UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 1: Kinematics of Mechanisms	**Suggested Teaching Time:** 1 hour

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources

Revision of Basic Concepts	Although there is a certain level of prerequisite knowledge required for entering this course the tutor will benefit from taking time at the beginning of the course to reinforce the basic equations.
	• Whole-class teaching: Tutor to get the whole class involved in learner research and activity to cover the following principles and the meaning of the following terms:
	  ○ Potential Energy (P.E.) and Kinetic Energy (K.E.),
	  ▪ Potential Energy (P.E.) Work = mass x g x distance
	  ▪ Kinetic Energy (K.E.) K.E. = $mv^2/2$
	  ○ The difference between scalar and vector quantities
	  ▪ Any physical quantity that requires a direction to be stated in order to define it completely is known as a vector quantity
	  ▪ A scalar quantity, such as time, is adequately defined when the magnitude is given in the appropriate units.
	  ○ force and motion
	  ▪ Force, measured in newtons, is a vector quantity because its effect depends upon its magnitude and direction
	  ○ How to determine the resultant of two coplanar vectors by using a vector triangle
	  ○ How to calculate the resultant of two perpendicular vectors
	  ○ How to resolve a vector into two perpendicular vector.
	Show video.
	Split class into smaller groups and issue a series of questions covering the equations used so far. Where possible include practical elements, tutor to circulate and correct as required.
		Books
		Johnson K (2006)
		Physics for you
		Nelson Thorne
		Jason Z (2009)
		Force and Motion
		Johns Hopkins University Press
		Oxlade C (2005)
		Forces and Motion
		Hodder Wayland
		Doherty JJJ (2008)
		Kinematics and Dynamics
		Bibliolife
		Wilson CE (2003)
		Kinematics and Dynamics of Machinery
		Pearson
		Website
		Kinematics 63 videos
		www.metacafe.com/tags/Kinematics/page-3
		Shockwave Physics Studio: The Physics Classroom
		http://www.physicsclassroom.com/Shockwave-Physics-Studios
		Physics revision notes – Forces and Motion
		Lanther.co.uk/notes/physics_Forces.pdf
		Revision Physics – Force and Motion
		www.revisionworld.co.uk?node/7814
		Practical Equipment
		Laboratory equipment for evaluating forces, velocity and acceleration

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 2: Kinematics of Mechanisms (Continued)	**Suggested Teaching Time: 1** hour

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources
Revision of Basic Concepts (Continued)	• Whole-class teaching: Tutor to get the whole class involved in learner research and activity to cover the following principles and the meaning of the following terms: ○ define the terms displacement, speed, velocity and acceleration ▪ Displacement – the change of position of a body in a particular direction and is a vector quantity, ▪ Speed – ratio of distance to time taken by a moving body and is a scalar quantity. ▪ Velocity – the rate of motion in a given direction and is a vector quantity ▪ Acceleration – the rate of change of velocity is a scalar quantity ▪ state and use the equations which represent uniformly accelerated motion in a straight line • v = u + at • s = 1/2(u+v)t • s = ut + ½at2 • v2 = u2 + 2as ▪ Where a is acceleration, s is distance, t is time, u is initial velocity and v is final velocity. Split class into smaller groups and issue a series of questions covering the equations used so far. Where possible include practical elements, tutor to circulate and correct as required.	**Books** As per lesson 1 **Website** www.scienceaid.co.uk/physics/forces/motion.html Shockwave Physics Studio: The Physics Classroom http://www.physicsclassroom.com/Shockwave-Physics-Studios www.bbc.co.uk/learningzone/clips/contact Area Dynamic Online Videos http://www.YourOtherTeacher.com **Software** **Practical equipment** Laboratory equipment for evaluating forces, Displacement, velocity and acceleration

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 3: Kinematics of Mechanisms (Continued)	**Suggested Teaching Time: 0.5** hours

