodes and the power dissipated in a load resistor containing two voltage sources	
P2 use a multimeter to carry out circuit measurements in a DC network		
P3 Describe the forward and reverse characteristics of two different types of semiconductor diode		
P4 describe the types and function of capacitors		
P5 carry out an experiment to determine the relationship between the voltage and current for a charging and discharging capacitor		
P6 calculate the charge, voltage and energy values in a DC network for both	M2 explain capacitance, charge, voltage and energy in a network containing a series-	

three capacitors in series and three capacitors in parallel	parallel combination of three capacitors	
P7 describe the characteristics of a magnetic field		D1 evaluate the performance of a motor and a generator by reference to electrical theory.
P8 describe the relationship between flux density (B) and field strength (H)		
P9 describe the principles and applications of electromagnetic induction	M3 explain the application of electromagnetic induction in motors and generators	
P10 use single phase AC circuit theory to determine the characteristics of a sinusoidal AC waveform	M4 compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram.	D2 analyse the operation and the effects of varying component parameters of a power supply circuit that includes a transformer, diodes and capacitors
P11 use an oscilloscope to measure and determine the inputs and outputs of a single phase AC circuit.		

Essential guidance for tutors

Assessment

Much of the evidence for the pass criteria can be achieved by practical experimentation with real components and circuits and computer-based software packages, where appropriate.

It is likely that at least five assessment instruments will be required for this unit. If practical work and tests are also used then the total number of pieces of assessed work could be even more than this. This should be carefully considered so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Clearly, the ability to safely use a multimeter (P2) will require process evidence, i.e, it will need to be observed by the tutor during relevant practical activities. Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The assessment of the use of circuit theory to calculate current, voltage and resistance in DC networks (P1) could be achieved by using a paper-based or computer-based method. However, it is essential that centres combine any testing of this sort with practical hands-on experience of real circuits and components. This could be achieved by prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement. Whichever method is used, centres need to ensure that sufficient product evidence is available of the circuit being used/developed and the formulae selected/used to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where print-outs do not show sufficient detail to meet the criteria.

The description of the forward and reverse characteristics of two types of semi-conductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box.

For P4, learners will need to describe the full range of types of capacitors (electrolytic, mica, plastic, and paper, ceramic, fixed and variable) including typical capacitance values, construction (plates, dielectric materials and strength, flux density, permittivity), their function and working voltages.

P5 requires learners to carry out a laboratory experiment to investigate the charging and discharging of a capacitor through a resistor. A simple but effective way of doing this is to use a power supply unit, a 500μF electrolytic capacitor, a stopwatch or clock and an AVO type multimeter, using the internal resistance of the meter as the resistor. Learners could then be asked to plot the graph of the growth of capacitor voltage against time and evaluate the time constant by comparing the results with standard theory.

P6 involves the calculation of charge, voltage and energy values for DC networks that include a DC power source with two/three capacitors connected in series and a DC power source with two/three capacitors connected in parallel.

The characteristics of magnetic fields for P7 could be demonstrated on an OHP by using magnets and iron filings. Learners could sketch the results and then make appropriate comparisons with expected theoretical results. For P8, learners need to explain the relationship between flux density (B) and field strength (H) with particular emphasis on BH curves and the use of different materials such as silicon iron and mild steel.

The evidence for P9 will be descriptive and requires learners to provide basic explanations of the principles and concepts of electromagnetic induction such as the movement of a conductor within a magnetic field.

P10 and P11 could link AC theory and practice with learners observing and measuring some of the fundamental characteristics of a single wave AC circuit. This will require the use of a multimeter and an oscilloscope to make appropriate comparisons of frequency, maximum and rms values.

M1 relates to the use of Kirchhoff's laws and here again learners should be encouraged to check their results by using a computer software package and/or practical experiment. This criterion naturally follows on from the work on resistors in series and parallel in DC circuits and, as such, could perhaps be incorporated into an assignment covering P1, P2 and M1. For M2, learners need to explain capacitance, charge, voltage and energy for specific capacitors in a series parallel combination. This extends the understanding from the pass grade criterion and could naturally form a next step in an assignment/assessment activity devised for P6. M3 is an extension of P9 requiring an explanation of the application of electromagnetic induction in motors and generators. M4 is intended as an exercise in the graphical addition of two sinusoidal voltages or currents, checking the values theoretically by calculation and also by practical means. This criterion could be linked to *Unit 3: Mathematics for Engineering Technicians* and, once learners had been taught the sine and cosine rules, could be used to provide evidence for both units.

