15BEME504 **DYNAMICS OF MACHINERY** 3 1 0 4 100

OBJECTIVES

1. To understand the force-motion relationship in components subjected to external forces and analysis of standard mechanisms.
2. To understand the undesirable effects of unbalances resulting from prescribed motions in mechanism.
3. To understand the effect of Dynamics of undesirable vibrations.
4. To understand the principles in mechanisms used for speed control and stability control.

UNIT I FORCE ANALYSIS 9 + 3

Rigid Body dynamics in general plane motion – Equations of motion – Dynamic force analysis – Inertia force and Inertia torque – D'Alemberts principle – The principle of superposition – Dynamic Analysis in Reciprocating Engines – Gas Forces – Equivalent masses – Bearing loads – Crank shaft Torque – Turning moment diagrams – Fly wheels.

UNIT II BALANCING 9 + 3

Static and dynamic balancing – Balancing of rotating masses – Balancing a single cylinder Engine – Balancing Multi-cylinder Engines – Partial balancing in locomotive Engines.

UNIT III FREE VIBRATION 9 + 3

Basic features of vibratory systems – idealized models – Basic elements and lumping of parameters – Degrees of freedom – Single degree of freedom – Free vibration – Equations of motion – natural frequency – Damping Types of Damping – Damped vibration, critical speeds of simple shaft.

UNIT IV FORCED VIBRATION AND TORSIONAL VIBRATION 9 + 3

Response to periodic forcing – Harmonic Forcing – Forcing caused by unbalance – Support motion – Force transmissibility and amplitude transmissibility – Vibration isolation.
Torsional systems; Natural frequency of free torsional vibrations, Natural frequency of two and three rotor systems.

UNIT V MECHANISMS FOR CONTROL 9 + 3

Governors – Types – Centrifugal governors – Gravity controlled and spring controlled centrifugal governors – Characteristics – Effect of friction – Controlling Force – other Governor mechanisms.
Gyroscopes – Gyroscopic forces and Torques – Gyroscopic stabilization – Gyroscopic effects in Automobiles, ships and airplanes

TOTAL 45 + 15 = 60 PERIODS

TEXT BOOKS

S. No.	Author(s) Name	Title of the book	Publisher	Year of Publication
1	Rattan S.S	Theory of Machines	Tata McGraw-Hill Publishing Company Ltd., New Delhi	2009
2	Shigley J.E, Uicker J.J	Theory of Machines and Mechanisms	McGraw-Hill, New York	2011

REFERENCES

S. No.	Author(s) Name	Title of the book	Publisher	Year of Publication
1	Rao J.S., Dukkipati R.V	Mechanism and Machine Theory	Wiley- Eastern Limited, New Delhi	2007
2	John Hannah and Stephens R.C	Mechanics of Machines	Viva Books Pvt Ltd	2005
3	Thomas Bevan	Theory of Machines	CBS Publishers and Distributors, New Delhi	2011

WEB REFERENCES

1. http://freevideolectures.com/Course/2364/Dynamics-of-Machines
2. http://en.wikipedia.org/wiki/Balancing_of_rotating_masses
3. http://www.efunda.com/formulae/vibrations/sdof_free_damped.cfm
4. http://www.roymech.co.uk/Useful_Tables/Vibrations/Free_Vibrations.html

KARPAGAM ACADEMY OF HIGHER EDUCATION

COIMBATORE – 21

FACULTY OF ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

LESSON PLAN

Subject Name : **Dynamics Of Machinery**
Subject Code : **15BEME504 (Credits - 3)**
Name of the Faculty : **Dr.N.M.SIVARAM**
Designation : **Assistant Professor**
Year/Semester/Section : **III / V /**
Branch : **B.E. – Mechanical Engineering**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
		UNIT – I :Force Analysis	
1.	1	Rigid Body Dynamics in general plane motion	T(1)
2.	1	Equation of Motion	T(1)
3.	1	Dynamic Force Analysis	T(1)
4.	1	Inertia Force And Inertia Torque	T(1)
5.	1	D'Alemberts Principle	T(1)
6.	1	The principle of Superposition	T(1)
7.	1	Dynamic Analysis in Reciprocating Engine	T(1)
8.	1	Gas Force-Equivalent Masses-Bearing Loads	T(1)
9.	1	Crank shaft Torque-Turning Moment Diagrams	T(1)
10.	1	Flywheels	T(1)
		Total No. of Periods Planned for Unit - I	**10**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
		UNIT – II : Balancing	
11.	1	Static Balancing	T(1) R(2)
12.	1	Dynamic Balancing	T(1) R(2)
13.	1	Balancing Of Rotating Masses	T(1) R(2)
14.	1	Balancing Of Rotating Masses	T(1) R(3)
15.	1	Balancing Of Rotating Masses	T(1) R(3)
16.	1	Balancing a single cylinder Engine	T(1) R(3)
17.	1	Balancing Multi cylinder Engine	T(1) R(3)
18.	1	Balancing Multi cylinder Engine	T(1) R(3)
19.	1	Balancing Multi cylinder Engine	T(1) R(3)
20.	1	Partial Balancing in Locomotive Engines	T(1) R(3)