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources

Revision of Basic Concepts (Continued)	• Whole-class teaching: Tutor to get the whole class involved in learner research and activity to cover the following principles and the meaning of the following terms:
	  ○ state that mass is the property of a body which resists change in motion
	  ○ state and apply the formula for density (D) of a material
	  ▪ D = m/v, where D is density, m is mass and v is volume
	  ○ state and apply the formula for force (F)
	  ▪ F = ma, where a is acceleration, F is force and m is mass
	  ○ define the term Newton
	  ▪ Newton – the derived SI unit of force. The force required to give a mass of 1 kg an acceleration of 1 m/s2describe and apply the concept of weight as the effect of a gravitational field on mass
	  ○ state and apply the formula for weight (W)
	  ▪ W = mg, where W is weight, m is mass and g is acceleration due to gravity.
	• Split class into smaller groups and issue a series of questions covering the equations used so far. Where possible include practical elements, tutor to circulate and correct as required.
		Books
		As per lesson 1
		Website
		www.scienceaid.co.uk/physics/forces/motion.html
		Shockwave Physics Studio: The Physics Classroom
		http://www.physicsclassroom.com/Shockwave-Physics-Studios
		www.bbc.co.uk/learningzone/clips/contact Area
		Dynamic Online Videos
		http://www.YourOtherTeacher.com
		Software
		
		Practical equipment
		Laboratory equipment for evaluating forces, density, weight, displacement, velocity and acceleration

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 4: Kinematics of Mechanisms (Continued)	**Suggested Teaching Time: 0.5** hours

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources

Revision of Basic Concepts (Continued)	• Whole-class teaching: Tutor to get the whole class involved in learner research and activity to cover the following principles and the meaning of the following terms:
	  ○ state that the weight of a body may be considered as acting at a single point called the centre of gravity
	  ○ explain that a couple as a pair of equal parallel forces tends to produce rotation only
	  ○ define and use the moment of a force and the torque of a couple
	  ▪ Moment of a force – the tendency of a force to rotate a body
	  ○ state that for a system in equilibrium there is no resultant force and no resultant torque
	  ○ define the term joule and apply the formula for work done (W)
	  ○ explain the relationship between power (P), work done (W) and time (t)
	  ▪ W = Pt, where W is work done, P is power and t us time.
	• Split class into smaller groups and issue a series of questions covering the equations used so far. Where possible include practical elements, tutor to circulate and correct as required.
		Books
		As per lesson 1
		Website
		www.scienceaid.co.uk/physics/forces/motion.html
		Shockwave Physics Studio: The Physics Classroom
		http://www.physicsclassroom.com/Shockwave-Physics-Studios
		www.bbc.co.uk/learningzone/clips/contact Area
		Dynamic Online Videos
		http://www.YourOtherTeacher.com
		Software
		
		Practical equipment
		Laboratory equipment for evaluating forces, equilibrium and moments of force

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 5: Kinematics of Mechanisms (Continued)	**Suggested Teaching Time: 0.5** hours

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources

Revision of Basic Concepts (Continued)	• Whole-class teaching: Tutor to get the whole class involved in learner research and activity to cover the following principles and the meaning of the following terms:
	  ○ represent distance travelled, displacement, speed, velocity and acceleration using graphical methods
	  ○ determine the distance travelled by calculating the area under a speed – time graph
	  ○ determine velocity by using the gradient of a displacement – time graph
	  ○ determine speed by using the gradient of a displacement – time graph
	  ○ determine acceleration by using the gradient of a velocity – time graph.
	• Split class into smaller groups and issue a series of questions covering the equations used so far. Where possible include practical elements, tutor to circulate and correct as required.
		Books
		As per lesson 1
		Website
		www.scienceaid.co.uk/physics/forces/motion.html
		Shockwave Physics Studio: The Physics Classroom
		http://www.physicsclassroom.com/Shockwave-Physics-Studios
		www.bbc.co.uk/learningzone/clips/contact Area
		Dynamic Online Videos
		http://www.YourOtherTeacher.com
		Software
		
		Practical equipment
		Laboratory equipment for evaluating displacement, velocity and acceleration

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

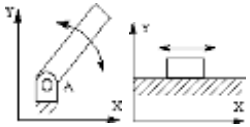
Lesson 6: Kinematic Modelling	**Suggested Teaching Time: 6** hours