D1 requires learners to evaluate the performance of motors and generators by reference to electrical theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines.

For D2, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of high voltages or currents present. This could be achieved using a function generator as a source of sinusoidal alternating voltage, along with a small isolating transformer, diode rectifiers (half wave and bridge) smoothing capacitors and load resistors.

As suggested earlier, and illustrated in the assignment grid, it would be appropriate to use a five-assessment model to assess this unit.

The first is a theoretical assignment under controlled conditions could assess P1 and M1.

A second practical assignment could be used to assess P2 and P3, again possibly under controlled conditions.

Assignment 3 is to assess P4, P5, P6 and M2 and could be a mixed assignment, preferable not done under controlled conditions.

The fourth assignment could again be a mixed assignment to assess P7, P8, P9, M3 and D1.

Finally, assignment 5 assesses P10, P11, M4 and D2 and could be of a practical nature carried out under controlled conditions.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Edexcel assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	DC Circuit Theory/Resistor Networks and Kirchhoff's Laws	An activity requiring learners to complete two tasks, one for each criterion. Task 1 involves learners evaluating current, voltage and resistance in a DC network and task 2 using Kirchhoff's laws to determine the current and power dissipated in a load resistor.	A report containing the results of calculations to evaluate current, voltage, resistance and power for a DC network using DC circuit theory and Kirchhoff's laws. Carried out under controlled conditions.
P2, P3	DC Circuit Theory/Measurement and Diodes	A practical activity requiring learners to complete measurements using a multimeter in a DC network for task 1 and compare the forward and reverse characteristics of two different types of semi-conductor diode for task 2	For both tasks learners will be required to complete pre-prepared response sheets with their measurements and make required responses together with a brief conclusion. Carried out under controlled conditions
P4, P5, P6, M2	Capacitors	A mixed activity comprising of four tasks. The first being of a descriptive nature to describe the types and function of capacitors	A written report containing written responses to the descriptive task, tabulated results and graphs for the practical, together with calculations for the DC networks

		Second, an experiment to determine the relationship between voltage and current for a charging and discharging capacitor. The third and fourth involve the learner carrying out calculations to evaluate capacitance, charge voltage and energy in DC networks	
P7, P8, P9, M3, D1	Magnetism, Transformers and Motor/Generators	A mixed activity comprising four tasks. The first three are to describe the characteristics of a magnetic field, explain the relationship between flux density and field strength, and describe the principles and applications of electromagnetic induction. The final task is to evaluate the performance of a motor and generator	A written report containing labelled diagrams illustrating magnetic fields, graphical plots of BH curves and diagrams with descriptions to illustrate principles and applications of electromagnetic induction For the distinction criteria it would be envisaged that comprehensive answers to pre-prepared response sheets together with diagrams, graphs and calculations need to be submitted
P10, P11, M4, D2	Single Phase AC	A practical activity requiring learners to complete four tasks. First, using single-phase AC theory to consider the characteristics of a sinusoidal AC waveform and	A written report using pre-prepared response sheets and graph paper carried out under controlled conditions.

		second, use an oscilloscope to evaluate the inputs and outputs of a single phase AC circuit. Third, to compare the results of the addition and subtraction of two sinusoidal AC waveforms. Fourth, to analyse the operation of a power supply.	

Essential resources

It is essential that learners have access to a well-equipped electrical and electronics laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content, together with the means to physically construct circuits.

With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9781466501096

Robertson C R – *Fundamental Electrical and Electronic Principles* (Routledge, 2008) ISBN 9780750687379

14 Further information and useful publications

To get in touch with us visit our ‘Contact us’ pages:

- Edexcel, BTEC and Pearson Work Based Learning contact details: qualifications.pearson.com/en/support/contact-us.html
- books, software and online resources for UK schools and colleges: www.pearsonschoolsandfecolleges.co.uk

Key publications:

- *Adjustments for candidates with disabilities and learning difficulties – Access and Arrangements and Reasonable Adjustments, General and Vocational qualifications* (Joint Council for Qualifications (JCQ))
- *Equality Policy* (Pearson)
- *Recognition of Prior Learning Policy and Process* (Pearson)
- *UK Information Manual* (Pearson)
- *UK Quality Vocational Assurance Handbook* (Pearson).