Total No. of Periods Planned for Unit - II	10

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
UNIT – III : Free Vibration			
21.	1	Basic features of vibratory system	T(1)
22.	1	Idealized models	T(1)
23.	1	Basic Elements and lumping Parameters	T(1)
24.	1	Degrees of Freedom	T(1)
25.	1	Single degree of freedom	T(1)
26.	1	Free vibration	T(1) R(1)
27.	1	Equations of motions	T(1) R(1)
28.	1	Natural Frequency	T(1)
29.	1	Damping -Types of Damping -Damped vibration	T(1)
30.	1	Critical Speed of simple shaft	T(1)
Total No. of Periods Planned for Unit - III			**10**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
UNIT – IV : Forced Vibration And Torsional Vibration			
31.	1	Response to Periodic Forcing	T(1)
32.	1	Harmonic Forcing	T(1)
33.	1	Forcing Caused by unbalance	T(1)
34.	1	Support Motion	T(1)
35.	1	Force Transmissiblity	T(1)
36.	1	Amplitude transmssiblity	T(1)
37.	1	Vibration isolation-Torsional system	T(1)
38.	1	Natural frequency of free torsional vibration	T(1)
39.	1	Natural frequency of Two rotor system	T(1)
40.	1	Natural frequency of Three rotor system	T(1)
Total No. of Periods Planned for Unit - IV			**10**

Sl. No.	No. of Periods	Topics to be Covered	Support Materials
UNIT – V : Mechanisms For Control			
41.	1	Governors-Types	R(1) R(3)
42.	1	Centrifugal Governors	R(1) R(3)
43.	1	Gravity controlled and spring controlled centrifugal governors	R(1) R(3)
44.	1	Gravity controlled and spring controlled centrifugal governors-characteristics	R(1) R(3)
45.	1	Effect of Friction	R(1) R(3)
46.	1	Controlling Force-other governor mechanism	R(1) R(3)
47.	1	Gyroscope-Gyroscopic force and Torques	R(1) R(3)
48.	1	Gyroscopic stabilization	R(1) R(3)

49.	1	Gyroscopic Effect in Automobile,ships	**R(1) R(3)**
50.	1	Gyroscopic Effect in planes	**R(1) R(3)**
51.	2	**Discussion on Competitive Examination related Questions / University previous year questions**	**GATE, ESE QP**
Total No. of Periods Planned for Unit - V			**12**

TOTAL PERIODS : 52

TEXT BOOKS

S. No.	Author(s) Name	Title of the book	Publisher	Year of Publication
1	Rattan ss	Theory of machine	Tata MC Graw Hill publishing company ltd New Delhi	2009

REFERENCES

S. No.	Author(s) Name	Title of the book	Publisher	Year of Publication
1.	Rao js	Mechanism and Machine theory	Wiley Eastern Limited,New Delhi	2007
2.	John	Mechanics of Machine	VIVA BOOKS PVT LTD	2005
3.	Thomson Bevan	Theory Of Machines	CBS PUBLISHERSAND DISTRIBUTORS,New Delhi	2011

WEB REFERENCES

1. https://en.wikipedia.org/wiki/Dynamics_(mechanics)
2. https://nptel.ac.in/courses/112/104/112104114/

Dynamics Of Machinery

UNIT	Total No. of Periods Planned	Lecture Periods	Tutorial Periods
I	10	10	0
II	10	10	0
III	10	10	0
IV	10	10	0
V	12	12	0
TOTAL	**52**	**52**	**0**

