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