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources

kinematic modelling of simple mechanisms
(A.C. 1.1)
	• Whole-class teaching to explain kinematic modelling of simple mechanisms
	• Tutor to get the whole class involved in learner research and activity to cover the following principles and the meaning of the following terms:
	  ○ Reference frames;
	  ▪ The movement of components of a mechanical system is analysed by attaching a reference frame to each part and determining how the reference frames move relative to each other. If the structural strength of the parts is sufficient then their deformation can be neglected and rigid transformations used to define this relative movement.
	  ○ Degrees of freedom
	  ▪ The degrees of freedom (DOF) of a rigid body is defined as the number of independent movements it has. e.g. a rigid body on a plane has 3 DOF. The bar can be translated along the x axis, translated along the y axis, and rotated about its centroid.
	  ○ Rigid body links,
	  ▪ Two or more rigid bodies in space are collectively called a rigid body system. We can hinder the motion of these independent rigid bodies with kinematic constraints. Kinematic constraints are constraints between rigid bodies that result in the decrease of the degrees of freedom of rigid body system.
		Books
		Johnson K (2006)
		Physics for you
		Nelson Thorne
		Jason Z (2009)
		Force and Motion
		Johns Hopkins University Press
		Oxlade C (2005)
		Forces and Motion
		Hodder Wayland
		Doherty JJJ (2008)
		Kinematics and Dynamics
		Bibliolife
		Wilson CE (2003)
		Kinematics and Dynamics of Machinery
		Pearson
		Website
		Kinematics 63 videos
		www.metacafe.com/tags/Kinematics/page-3
		Shockwave Physics Studio: The Physics Classroom
		http://www.physicsclassroom.com/Shockwave-Physics-Studios

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Topic	Suggested Teaching	Suggested Resources
Kinematic modelling of simple mechanisms (A.C. 1.1)	○ Revolute and prismatic joints (known as Lower Pairs in Planar Mechanisms) ▪ A rigid body in a plane has only three independent motions -- two translational and one rotary -- so introducing either a revolute pair or a prismatic pair between two rigid bodies removes two degrees of freedom.  ○ Discuss Gruebler's equation ▪ F=3(n-1) – 2l – h • Where F = total degrees of freedom in the mechanism n = number of links (including the frame) l = number of lower pairs (one degree of freedom) h = number of higher pairs (two degrees of freedom). ○ Kinematic chains ▪ A link is defined as a rigid body having two or more pairing elements which connect it to other bodies for the purpose of transmitting force or motion. In every machine, at least one link either occupies a fixed position relative to the earth or carries the machine as a whole along with it during motion. This link is the frame of the machine and is called the fixed link. The combination of links and pairs without a fixed link is not a mechanism but a kinematic chain.	**Books** As per lesson 6 **Website** http://www.cs.cmu.edu/~rapidproto/mechanisms/chpt4.html http://kmoddl.library.cornell.edu/model.php?m=reuleaux **Practical equipment** Examples of Resolute and Prismatic joins Examples of kinematic chains Examples of planar kinematic mechanisms Examples of spatial kinematic mechanisms These to include working examples of the following: • Four-bar linkage • crank and rocker • drag link • slider-crank • scotch yoke • Quick-return

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Topic	Suggested Teaching	Suggested Resources
Kinematic modelling of simple mechanisms (A.C. 1.1)	○ Planar kinematic mechanisms ▪ In a planar mechanisms, all of the relative motions of the rigid bodies are in one plane or in parallel planes ○ .Spatial kinematic mechanisms ▪ If there is any relative motion that is not in the same plane or in parallel planes, the mechanism is called the spatial mechanism ○ Discuss the terms general motion and relative motion. • Tutor to get the whole class involved in learner research and activity to cover the modelling of the following systems: ▪ Four-bar linkage; ▪ Crank and rocker ▪ Drag link ▪ Slider-crank ▪ Scotch yoke ▪ Quick-return.	**Website** http://kmoddl.library.cornell.edu/model.php?m=reuleaux

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 7: Evaluation of velocities in kinematic mechanisms by graphical analysis	**Suggested Teaching Time:** 8 hours

Learning Outcome 1: understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources
Evaluate velocities in kinematic mechanisms by graphical analysis (A.C. 1.2)	Velocity Diagrams This involves the construction of diagrams which need to be done accurately and to a suitable scale. Students should use: a Drawing board, ruler, compass, protractor, and triangles or a suitable CAD Package which the students are familiar with. Tutor-led learning – learner research and activity on the concepts of: Absolute and Relative velocity, Tangential Velocity, Radial Velocity and the motion of a crank, con-rod and piston. Tutor should demonstrate the drawing of the different types of diagrams and then get the students to solve example questions using the graphical method, tutor to assist individual students, and correcting errors as required. Diagram types to include: Instantaneous centres; relative velocities; velocity and acceleration diagrams For the following types of mechanisms: Four-bar linkage; crank and rocker; drag link; slider-crank; scotch yoke; quick-return.	**Books** **Software** Basic CAD programme **Practical equipment** Drawing board, ruler, compass, protractor, and triangles Examples of Resolute and Prismatic joins, kinematic chains, planar kinematic mechanisms, and spatial kinematic mechanisms These are to include working examples of the following: • Four-bar linkage; • Crank and rocker • Drag link • Slider-crank • Scotch yoke • Quick-return **Website** http://www.freestudy.co.uk/dynamics/velaccdiag.pdf https://www.youtube.com/watch?v=IzaZ38Rn9Tk