I. CONTINUOUS INTERNAL ASSESSMENT : 40 Marks

(Internal Assessment Tests: 30, Attendance: 5, Assignment/Seminar: 5)

II. END SEMESTER EXAMINATION : 60 Marks

TOTAL : 100 Marks

FACULTY **HOD / MECH** **DEAN / FOE**

UNIT 1 – FORCE ANALYSIS

1.1 Rigid Body dynamics in general plane motion

A rigid body is an idealization of a body that does not deform or change shape. Formally it is defined as a collection of particles with the property that the distance between particles remains unchanged during the course of motions of the body. Like the approximation of a rigid body as a particle, this is never strictly true. All bodies deform as they move. However, the approximation remains acceptable as long as the deformations are negligible relative to the overall motion of the body.

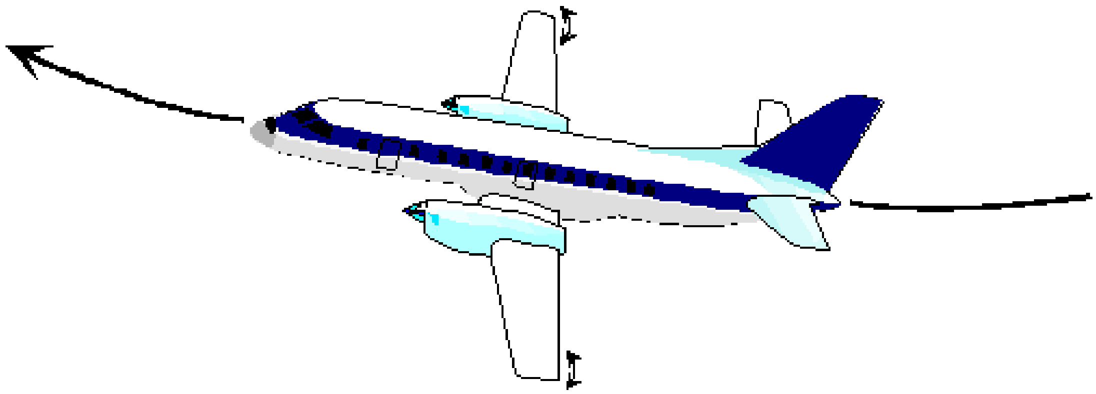


Figure 1.1: Deformations experienced by an aircraft are small relative to its motion.

As an example, the flutter of an aircraft wing during the course of a flight is clearly negligible relative to the motion of the aircraft as a whole. On the other hand, if one was interested in stresses induced in the wing as a consequence of the flutter, these deformations become of primary importance.

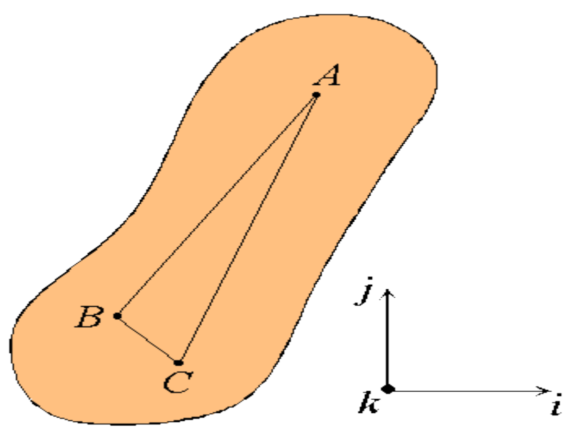


Figure 1.2: Schematic showing a planar rigid body.

In the following, we will restrict attention to the planar motion of rigid bodies. In particular, we will take all rigid bodies to be thin slabs with motion constrained to lie within the plane of the slab. Unless otherwise indicated, we will assume basis vectors of the form {***i***, ***j***, ***k***}, such that ***i*** and ***j*** lie in the plane, with ***k*** is the plane normal.

1.2 Equation of Motion

A `Particle' is a point mass at some position in space. It can move about, but has no characteristic orientation or rotational inertia. It is characterized by its mass.

Examples of applications where you might choose to idealize part of a system as a particle include:

1. Calculating the orbit of a satellite _ for this application, you don't need to know the orientation of the satellite, and you know that the satellite is very small compared with the dimensions of its orbit.
2. A molecular dynamic simulation, where you wish to calculate the motion of individual atoms in a material. Most of the mass of an atom is usually concentrated in a very small region (the nucleus) in comparison to inter-atomic spacing. It has negligible rotational inertia. This approach is also sometimes used to model entire molecules, but rotational inertia can be important in this case.