All of these publications are available on our website.

Publications on the quality assurance of BTEC qualifications are available on our website.

Our publications catalogue lists all the material available to support our qualifications. To access the catalogue and order publications, please visit our website.

Additional resources

If you need further learning and teaching materials to support planning and delivery for your learners, there is a wide range of BTEC resources available.

Any publisher can seek endorsement for their resources, and, if they are successful, we will list their BTEC resources on our website, qualifications.pearson.com

15 Professional development and training

Pearson supports UK and international customers with training related to BTEC qualifications. This support is available through a choice of training options offered on our website, qualifications.pearson.com

The support we offer focuses on a range of issues, such as:

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- developing effective assignments
- building your team and teamwork skills
- developing learner-centred learning and teaching approaches
- building in effective and efficient quality assurance systems.

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Regional support: our team of Curriculum Development Managers and Curriculum Support Consultants, based around the country, are responsible for providing advice and support in centres. They can help you with planning and curriculum developments.

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Your Pearson support team

Whether you want to talk to a sector specialist, browse online or submit your query for an individual response, there’s someone in our Pearson support team to help you whenever – and however – you need:

- Subject Advisors: find out more about our subject advisor team – immediate, reliable support from a fellow subject expert
- Ask the Expert: submit your question online to our Ask the Expert online service and we will make sure your query is handled by a subject specialist.

Please visit, qualifications.pearson.com/en/support/contact-us.html

Apprenticeship Standard

Automotive Manufacturing Sector

Employer Occupational Brief

Occupational Competence and Technical Knowledge Qualifications

Assessment Strategy for

Employers, Training Providers and Awarding Organisations

Version 2

Table of Contents

Article XIV. Introduction

Employers in the Automotive Manufacturing Sector have produced this Assessment Strategy to:

- support the implementation and delivery of the Apprenticeship Standard
- provide clarity for Awarding Organisations on what constitutes competent performance
- encourage and promote consistent assessment of Competence and Technical Knowledge requirements
- promote cost effective delivery and assessment plans.

This document also provides definitions for:

- the qualifications and experience required for Assessors/Trainers/Teachers and Verifiers
- the assessment environment for the Foundation and Development Phase Occupational Competence Qualifications
- access to assessment.

and requirements relating to:

- carrying out occupational competence assessments
- performance evidence requirements for occupational competence
- assessing knowledge and understanding
- use of witness testimonies
- continuing professional development
- quality control of assessment.

Article XV. Section 1

1) Occupational Competence Qualifications (Foundation and Development Phase)

Article XVI.

Article XVII. Assessor Requirements to Demonstrate Effective Assessment Practice

Article XVIII.

Assessment must be carried out by competent Assessors that as a minimum must hold the QCF Level 3 Award in Assessing Competence in the Work Environment**.** Current and operational Assessors that hold units D32 and/or D33 or A1 and/or A2 as appropriate to the assessment being carried out, will not be required to achieve the QCF Level 3 Award as they are still appropriate for the assessment requirements set out in this Assessment Strategy. However, they will be expected to regularly review their skills, knowledge and understanding and where applicable undertake continuing professional development to ensure that they are carrying out workplace assessment to the most up to date Employer Units of Competence.

Assessor Technical Requirements

Assessors must be able to demonstrate that they have verifiable, relevant and sufficient technical competence to evaluate and judge performance and knowledge evidence requirements as set out in the relevant outcomes in the Employer Units of Competence.

This will be demonstrated either by holding a relevant technical qualification or by proven industrial experience of the technical areas to be assessed. The assessor's competence must, at the very least, be at the same level as that required of the Apprentice in the units being assessed.

Assessors must also:

Article XIX.

Article XX. Be fully conversant with the Awarding Organisation's assessment recording documentation used for the Employer Units of Competence against which the assessments and verification are to be carried out, plus any other relevant documentation and system and procedures to support the QA process.

Article XXI.

Article XXII. Verifier Requirements (internal and external)

Article XXIII.