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 8: Evaluation the accelerations in kinematic mechanisms by graphical analysis	**Suggested Teaching Time:** 8 hours

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources
Evaluate **the accelerations** in kinematic mechanisms by graphical analysis (A.C. 1.3)	Acceleration Diagrams This involves the construction of diagrams which need to be done accurately and to a suitable scale. Students should use: a Drawing board, ruler, compass, protractor, and triangles or a suitable CAD Package which the students are familiar with. Tutor-led learning. learner research and activity on the concepts of: Centripetal (radial) Acceleration, Tangential acceleration and Coriolis Acceleration. Tutor should demonstrate the drawing of the different types of drawings and then get the students to solve example questions using the graphical method, tutor to assist individual students, and correcting errors as required. Diagram types to include: Instantaneous centres; relative velocities; velocity and acceleration diagrams. For the following types of mechanisms: Four-bar linkage; crank and rocker; drag link; slider-crank; scotch yoke; quick-return.	**Books** **Software** Basic CAD programme **Practical equipment** Drawing board, ruler, compass, protractor, and triangles Examples of Resolute and Prismatic joins, kinematic chains, planar kinematic mechanisms, and spatial kinematic mechanisms These are to include working examples of the following: • Four-bar linkage; • crank and rocker; • drag link; • slider-crank; • scotch yoke; • Quick-return **Website** http://www.freestudy.co.uk/dynamics/velaccdiag.pdf

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 9: Evaluation of the motions in kinematic mechanisms by mathematical analysis	**Suggested Teaching Time:** 8 hours

Learning Outcome 1: Understand the kinematics of mechanisms

Topic	Suggested Teaching	Suggested Resources
evaluate the motions in kinematic mechanisms by mathematical analysis (A.C. 1.4)	Whole-class teaching to cover the relationship between Displacement, Velocity and Acceleration • Displacement (x) = R(sin ωt) • Velocity (v) = dx/dt = ωR cos(ωt) • Acceleration (a) = dv/dt = $-\omega^2 R \sin(\omega t)$ Tutor-led discussion on how we can use mathematics to solve the problems given in previous lesson rather than using diagrams. The tutor should work through typical examples of calculations covering the different equations and the learners should then work through other examples of such calculations. These examples should cover the following types of mechanisms: Four-bar linkage; crank and rocker; drag link; slider-crank; scotch yoke; quick-return. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** **Software** **Practical equipment** Examples of Resolute and Prismatic joins Examples of kinematic chains Examples of planar kinematic mechanisms Examples of spatial kinematic mechanisms These to include working examples of the following: • Four-bar linkage • Crank and rocker • Drag link • Slider-crank • Scotch yoke • Quick-return **Website** http://www.freestudy.co.uk/dynamics/velaccdiag.pdf

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 10: Gear Trains	**Suggested Teaching Time:** 4 hours

Learning Outcome 2: Understand the dynamics of machines

Topic	Suggested Teaching	Suggested Resources
Analyse the operation of a gear train in a machine (A.C. 2.1)	Tutor-led group teaching on the concept of gears, how and why they are used progressing from simple gear trains to compound gear trains and introducing the three types of epicyclic gearboxes. Tutor to discuss Basic gearbox theory, covering gear ratios, Torque and efficiency. Tutor-led discussion on how we can use mathematics to analyse the operation of a gear train in a machine. The tutor should work through typical examples of calculations covering the different equations and the learners should then work through other examples of such calculations. These examples should cover the following types of gearing: simple gear trains, compound gear trains and the three types of epicyclic gearboxes. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** **Software** **Practical equipment** Practical boards and equipment demonstrating different layouts of gears with the option of changing gear ratios **Website** http://www.freestudy.co.uk/dynamics/gears.pdf http://ocw.uc3m.es/ingenieria-mecanica/machine-theory/lab-reports/analisis-of-gear-trains/at_download/file www.asee.org/public/conferences/1/papers/838/download

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 11: The Forces in a machine	**Suggested Teaching Time:** 3 hours