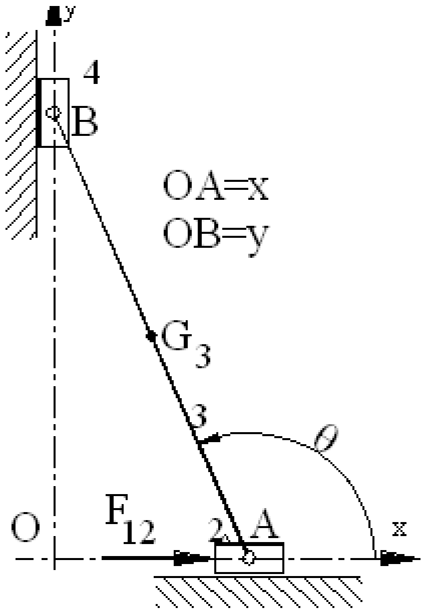
Obviously, if you choose to idealize an object as a particle, you will only be able to calculate its position. Its orientation or rotation cannot be computed.

1.3 Dynamic Force Analysis

In this section we shall assume that the motion of the machine parts are specified beforehand, e.g. the position velocity and acceleration of each rigid body is known or can be calculated by performing kinematic analysis. We shall also assume that the mass and the moment of inertia of each machine member is known or can be calculated from the given data. There may be external forces of known magnitude and direction or friction forces present. However, we shall assume that there is one external force (such as the input torque) of an unknown magnitude but of a known direction and a point of application. The system is in a state of dynamic equilibrium under the action of these forces. We would like to determine the joint forces, forces acting on the members and the magnitude of the unknown external force.

The above problem is commonly known as ***kinetostatics*** or ***Wittenbauer's second problem***. Such a formulation is valid under steady state conditions and when the mechanism involved is a constrained mechanism. The input speed(s) must be almost constant for these assumptions to be valid or the changes in the velocity and acceleration of the input link is determined� by some other means.

In kinetostatics we determine the velocity and acceleration of each machine member by performing kinematic analysis. If the mass and mass distribution of the members are known, we can calculate the inertia forces and torques. Next we apply D'Alambert's principle so that we can treat the fictitious inertia forces as if they are external forces. The problem reduces to static force analysis of machinery



1.4 Inertia Force And Inertia Torque

Inertial Force — The presence of particular force in that particular system in order to bring the whole system in equilibrium, it can be easily observe when system is moving in straight line.

Inertial torque — The presence of particular torque in that particular system in order to bring the whole system in equilibrium, it can be easily observe when system having rotational motion.

1.5 D'Alemberts Principle

Alembert's principle, alternative form of Newton's second law of motion, stated by the 18th-century French polymath Jean le Rond d'Alembert. In effect, the principle reduces a problem in dynamics to a problem in statics. The second law states that the force F acting on a body is equal to the product of the mass m and acceleration a of the body, or $F = ma$; in d'Alembert's form, the force F plus the negative of the mass m times acceleration a of the body is equal to zero: $F - ma = 0$. In other words, the body is in equilibrium under the action of the real force F and the fictitious force $-ma$. The fictitious force is also called an inertial force and a reversed effective force. Because unknown forces are more easily determined on bodies in equilibrium than on moving bodies, the force and stress analysis of machine components can usually be simplified by using inertial forces. When developing the formulas for the stresses in a rotating disk, for example, it is convenient to assume that a representative element in the disk is in equilibrium under the action of a system of radial and tangential forces produced by the stresses and an outward-acting inertial (centrifugalforce.)

1.6 The Principle Of superpositon

Superposition Principle lets us calculate the total force on a given charge due to any number of point charges acting on it. Every charged particle creates an electric field in the universe in the space surrounding it. The electric field created due to the charge is independent of the presence or absence of all other charges. The electric field created can be calculated with the help of Coulomb's law. The principle of superposition allows for the combination of two or more electric fields

The superposition principle is used to compute the net flux, net field, the net potential energy of the system.In the next section, let us discuss how the superposition principle is applied in electrostatics.