Article XXIV. Internal quality assurance (Internal Verification) must be carried out by competent Verifiers that as a minimum must hold the QCF Level 4 Award in the Internal Quality Assurance of Assessment Processes and Practices. Current and operational Internal Verifiers that hold internal verification units V1 or D34 will not be required to achieve the QCF Level 4 Award as they are still appropriate for the verification requirements set out in this Assessment Strategy. Verifiers must be familiar with, and preferably hold, either the nationally recognised Assessor units D32 and/or D33 or A1 and/or A2 or the QCF Level 3 Award in Assessing Competence in the Work Environment.

Article XXV.

Article XXVI. External quality assurance (External Verification) must be carried out by competent External Verifiers that as a minimum must hold the QCF Level 4 Award in the External Quality Assurance of Assessment Processes and Practices**.** Current and operational External Verifiers that hold external verification units V2 or D35 will not be required to achieve the QCF Level 4 Award as they are still appropriate for the verification requirements set out in this Assessment Strategy. Verifiers must be familiar with, and preferably hold, either the nationally recognised Assessor units D32 and/or D33 or A1 and/or A2 or the QCF Level 3 Award in Assessing Competence in the Work Environment.

Article XXVII.

Article XXVIII. External and Internal Verifiers will be expected to regularly review their skills, knowledge and understanding and where applicable undertake continuing professional development to ensure that they are carrying out workplace Quality Assurance (verification) of Assessment Processes and Practices to the most up to date Employer Units of Competence.

Article XXIX.

Article XXX. Verifiers, both Internal and External, will also be expected to be fully conversant with the terminology used in the Employer Units of Competence against which the assessments and verification are to be carried out, the appropriate Regulatory Body's systems and procedures and the relevant Awarding Organisation's documentation, systems and procedures within which the assessment and verification is taking place.

Article XXXI.

Specific technical requirements for internal and external verifiers

Article XXXII.

Article XXXIII. Internal and external Verifiers for the Employer Units of Competence must be able to demonstrate that have verifiable, sufficient and relevant industrial experience, and must have a working knowledge of the processes, techniques and procedures that are used in the engineering industry.

Article XXXIV.

Article XXXV. The tables below and overleaf show the recommended levels of technical competence for assessors, internal verifiers, and external verifiers.

Article XXXVI.

Technical Requirements for Assessors and Verifiers

Position	Prime activity requirements	Support activity requirements	Technical requirements (see notes)
Assessor	Assessment Skills	IV Systems	Technical *competence* in the areas covered by the Employer Units of Competence being assessed
Internal Verifier	Verification Skills	Assessment Knowledge	Technical *understanding* of the areas covered by the Employer Units of Competence being verified
External Verifier	Verification skills	Assessment Understanding	Technical *awareness* of the areas covered by the Employer Units Competence being verified

Notes

1. Technical *competence* is defined here as a combination of practical skills, knowledge, and the ability to apply both of these, in familiar and new situations, within a real working environment.

2. Technical *understanding* is defined here as having a good understanding of the technical activities being assessed, together with knowledge of relevant Health & Safety implications and requirements of the assessments.

3. Technical *awareness* is defined here as a general overview of the subject area, sufficient to ensure that assessment and evidence are reliable, and that relevant Health and Safety requirements have been complied with.

4. The competence required by the assessor, internal verifier and external verifier, in the occupational area being assessed, is likely to exist at three levels as indicated by the shaded zones in the following table.

Technical Competence / required by:	An ability to *discuss* the general principles of the competences being assessed	An ability to *describe* the practical aspects of the competence being assessed	An ability to *demonstrate* the practical competences being assessed
Assessor	(shaded)	(shaded)	(shaded)
Internal Verifier	(shaded)	(shaded)	
External Verifier	(shaded)		

Article XXXVII.

Article XXXVIII. **Assessment Environment of the Employer Units of Competence in the Foundation Phase of the Apprenticeship**

Article XXXIX.

Article XL. The Employer Units of Competence are intended to have a wide application throughout the Automotive Manufacturing Sector. It is necessary therefore to have a flexible approach to the environment in which the Employer Units of Competence are delivered and assessed during the Foundation Phase of the Apprenticeship.

Article XLI.