Learning Outcome 2: Understand the dynamics of machines

Topic	Suggested Teaching	Suggested Resources
Analyse the forces in machines (A.C. 2.2)	Tutor-led discussion on how other forces affect the machines that we have been looking at so far, discussion to include: Gravitational; inertia; pressure; and frictional forces. Tutor to Adapt previous equations to include friction and the effect it has on a machine. Tutor to Adapt previous equations to include gravitational force and the effect it has on a machine. Tutor to Adapt previous equations to include inertia and the effect it has on a machine. Tutor to Adapt previous equations to include pressure and the effect it has on a machine. The tutor should work through typical examples of calculations covering the different equations and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** Theory of machines and mechanisms by Dr.Jagadishlal, Metropolitain Book co. Pvt. Ltd., New Delhi Mechanisms and Dynamics of machinery by Hamitton H.Mabie and Fred W.Ocvirk, John Wiley & sons, Newyork. Machine Dynamics (DOM), Vol ii, G.Bapaiah, Mechanical Engineering, Monograph Series, IIT, Madras. Theory of Machines, by S.S Rathan, Tata McGraw-hill. Mechanism & Machine Theory by Ashok G.Ambekar, Prentice Hall of India Pvt. Limited, New Delhi – 110001, 2007. **Website** http://ocw.metu.edu.tr/pluginfile.php/6467/mod_resource/content/6/ch7/index.htm http://elearning.vtu.ac.in/17/e-Notes/10ME54/Unit1-SRJ.pdf

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 12: Analysis of Torque in machines	**Suggested Teaching Time:** 2 hours

Learning Outcome 2: Understand the dynamics of machines

Topic	Suggested Teaching	Suggested Resources
Analyse the torque in machines (A.C. 2.3)	Discuss the relationship between torque power and energy $W = \int_{\theta_1}^{\theta_2} \tau \ \mathrm{d}\theta,$ where W is work, τ is torque, and θ1 and θ2 represent (respectively) the initial and final angular positions of the body $P = \boldsymbol{\tau} \cdot \boldsymbol{\omega},$ where P is power, T is torque, ω is the angular velocity $\text{power} = \frac{\text{force} \times \text{linear distance}}{\text{time}} = \frac{\left(\frac{\text{torque}}{r}\right) \times (r \times \text{angular speed} \times t)}{t} = \text{torque} \times \text{angular speed}$ The tutor should work through typical examples of calculations covering the different equations, including both input and output torque, and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** Theory of machines and mechanisms by Dr.Jagadishlal, Metropolitain Book co. Pvt. Ltd., New Delhi Mechanisms and Dynamics of machinery by Hamitton H.Mabie and Fred W.Ocvirk, John Wiley & sons, Newyork. Machine Dynamics (DOM), Vol ii, G.Bapaiah, Mechanical Engineering, Monograph Series, IIT, Madras. Theory of Machines, by S.S Rathan, Tata McGraw-hill. Mechanism & Machine Theory by Ashok G.Ambekar, Prentice Hall of India Pvt. Limited, New Delhi – 110001, 2007

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 13: Flywheels	**Suggested Teaching Time:** 2 hours

Learning Outcome 2: Understand the dynamics of machines

Topic	Suggested Teaching	Suggested Resources

Analyse the operation of a flywheel in a machine (A.C. 2.4)	Discuss the concept of a reciprocating machine and how it exerts erratic torque on to a shaft.
	Bring in concept of Kinetic energy and how it could be stored in a flywheel:
	• K.E. = I $\omega^2/2$
	  • I is moment of inertia given by formula I = Mk^2
	  • ω is the angular velocity in rad/s
	  • k is the radius of gyration in meters
	  • M is the mass of the wheel
	• For a plain disk I = $MR^2/2$ where R is the outer radius
	• When a rotating body changes speed , the angular acceleration is related to the moment of inertia and the applied torque by the formula T=Iα. Where α is the angular acceleration in Rad/s^2
	Develop these concepts into the cyclic torque diagram for a machine and how we can then use these to carry out an energy analysis of a flywheel.
	The tutor should work through typical examples of calculations covering the different equations, and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 14: Balancing rotating masses	**Suggested Teaching Time: 3** hours