1.7 Dynamics Analysis In Reciprocating Engines

Effect of static and kinetic forces of reciprocating parts .Static forces arise due to weight of reciprocating parts as well as due to variation of fluid pressure on account of expansion or compression. (I.C engines) .Due to reciprocating or to and fro motion, each member is subjected to varying acceleration at its different positions. This leads to varying kinetic forces from instant to instant. .The above variation of fluid pressure and kinetic forces for every position of crank leads to nonuniform development of torque and work. This necessitates use of flywheel in reciprocating engines to limit fluctuation of speed.

1.8 Equivalent Masses

In order to determine the motion of a rigid body, under the action of external forces, it is usually convenient to replace the rigid body by two masses placed at a fixed distance apart, in such a way that,

1. the sum of their masses is equal to the total mass of the body ;
2. the centre of gravity of the two masses coincides with that of the body ; and
3. the sum of mass moment of inertia of the masses about their centre of gravity is equal to the mass moment of inertia of the body.

1.9Bearing Loads

Bearings typically have to deal with two kinds of loading, **radial** and **thrust**. Depending on where the bearing is being used, it may see all radial loading, all thrust loading or a combination of both.

1.10 Crank shaft Torque

The **torque** at the **crankshaft** is produced by the force applied on the conrod journal through the connecting rod. ... The magnitude of the force F depends on the combustion pressure within the cylinder. The higher the pressure in the cylinder, the higher the force on the **crankshaft**, the higher the output **torque**.

1.11 Turning Moment Diagrams

The turning moment diagram (also known as ***crank-effort diagram***) is the graphical representation of the turning moment or crank-effort for various positions of the crank. It is plotted on cartesian co-ordinates, in which the turning moment is taken as the ordinate and crank angle as abscissa

1 Turning Moment Diagram for a Single Cylinder Double Acting Steam Engine

A turning moment diagram for a single cylinder double acting steam engine is shown in Fig. 16.1. The vertical ordinate represents the turning moment and the horizontal ordinate represents the crank angle.

We have discussed in other Chapter (Art. 15.10.) that the turning moment on the crankshaft,

$$T = F_P \times r\left(\sin\theta + \frac{\sin 2\theta}{2\sqrt{n^2 - \sin^2\theta}}\right)$$

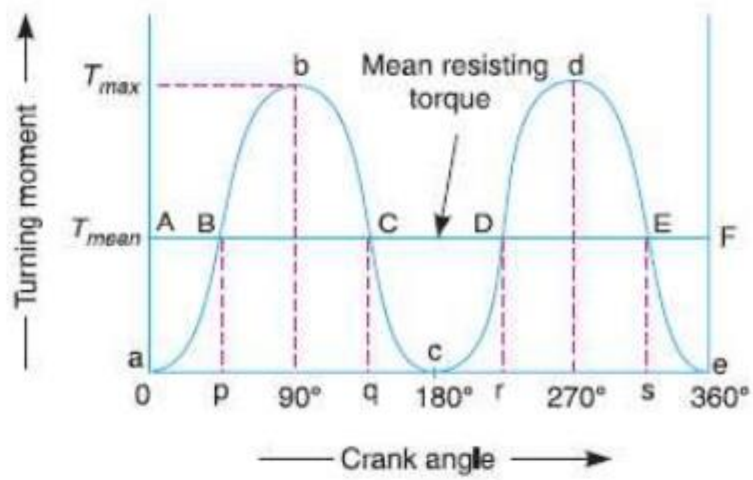


Fig. 16.1. Turning moment diagram for a single cylinder, double acting steam engine.

where F_P = Piston effort,

r = Radius of crank,

n = Ratio of the connecting rod length and radius of crank, and

θ = Angle turned by the crank from inner dead centre.

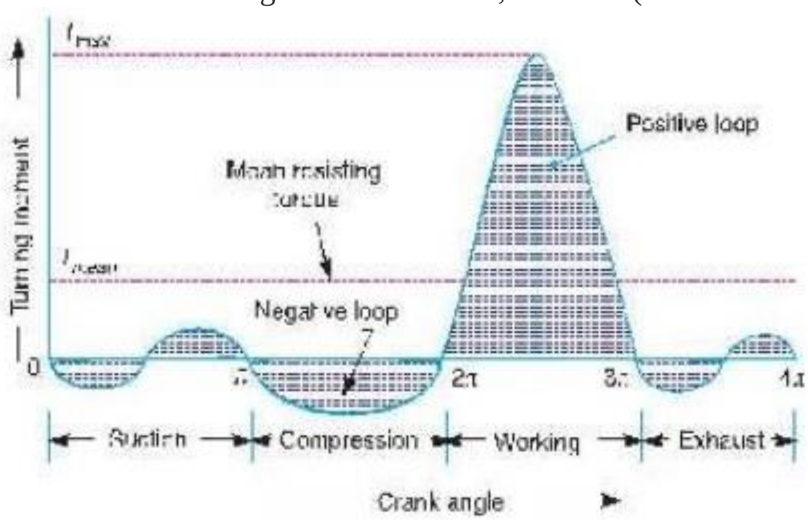
is maximum when the crank angle is 90° and it is again zero when crank angle is 180°.

