Unit 11: Further Mechanical Principles and Applications

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

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 of this unit cover the mechanical principles that underpin the design of framed structures, simply supported beams and structural components. The aim is to provide learners with 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 and the forces and power that they transmit is known as 'kinematics'. 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.

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 eg 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 eg concentrated loads; uniformly distributed loads; reactive forces eg support reactions, primary tensile and compressive force in structural members

Simply supported beams: distribution of shear force and bending moment for a loaded beam eg concentrated loads, uniformly distributed load (UDL); types of beam arrangement eg 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 eg bolted or riveted joints in single and double shear; joint parameters eg 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 eg plain struts and ties, series and parallel compound bars made from two different materials; loading eg 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 eg 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 eg angular displacement, angular velocity, angular acceleration, equations for uniform angular motion ($\omega_2 = \omega_1 + \alpha t,\ \theta = \omega_1 t + ½\alpha t^2,\ \omega_2^2 = \omega_1^2 + 2\alpha\theta,\ \theta = ½\ (\omega_1 + \omega_2)t$); dynamic parameters eg 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 ($KE = ½I\omega^2$), application of principle of conservation of energy

Rotating systems with uniform centripetal acceleration: systems eg 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 eg expressions for centripetal acceleration ($a = \omega^2 r,\ a = v^2/r$); dynamic parameters eg expressions for centripetal force ($F_c = m\omega^2 r,\ F_c = mv^2/r$)

 Edexcel Level 3 BTEC Nationals in Engineering – Issue 1 – May 2007 © Edexcel Limited 2007

4 **Be able to determine the operating characteristics of lifting machines**

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

Lifting machines: lifting machines eg 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)

Grading grid

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

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	graphically determine 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	analytically determine 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 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
P2	determine the distribution of shear force and bending moment for a simply supported beam without overhang carrying at least three concentrated loads	M2	determine the 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	D2	determine and evaluate the kinetic and dynamic parameters of operation of a differential lifting machine.
P3	determine the required parameters for a single shear lap joint and a double shear butt joint for given service conditions	M3	determine the applied torque, work done and power dissipated 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.		

 © Edexcel Limited 2007

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:
P4 determine the induced direct stress, dimensional change and factor of safety in operation for a rigidly held plain structural member when subjected to a combination of direct and thermal loading P5 determine the applied torque, work done and power dissipated in a uniformly accelerated simple rotating system to overcome the effects of inertia and friction P6 determine centripetal acceleration and centripetal force in a simple rotating system P7 determine the kinetic and dynamic parameters of operation of two different simple lifting machines from given data.		

Essential guidance for tutors

Delivery

There are close links between learning outcomes 1 and 2 of this unit, as they are both concerned with static force systems. It is therefore likely that these learning outcomes will be delivered concurrently and with some degree of integration. Learning outcomes 3 and 4 are concerned with dynamic systems but here the links are not so close and the order of delivery is a matter of centre preference. Wherever possible an investigative approach should be adopted in which the underpinning mechanical principles are consolidated in the solution of problems and laboratory investigations.

Revision of previous work may be needed at the start of learning outcome 1. In particular, learners will need a clear understanding of vector addition and the resolution of forces. In the solution of pin-jointed framed structures, a maximum of four members will give sufficient depth of treatment. With larger numbers, the process becomes repetitive and time consuming. Appropriate use should be made of Bow's notation in the construction of space and vector diagrams. The calculation of stress in structural members and fastenings can proceed directly from determination of the primary forces present in struts and ties.

Learners will already have encountered the calculation of beam reactions in *Unit 6: Mechanical Principles and Applications*. This knowledge can now be extended to cover distribution of shear force and bending moment in beams carrying a combination of concentrated and uniformly distributed loads. An appropriate and coherent sign convention should be adopted that can be extended at a higher level to the determination of slope and deflection.

The significance of points of contraflexure in the design of fabricated beams should be explained together with the relationship between shear force and bending moment. This will also give a firm foundation for beam analysis at a higher level. If available, the use of CAD packages can be useful in confirming the analysis of static force systems.