Article XLII. Therefore, there is much to be gained by acquiring the basic engineering competencies required in the Foundation Phase of the Apprenticeship whilst working in a sheltered but realistic environment such as in a Training Centre or College. This is due to an ongoing emphasis on safety critical work activities and the need to ensure flexibility of assessment opportunities to both maintain and enhance the provision of competent personnel within the Automotive Manufacturing sector. This assessment method will allow a minimum safe level of skills, knowledge and understanding to be achieved and demonstrated by the Apprentice prior to being exposed to the hazards of the industrial environment, thus minimising the risk of injury to themselves and other employees.

Article XLIII.

Article XLIV. For the above reasons the assessment of the Apprentices competence in a sheltered but realistic environment **is acceptable** for the Employer Units of Competence included the Foundation Stage of the Apprenticeship, where the environment replicates that expected in industry.

Article XLV. Where applicable, the machinery, tools, materials, equipment and resources used must be representative of industry standards and there must be sufficient equipment/resources available for each Apprentice to demonstrate their competence on an individual basis. Workpieces or work outcomes assessed must be the Apprentices own work and should be actual work examples that combine the skills, techniques required by the Employer Units of Competence so that achievement will properly reflect the Apprentices capabilities

Article XLVI.

Article XLVII. Assessors must therefore ensure that the competency is fully transferable to the workplace. Other aspects that should be considered could include:

- environmental conditions such as lighting conditions, noise levels and the presence of hazards
- pressure of work such as time constraints and repetitive activities
- producing actual workpieces or work outcomes and the consequence of making mistakes and the effect this has on customer, supplier and departmental relationships.

Article XLVIII.

Article XLIX. Assessment Environment of the Employer Units of Competence in the Development Phase of the Apprenticeship

Article L.

Article LI. The evidence put forward for the Employer Units of Competence can **only** be regarded valid, reliable, sufficient and authentic if achieved and obtained in the working environment, where the Apprentice is employed and be clearly attributable to the Apprentice. However, in certain circumstances, simulation/replication of work activities may be acceptable, but must be kept to an absolute minimum.

The use of high quality, realistic simulations/replication, which impose pressures which are consistent with workplace expectations, should only be used in relation to the assessment of the following:

- rare or dangerous occurrences, such as those associated with health, safety and the environment issues, emergency scenarios and rare operations at work;
- the response to faults and problems for which no opportunity has presented for the use of naturally occurring workplace evidence of learners competence;
- aspects of working relationships and communications for which no opportunity has presented for the use of naturally occurring workplace evidence of learners competence.

Simulations/replications will require prior approval from the specific Awarding Organisation and should be designed in relation to the following parameters:

- the environment in which simulations take place must be designed to match the characteristics of the working environment;
- competencies achieved via simulation/replication must be transferable to the working environment;
- simulations which are designed to assess competence in dealing with emergencies, accidents and incidents must be verified as complying with relevant health, safety and environmental legislation by a competent health and safety/environmental control officer before being used;
- simulated activities should place Apprentices under the same pressures of time, access to resources and access to information as would be expected if the activity was real;
- simulated activities should require Apprentices to demonstrate their competence using plant and/or equipment used in the working environment;
- simulated activities which require interaction with colleagues and contacts should require the Apprentice to use the communication media that would be expected at the workplace;
- for health and safety reasons simulations need not involve the use of genuine substances/materials. Any simulations which require the Apprentice to handle or otherwise deal with materials substances/should ensure that the substitute takes the same form as in the workplace.

Article LII. Access to Assessment

Article LIII.

Article LIV. There are no entry requirements required for the Employer Units of Competence unless this is a legal requirement of the process or the environment in which the Apprentice is working in. Assessment is open to any Apprentice who has the potential to reach the assessment requirements set out in the relevant units.

Article LV.

Article LVI. Aids or appliances, which are designed to alleviate disability, may be used during assessment, providing they do not compromise the standard required.

Article LVII.

Article LVIII. Carrying Out Assessments of the Occupational Competence Qualifications

Article LIX.

Article LX. The Employer Units of Competence have been specifically developed to cover a wide range of activities. The evidence produced for the units will, therefore, depend on the skills and knowledge required by employer and specified in the Apprentices Training Plan. The Skills section of the Employer Units of Competence makes reference to a number of optional items listed in the Skills section of the units **(for example 'any three from five')**. This is the minimum standard set by employers.