This is shown by the curve *abc* in Fig. 16.1 and it represents the turning moment diagram for outstroke. The curve *cde* is the turning moment diagram for instroke and is somewhat similar to the curve *abc*.

Since the work done is the product of the turning moment and the angle turned, therefore the area of the turning moment diagram represents the work done per revolution. In actual practice, the engine is assumed to work against the mean resisting torque, as shown by a horizontal line *AF*. The height of the ordinate *a A* represents the mean height of the turning moment diagram. Since it is assumed that the work done by the turning moment per revolution is equal to the work done against the mean resisting torque, therefore the area of the rectangle *aAFe* is proportional to the work done against the mean resisting torque.

2 Turning Moment Diagram for a Four Stroke Cycle Internal Combustion Engine

A turning moment diagram for a four stroke cycle internal combustion engine is shown in Fig. 16.2. We know that in a four stroke cycle internal combustion engine, there is one working stroke after the crank has turned through two revolutions, *i.e.* 720° (or 4 π radians).



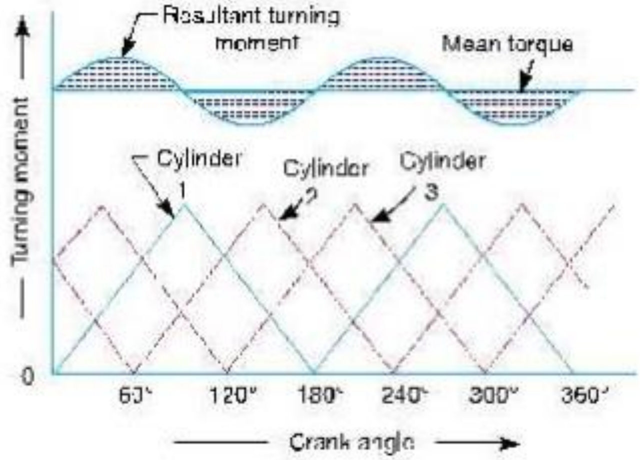
Turning moment diagram for a four stroke cycle internal combustion engine.

Fig. 3 . Turning moment diagram for a four stroke cycle internal combustion engine.

Since the pressure inside the engine cylinder is less than the atmospheric pressure during the suction stroke, therefore a negative loop is formed as shown in Fig. 16.2. During the compression stroke, the work is done on the gases, therefore a higher negative loop is obtained. During the expansion or working stroke, the fuel burns and the gases expand, therefore a large positive loop is obtained. In this stroke, the work is done by the gases. During exhaust stroke, the work is done on the gases, therefore a negative loop is formed. It may be noted that the effect of the inertia forces on the piston is taken into account in Fig. 3.

3. Turning Moment Diagram for a Multi-cylinder Engine

A separate turning moment diagram for a compound steam engine having three cylinders and the resultant turning moment diagram is shown in Fig. 4. The resultant turning moment diagram is the sum of the turning moment diagrams for the three cylinders. It may be noted that the first cylinder is the high pressure cylinder, second cylinder is the intermediate cylinder and the third cylinder is the low pressure cylinder. The cranks, in case of three cylinders, are usually placed at 120° to each other.



1.12 Flywheels

Flywheels are used to smooth out fluctuating torques such as produced on the crank of piston engines. The diagram shows a torque - angle diagram for a certain **machine**. The speed of the shaft must be maintained between 490 and 510 rev/min. Calculate the mass required if the radius of gyration is to be 0.3 m.