Learning Outcome 3: Understand the need for machine balancing

Topic	Suggested Teaching	Suggested Resources
Analyse balancing of rotating masses in a machine (A.C. 3.1)	Tutor-led discussion on the concepts of balancing and why we need it. Explain the difference between Static balancing; and dynamic balancing: • *Static Balance.* This occurs when there is no resultant centrifugal force and the centre of gravity is on the axis of rotation • *Dynamic Balance.* This occurs when there is no resulting turning moment along the axis. Tutor-led instruction to cover a simple rotating disk. E.g. in machine where the centre of gravity is not the same as the centre of rotation there will be a single out of balance force and the force applied can be calculated using earlier calculations C.F.= M $\omega^2 r$ in order to balance this an equal and opposite force is needed such that $M_1 \omega^2 r_1 = M_2 \omega^2 r_2$ Develop this into a machine with several masses in one transverse plane, drawing Mr diagrams and solving the missing vector. The tutor should work through typical examples of calculations covering the different equations, and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained. Students to be given the opportunity to carry out practical activities involving the balancing of a simple shaft and flywheel assembly.	**Practical equipment** Laboratory equipment to evaluate the effects of out-of-balance rotating masses in a simple shaft and flywheel assembly **Website** https://www.youtube.com/watch?v=I3jE-PXV-68

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Topic	Suggested Teaching	Suggested Resources
Analyse balancing of rotating masses in a machine (A.C. 3.1)	Tutor-led discussion to consider machines that are not quite so simple and therefore have masses in different transverse planes. The centrifugal force produced is F=Mrω2 The turning moment about the reference plane = T.M. = Fx = Mrω2x For dynamic and static balance we must work out the resultant turning moment and add masses at appropriate points to cancel it out. The appropriate points will be on two planes not coplanar with any of the original masses. This involves drawing two vector diagrams and since ω is common to all vectors we can again take ω=1 and draw vectors representing Mr and Mrx. The tutor should work through typical examples of calculations covering the different equations, and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained. Students to be given the opportunity to carry out practical activities involving the balancing of a simple shaft and flywheel assembly.	**Practical equipment** laboratory equipment to evaluate the effects of out-of-balance rotating masses in a simple machine having masses in different transverse planes

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 15: Balancing reciprocating masses	**Suggested Teaching Time:** 3 hours

Learning Outcome 3: Understand the need for machine balancing

Topic	Suggested Teaching	Suggested Resources
analyse balancing of reciprocating masses in a machine (A.C. 3.2)	Group Discussion, recapping lessons learned about Slider-crank mechanisms discussing the general layout of piston con rod and crankshaft machine within the machine. Revisit the acceleration equation and work through a couple of examples as revision. Tutor to split the class into several groups and present them with the data for several reciprocating engines and get the groups to produce graphs showing displacement, velocity and acceleration against angle. Discuss results of graphs and how as n gets larger the nearer the results get to being harmonic Explain using the close approximation for acceleration how the inertia force required to accelerate can be given by $F = M\omega r^2 R\left[\cos(\theta) + \frac{\cos(2\theta)}{n}\right]$ and how this may be thought of as two separate forces. primary forces $F_P = M\omega^2 R\cos(\theta)$ secondary forces $F_S = M\omega r^2 R\left[\frac{\cos(2\theta)}{n}\right]$ The tutor should work through typical examples of calculations covering a single reciprocating mass, and the learners should then work through other examples of such calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** **Software** **Practical equipment** **Reciprocating machine with laboratory equipment for measuring vibration** **Website**

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Topic	Suggested Teaching	Suggested Resources
Analyse balancing of reciprocating masses in a machine (Continued) (A.C. 3.2)	Group discussion to develop this into a machine with several reciprocating masses in one transverse plane, and discussing complexity of arrangements. The tutor should work through typical examples of primary force calculations for multiple cylinder machines. They should then discuss the complexity of calculating the secondary forces in multiple piston machines and show the development of the formula for calculating the rotating masses. $M\omega 2(R/n) \cos 2\theta = M_S(2\omega)^2 R_S \cos 2\theta = 4 M_S \omega^2 R \cos 2\theta$ The tutor should work through typical examples of secondary force calculations for multiple cylinder machines. The learners should then work through examples of both primary and secondary force calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained. Tutor-led group learning to introduce different methods of balancing including the Lanchester balancer, reciprocating balance and contra rotating masses.	**Practical equipment** Reciprocating machine with laboratory equipment for measuring vibration Example of a Lanchester balancer **Website** http://www.fordscorpio.co.uk/tech2_3_2.htm

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 16: Vibration	**Suggested Teaching Time:** 2 hours