Article LXI. Where the unit requirements gives a choice of optional areas**,** assessors should note that Apprentices do not need to provide evidence of the other areas to complete the unit, unless specified by the employer (in this example above, two items) particularly where these additional items may relate to other activities or methods that are not part of the Apprentices normal workplace activities or required by the employer.

Article LXII.

Article LXIII. Performance Evidence Requirements of the Occupational Competence Qualifications

Article LXIV. Performance evidence must be the main form of evidence gathered.

Article LXV. For the Mechatronics Maintenance Technician and Product Design and Development Technician Apprenticeship Standards, in order to demonstrate consistent competent performance for a unit, a minimum of **two** different examples of performance of the unit activity will be required in the Foundation Phase plus the successful achievement of the gateway assessment. For the Development Phase a minimum of **three** different examples of performance of the unit activity will be required (there will be no gateway assessment at the end of the Development Phase). Items of performance evidence often contain features that apply to more than one unit, and **can be used as evidence in any unit** where they are suitable performance evidence must be:

- products of the Apprentices work, such as items that have been produced or worked on, plans, charts, reports, standard operating procedures, documents produced as part of a work activity, records or photographs of the completed activity

together with:

- evidence of the way the Apprentice carried out the activities, such as witness testimonies, assessor observations or authenticated Apprentice reports of the activity undertaken.

Article LXVI. Competent performance is more than just carrying out a series of individual set tasks. Many of the units in the Foundation Phase contain statements that require the Apprentice to provide evidence that proves they are capable of combining various features and techniques. Where this is the case, separate fragments of evidence would not provide this combination of features and techniques and, therefore, will not be acceptable as demonstrating competent performance.

Article LXVII. If there is any doubt as to what constitutes suitable evidence the internal/external verifier should be consulted.

Article LXVIII. Example:

Article LXIX.

Article LXX. Foundation Unit 6: Maintaining Mechanical Devices and Equipment

Article LXXI.

Unit specific additional assessment requirements:

Specific Unit Requirements

In order to prove their ability to combine different maintenance operations, at least one of the maintenance activities must be of a significant nature, and must cover at least **seven** of the activities listed in paragraph 4 plus the removal and replacement/refitting of a minimum of **five** of the components listed in paragraph 5 in the Skills Section.

It is a requirement that training providers and assessors develop a written training plan and/or scheme of work that outlines the number of training activities and interventions throughout each planned session. The plan should also outline when assessment is planned to take place, which should be after a number of training activities on the topic have taken place over a sustained period. Competency assessments should not start until the relevant training has been given and the providers/assessors are confident the learner can achieve the assessment requirements.

Assessing Knowledge and Understanding requirements in the Occupational Competence Qualifications

Knowledge and understanding are key components of competent performance, but it is unlikely that performance evidence alone will provide enough evidence in this area. Where the Apprentices knowledge and understanding is not apparent from performance evidence, it must be assessed by other means and be supported by suitable evidence.

Knowledge and understanding can be demonstrated in a number of different ways. It is recommended that oral questioning and practical demonstrations are used perhaps whilst observing the apprentice undertake specific tasks, as these are considered the most appropriate for these units. Assessors should ask enough questions to make sure that the Apprentice has an appropriate level of knowledge and understanding, as required by the unit.

Evidence of knowledge and understanding will **not** be required for those items in the skills section of the Employer Units of Competence that have not been selected by the Employer.

The achievement of the specific knowledge and understanding requirements in the units **may** not simply be inferred by the results of tests, exams or assignments from other units such as in the technical knowledge qualifications or other training programmes. Where evidence is submitted from these sources, the assessor must, as with any assessment, make sure the evidence is valid, reliable, authentic, directly attributable to the Apprentice, and meets the full knowledge and understanding requirements of the unit. Awarding Organisations should be able to provide advice and guidance where evidence from Technical Knowledge qualification tests and/or assignments can be mapped and used to meeting the requirements of the Occupational Competence unit requirements.

Where oral questioning is used the assessor must retain a record of the questions asked, together with the Apprentices answers.

Article LXXII. Witness testimony

Article LXXIII. Where 'observation is used to obtain performance evidence, this must be carried out against the unit assessment criteria. Best practice would require that such observation is carried out by a qualified Assessor. If this is not practicable, then alternative sources of evidence may be used.