Learning outcome 3 will extend learners' knowledge of dynamics to cover uniform rotational motion. The use of both D'Alembert's principle and the principle of conservation of energy should be encouraged when problem solving. The application of D'Alembert's principle is in effect the application of Newton's second and third laws of motion with the inertial reaction ma or $I\alpha$, considered as an external force or torque. It enables a free body diagram to be drawn which aids the mathematical modelling of a dynamic system. For a linear system the diagram might also contain frictional resistance F_f and weight mg, or some component of weight $mg\ Sin\theta$, if the body is on an incline. The resultant force F (tractive effort or braking force) is then the vector sum of these three, ie $F = ma + F_f + mg\ Sin\theta$.

 © Edexcel Limited 2007

The same applies to rigid body rotation where the resultant tractive or braking torque T is the vector sum of the internal inertial resistance $I\alpha$. This is again imagined to be an external torque and the friction torque T_f, ie, $T = I\alpha + T_f$.

Laboratory investigation of moment of inertia and radius of gyration of a rotor will help reinforce delivery. An explanation of vector subtraction may be necessary prior to derivation of the expressions for centripetal acceleration and centripetal force. The expressions may be verified experimentally using turntable apparatus if available. A range of simple and complex applications should be considered when problem solving.

The lifting machines listed as examples for learning outcome 4 have many practical applications and the underpinning theory is highly relevant to machine design. The topic lends itself to practical investigations which may be incorporated into the assessment strategy.

Note that the use of 'eg' 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 'eg' needs to be taught or assessed.

Assessment

It is possible to assess the criteria P1, P2, M1 and M2 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 determined 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 M2 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 D1. 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 thermal 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 (D1) when subjected to direct loading.

A third assignment could be used to assess the criteria P5, P6, M3 and M4. 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 (M4). 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 rotating system given/used.

A final assignment containing two tasks could be used to achieve the P7 and D2 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 D2 distinction 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 comparing it to 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.

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

This unit builds on the mechanical principles covered in *Unit 6: Mechanical Principles and Applications* and leads to *Unit 18: Advanced Mechanical Principles and Applications* or study at BTEC Higher National Certificate/Diploma level. The unit also has links with *Unit 4: Mathematics for Technicians* and *Unit 12: Applications of Mechanical Systems and Technology*.

The unit provides some of the underpinning knowledge for the SEMTA Level 3 NVQ in Mechanical Manufacture, Level 3 NVQ in Engineering Maintenance and Level 3 NVQ in Engineering Technical Support.

Essential resources

Centres should have access to investigation and demonstration equipment such as turntable apparatus for the investigation of centripetal acceleration and force, and a variety of simple lifting devices. Use should be made of appropriate software packages, particularly in the learning outcomes relating to structural and stress analysis.

Indicative reading for learners

Textbooks

Bird J — *Science for Engineering* (Newnes, 2003) ISBN 0750657774

Bolton W — *Engineering Science* (Newnes, 2001) ISBN 0750652594

Darbyshire A — *Mechanical Engineering BTEC Optional Units* (Newnes, 2003)
ISBN 0750657618

Tooley M and Dingle L — *BTEC National Engineering* (Newnes, 2002) ISBN 0750651660

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Staff should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• determining the distribution of shear force and bending moment for a simply supported beam without overhang and carrying at least three concentrated loads • determining the required parameters for a single shear lap joint and a double shear butt joint for given service conditions.	N3.1 Plan an activity and get relevant information from relevant sources. N3.2 Use this information to carry out multi-stage calculations to do with: a amounts or sizes b scales or proportion c handling statistics d using formulae. N3.3 Interpret the results of your calculations, present your findings and justify your methods.

Problem solving Level 3	
When learners are:	**They should be able to develop the following key skills evidence:**
• determining the applied torque, work done and power dissipated in a uniformly accelerated simple rotating system to overcome the effects of inertia and friction.	PS3.1 Explore a problem and identify different ways of tackling it. PS3.2 Plan and implement at least one way of solving the problem. PS3.3 Check if the problem has been solved and review your approach to problem solving.