Learning Outcome 4: Understand the vibration of machines

Topic	Suggested Teaching	Suggested Resources
Explain the causes of vibration in a simple machine system (A.C. 4.1)	Tutor-led discussion to cover what is meant by vibration and its causes. Discuss the following: Vibration can result from a number of conditions, acting alone or in combination. Problems may be caused by auxiliary equipment, not just the primary equipment. **Imbalance** (Imbalance could be caused by manufacturing defects (machining errors, casting flaws) or maintenance issues (deformed or dirty fan blades, missing balance weights)). Discuss the effect that machine speed has on the vibration and what effects vibration may have on the machine. Discuss **Misalignment**/shaft runout – Vibration can result when machine shafts are out of line. Angular misalignment occurs when the axes of (for example) a motor and pump are not parallel. When the axes are parallel but not exactly aligned, the condition is known as parallel misalignment. Misalignment may be caused during assembly or develop over time, due to thermal expansion, components shifting or improper reassembly after maintenance. The resulting vibration may be radial or axial (in line with the axis of the machine) or both. Discuss **Wear** – As components such as ball or roller bearings, drive belts or gears become worn, they may cause vibration. When a roller bearing race becomes pitted, for instance, the bearing rollers will cause a vibration each time they travel over the damaged area. A gear tooth that is heavily chipped or worn, or a drive belt that is breaking down, can also produce vibration. Discuss **Looseness** – Vibration that might otherwise go unnoticed may become obvious and destructive if the component that is vibrating has loose bearings or is loosely attached to its mounts. Such looseness may or may not be caused by the underlying vibration. Whatever its cause, looseness can allow any vibration present to cause damage, such as further bearing wear, wear and fatigue in equipment mounts and other components.	**Website** http://www.reliableplant.com/Read/24117/introduction-machinery-vibration http://www.proviso-systems.co.uk/images/stories/pdf/beginners_guide.pdf

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Topic	Suggested Teaching	Suggested Resources
Explain the causes of vibration in a simple machine system (Continued) (A.C. 4.1)	Tutor-led discussion on degrees of freedom recapping info learned in kinematic modelling lesson. Tutor to introduce the concept of free vibration and Forced vibration. Under the topic of free vibration the tutor should discuss a pendulum, an object bobbing in the water and a weight on a spring (Simple Harmonic Motion (SHM)); emphasising that it occurs naturally without energy being added to the vibrating system and dies away with time as the energy is dissipated. Whilst discussing these bring in Natural Frequency and the idea of dampening to reduce vibration. Tutor-led group learning, tutor to introduce the concept of forced vibration, develop discussion to cover the concepts of phase and resonance; where the phase relationship between the driving oscillation and the oscillation of the object being driven is different at different frequencies. Below resonance they are in phase with each other. At resonance the phase relationship is 90^{o} or $\pi/2$ rad. Above resonance the phase relationship is 180o or π rad.	**Books** Mechanical Vibration Practice with Basic Theory Viswanatha Ramamurti Illustrated CRC Press, 2000 ISBN 0849309751, 9780849309755 If applicable to local area/expertise Noise and Vibration from High-speed Trains Victor V. Krylov Illustrated Thomas Telford, 2001 ISBN 0727729632, 9780727729637 Fundamentals of Noise and Vibration Analysis for Engineers Michael Peter Norton, D. G. Karczub Illustrated, revised Cambridge University Press, 2003 ISBN 0521499135, 9780521499132 **Website** http://physicsnet.co.uk/a-level-physics-as-a2/further-mechanics/forced-vibrations-resonance/

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 17: Vibration Analysis	**Suggested Teaching Time:** 3.5 hours

Learning Outcome 4: Understand the vibration of machines

Topic	Suggested Teaching	Suggested Resources
Analyse a system with one degree of freedom (A.C. 4.2)	Recap the following calculations Displacement (x) = R(sin ωt) Velocity (v) = dx/dt = ωR cos(ωt) Acceleration (a) = dv/dt = $-\omega^2 R \sin(\omega t)$ Tutor-led Instruction: Set up a pendulum and get students to discuss what will happen when you move the pendulum by applying a force and then remove the force. Show calculations for restoring torque and inertia torque and balance of moments. The tutor should work through typical examples of pendulum type calculations, the learners should then work through further examples of these calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained. Set up a Spring/mass system and get students to discuss what will happen when you raise and release the weight. The tutor should work through typical examples of spring mass system type calculations, the learners should then work through further examples of these calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained Set up a shaft/flywheel system and get students to discuss what will happen when you apply a force to the flywheel and release it. The tutor should work through typical examples of shaft/flywheel system type calculations, the learners should then work through further examples of these calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** Mechanical Vibration Practice with Basic Theory Viswanatha Ramamurti Illustrated CRC Press, 2000 ISBN 0849309751, 9780849309755 **Practical equipment** Pendulum Stopwatch Spring/Mass system shaft/flywheel system; **Website** https://www.youtube.com/watch?v=dRkJuVh9hF0 https://www.youtube.com/watch?v=YbFgNsM6r44