For example, the observation may be carried out against the assessment criteria by someone else that is in close contact with the Apprentice. This could be a team leader, supervisor, mentor or line manager who may be regarded as a suitable witness to the Apprentices competency. However, the witness must be technically competent in the process or skills that they are providing testimony for, to at least the same level of expertise as that required of the Apprentice. It will be the responsibility of the assessor to make sure that any witness testimonies accepted as evidence of the Apprentices competency are reliable, auditable and technically valid.

Maximising opportunities to use assessment evidence

One of the critical factors required in order to make this Assessment Strategy as efficient and effective as possible and to ease the burden of assessment, is the Assessors ability and expertise to work in partnership with the Apprentice and their employer to provide advice and guidance on how to maximise opportunities to cross reference performance and knowledge evidence to all relevant Employer Units of Competence. For example if a knowledge statement is repeated in a number of separate Employer Units of Competence and the expected evidence/response to that statement is the same including the context, then the same piece of evidence should be cross referenced to the appropriate units. As stated above, evidence from Technical Knowledge qualification test and assignments etc. should be used where this is valid, reliable and can be attributed to the individual Apprentice.

Section 2

General Requirements

Article LXXIV. Continuing Professional Development (CPD)

Centres must support their staff to ensure that they have current technical knowledge of the occupational area, that delivery, mentoring, training, assessment and verification are in line with best practice, technical advancements and that they will take account of any national or legislative developments.
There must be an auditable individual CPD plan in place for all staff assessing and verifying the qualifications within the relevant foundation and development phases, the plan must meet the relevant provider and Automotive Manufacturing employer requirements.

Assessors/Teachers/Trainers/Lecturers (as applicable):

- Must understand the Engineering Technician (UK spec) requirements when providing guidance to assessors. They will be required to provide a signed declaration confirming they have read and understood the Engineering Technician (UK spec) and the evidence requirements to meet the Engineering Technician (UK spec) criteria (Currently in development). The Engineering Technician (UK spec) can be found at www.engc.org.uk
- Must understand the requirements of the relevant Apprenticeship Standards – End of Scheme Assessment Recording Document (Currently in development).
- Must understand the requirements of the relevant Apprenticeship Standards – Behavioral Framework and the review and assessment recording documentation (Currently in development).

Quality Control of Assessment

General

There are two major points where an Awarding Organisation interacts with the Centre in relation to the External Quality Control of Assessment and these are:

- approval - when a Centre take on new qualifications/units, the Awarding Organisation, normally through an External Verifier (EV) ensures that the Centre is suitably equipped and prepared to deliver the new units/qualification
- monitoring - throughout the ongoing delivery of the qualification/units the Awarding Organisation, through EV monitoring and other mechanisms must maintain the quality and consistency of assessment of the units/qualification.

Approval

In granting Approval, the Awarding Organisation, normally through its External Verifiers (EV) must ensure that the prospective Centre:

- meets the requirements of the Qualification Regulator
- has sufficient and appropriate physical and staff resources
- meets relevant health and safety and/or equality and access requirements
- has a robust plan for the delivery of the qualification/units.

The Awarding Organisation may visit the Centre to view evidence or may undertake this via other means.

Monitoring

The Awarding Organisation, through EV monitoring and other mechanisms must ensure:

- that a strategy is developed and deployed for the ongoing Awarding Organisation monitoring of the Centre. This strategy must be based on an active risk assessment of the Centre. In particular the strategy must identify the Apprentice, assessors and Internal Verifier sampling strategy to be deployed and the rationale behind this
- that the Centre's internal quality assurance processes are effective in assessment
- that sanctions are applied to a Centre where necessary and that corrective actions are taken by the Centre and monitored by the Awarding Organisation/EV
- that reviews of Awarding Organisation's external auditing arrangements are undertaken.

Notes:

a) It is recognised that each Awarding Organisation (AO) will have its own guidance and procedure on the internal and external quality assurance process applied to these qualifications. See individual AO websites for further information

b) This Assessment Strategy is "work in progress" and will be amended and re issued as the Competence and Technical Knowledge Qualifications and assessment methodologies are developed and modified

c) The Automotive Manufacturing Sector is mindful that its Apprenticeships are and **must** be available across all four Nations in the UK where applicable. Therefore the Sector has ensured that the Employer Occupational Brief (EOB) and the associated Employer Units of Competence are directly aligned to the existing format and content of the Sectors National Occupational Standards (NOS).

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