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.

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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 ($F_c = m\omega^2 r$, $F_c = mv^2/r$)

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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		

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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).

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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.

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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