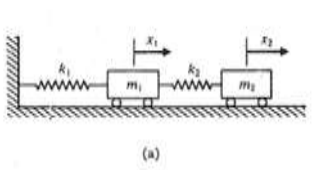
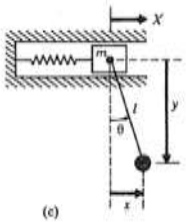
UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Topic	Suggested Teaching	Suggested Resources
Analyse a system with one degree of freedom (A.C. 4.2)	Tutor-led discussion Recap the contents of the lesson and the concept of free vibration and apply to a cars suspension and what it would be like to wait for the vibration to naturally die down, introduce concept of vibration dampening and cover the term critical damping. The tutor should work through typical examples of dampened system type calculations, the learners should then work through further examples of these calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** Mechanical Vibration Practice with Basic Theory Viswanatha Ramamurti Illustrated CRC Press, 2000 ISBN 0849309751, 9780849309755 **Practical equipment** stopwatch Spring/Mass system shaft/flywheel system; Different methods of dampening vibration

Lesson 18: Vibration Analysis (continued)	**Suggested Teaching Time:** 2 hours

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Learning Outcome 4: Understand the vibration of machines

Topic	Suggested Teaching	Suggested Resources
Analyse the normal modes of vibration in a system with two degrees of freedom (A.C. 4.3)	  $m_1 \frac{d^2 x_1}{dt^2} + (k_1 + k_2) x_1 - k_2 x_2 = 0$ $m_2 \frac{d^2 x_2}{dt^2} - k_2 x_1 + (k_2 + k_3) x_2 = 0$ Recap calculations covered in previous lessons and adapt to systems with two degrees of freedom as illustrated. The tutor should work through typical examples of calculations for systems with two degrees of freedom, both dampened and un dampened, the learners should then work through further examples of these calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** Mechanical Vibration Practice with Basic Theory Viswanatha Ramamurti Illustrated CRC Press, 2000 ISBN 0849309751, 9780849309755 **Practical equipment** Laboratory equipment to illustrate systems with two degrees of freedom **Website** http://www.brown.edu/Departments/Engineering/Courses/En4/Notes/vibrations_mdof/vibrations_mdof.htm

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 19: Torsional vibration Analysis	**Suggested Teaching Time:** 2 hours

Learning Outcome 4: Understand the vibration of machines

Topic	Suggested Teaching	Suggested Resources
Analyse torsional vibration of a multi-mass system using Holzer's method (A.C. 4.4)	Tutor-led group discussion to expand principles learned about a simple flywheel and shaft arrangement to a shaft with multiple disks, introducing concepts of multiple inertia, torsion in shafts and simple harmonics. The tutor should work through typical examples of calculations for systems with multiple masses using the Holzer method, the learners should then work through further examples of these calculations. The tutor should provide feedback on the answers obtained and repeat the process until consistent answers are obtained.	**Books** Mechanical Vibration Practice with Basic Theory Viswanatha Ramamurti Illustrated CRC Press, 2000 ISBN 0849309751, 9780849309755 **Practical equipment** Simple machine with turbine and compressor on a single shaft to demonstrate theory **Website** http://www.freestudy.co.uk/dynamics/holzer.pdf

UNIT 518: THE DYNAMICS OF MACHINE SYSTEMS

Lesson 20: Vibration Reduction	**Suggested Teaching Time:** 2 hours

Learning Outcome 4: Understand the vibration of machines

Topic	Suggested Teaching	Suggested Resources
Evaluate **methods for reducing vibration** in a machine (A.C. 4.4)	Tutor-led group discussion on what methods could be used to reduce vibration, building on material covered to date. Topics to cover include: • Reducing harmonic forces • Vibration isolation • Additional damping • Dynamic absorber.	**Books** Fundamentals of Noise and Vibration Analysis for Engineers Michael Peter Norton, D. G. Karczub Illustrated, revised Cambridge University Press, 2003 ISBN 0521499135, 9780521499132 **Practical equipment** Practical machinery that can be adapted to reduce vibration **Website** https://www.youtube.com/watch?v=xktZSlI_bfY