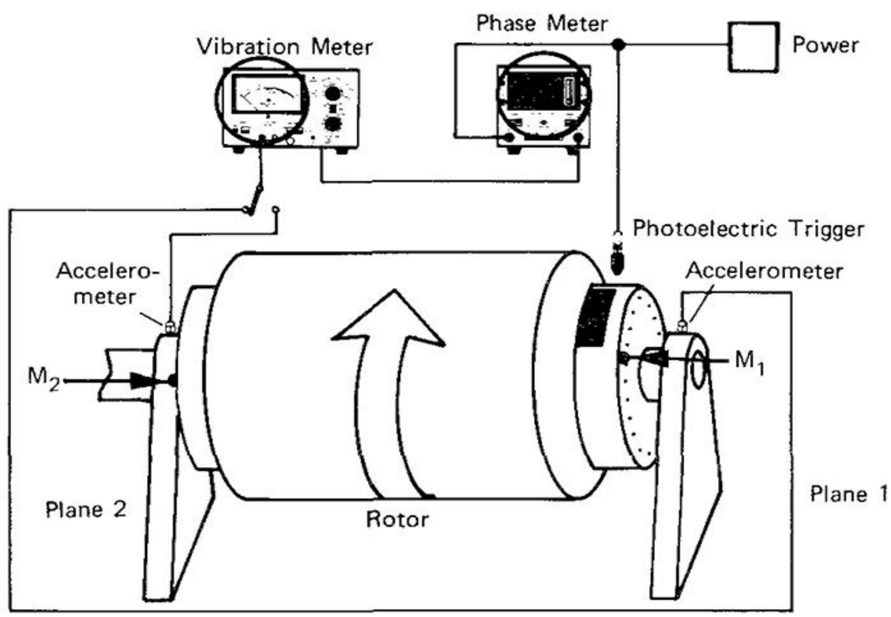
UNIT-II
BALANCING

2.1 STATIC AND DYNAMIC BALANCING

Primary Balancing describes the process where primary forces caused by unbalanced mass components in a rotating object may be re solved into one plane and balanced by adding a mass in that plane only. As the object would now be completely balanced in the static condition (but not necessarily in dynamic) this is often known as Static Balancing.

Secondary Balancing describes the process where primary forces and secondary force couples caused by unbalanced mass components in a rotating object may be resolved into two (or more) planes and balanced by adding mass increments in those planes.

This balancing process is often known as Dynamic Balancing because the unbalance only becomes apparent when the object is rotating. After being balanced dynamically, the object would be completely balanced in both static and dynamic conditions.



The difference between static balance and dynamic balance. It will be observed that when the rotor is stationary (static) the end masses may balance each other. However, when rotating (dynamic) a strong unbalance will be experienced.

2.2 BALANCING OF ROTATING MASSES

When a mass moves along a circular path, it experiences a centripetal acceleration and a force is required to produce it. An equal and opposite force called centrifugal force acts radially outwards and is a disturbing force on the axis of rotation. The magnitude of this remains constant but the direction changes with the rotation of the mass. In a revolving rotor, the centrifugal force remains balanced as long as the centre of the mass of rotor lies on the axis of rotation of the shaft. When this does not happen, there is an eccentricity and an unbalance force is produced. This type of unbalance is common in steam turbine rotors, engine crankshafts, rotors of compressors, centrifugal pumps etc. The unbalance forces exerted on machine members are time varying, impart vibratory motion and noise, there are human discomfort, performance of the machine deteriorate and detrimental effect on the structural integrity of the machine foundation. Balancing involves redistributing the mass which may be carried out by addition or removal of mass from various machine members Balancing of rotating masses can be of 1. Balancing of a single rotating mass by a single mass rotating in the same plane. 2. Balancing of a single rotating mass by two masses rotating in different planes. 3. Balancing of several masses rotating in the same plane 4. Balancing of several masses rotating in different planes

2.3 Balancing a single cylinder Engine

A single cylinder engine produces three main vibrations. In describing them we will assume that the cylinder is vertical. Firstly, in an engine with no balancing counterweights, there would be an enormous vibration produced by the change in momentum of the piston, gudgeon pin, connecting rod and crankshaft once every revolution. Nearly all single-cylinder crankshafts incorporate balancing weights to reduce this. While these weights can balance the crankshaft completely, they cannot completely balance the motion of the piston, for two reasons. The first reason is that the balancing weights have horizontal motion as well as vertical motion, so balancing the purely vertical motion of the piston by a crankshaft weight adds a horizontal vibration. The second reason is that, considering now the vertical motion only, the smaller piston end of the connecting rod (little end) is closer to the larger crankshaft end (big end) of the connecting rod in mid-stroke than it is at the top or bottom of the stroke, because of the connecting rod's angle. So during the 180° rotation from mid-stroke through top-dead-center and back to mid-stroke the minor contribution to the piston's up/down movement from the connecting rod's change of angle has the same direction as the major contribution to the piston's up/down movement from the up/down movement of the crank pin. By contrast, during the 180° rotation from mid-stroke through bottom-dead-center and back to mid-stroke the minor contribution to the piston's up/down movement from the connecting rod's change of angle has the opposite direction of the major contribution to the piston's up/down movement from the up/down movement of the crank pin. The piston therefore travels faster in the top half of the cylinder than it does in the bottom half, while the motion of the crankshaft weights is sinusoidal. The vertical motion of the piston is therefore not quite the same as that of the balancing weight, so they can't be made to cancel out completely.

Secondly, there is a vibration produced by the change in speed and therefore kinetic energy of the piston. The crankshaft will tend to slow down as the piston speeds up and absorbs energy, and to speed up again as the piston gives up energy in slowing down at the top and bottom of the stroke. This vibration has twice the frequency of the first vibration, and absorbing it is one function of the flywheel.

Thirdly, there is a vibration produced by the fact that the engine is only producing power during the power stroke. In a four-stroke engine this vibration will have half the frequency of the first vibration, as the cylinder fires once every two revolutions. In a two -stroke engine, it will have the same frequency as the first vibration. This vibration is also absorbed by the flywheel.

2.4 Balancing Multi Cylinder Engine

In multi-cylinder engines the mutual counteractions of the various components in the Crank shaft assembly are one of the essential factors determining the selection of the Crank shafts configuration and with it the design of the engine itself. The inertial forces are Balanced if the common centre of gravity for all moving crankshaft-assembly components lies at the crankshaft's midpoint, i.e. if the crankshaft is symmetrical (as viewed from the front). The crankshaft's symmetry level can be defined using geometrical representations of 1st- and 2nd- order forces (star diagrams). The 2nd order star diagram for the four-cylinder in-line engine is asymmetrical, meaning that this order is characterized by substantial free inertial Forces. These forces can be balanced using two countershafts rotating in opposite directions at double the rate of the crankshaft (Lanchester system).

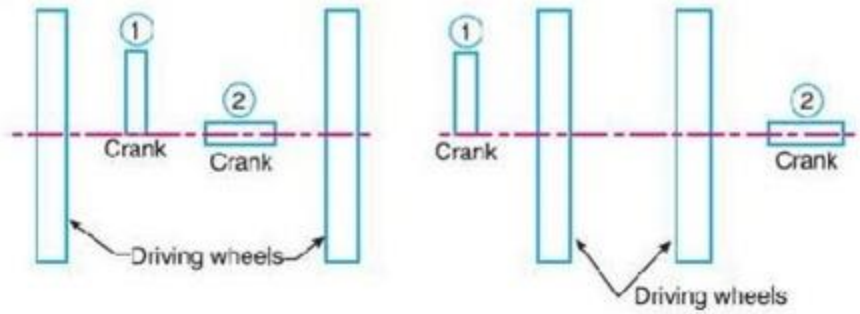
2.5 Partial Balancing in locomotive Engine

The locomotives, usually, have two cylinders with cranks placed at right angles to each other in order to have uniformity in turning moment diagram. The two cylinder locomotives may be classified as :

1. Inside cylinder locomotives ; and 2. Outside cylinder locomotives.

In the ***inside cylinder locomotives***, the two cylinders are placed in between the planes of two driving wheels as shown in Fig. (*a*) ; whereas in the ***outside cylinder locomotives***, the two cylinders are placed outside the driving wheels, one on each side of the driving wheel, as shown in Fig. (*b*). The locomotives may be

(*a*) Single or uncoupled locomotives ; and (*b*) Coupled locomotives.



(*a*) Inside cylinder locomotives. (*b*) Outside cylinder locomotives.

UNIT-III
FREE VIBRATION

3.1 Basic Features of a Vibratory System

Periodic Motion The motion which repeats after a regular interval of time is called periodic motion. Frequency The number of cycles completed in a unit time is called frequency. Its unit is cycles per second (cps) or Hertz (Hz). Time Period Time taken to complete one cycle is called periodic time. It is represented in seconds/cycle. Amplitude The maximum displacement of a vibrating system or body from the mean equilibrium position is called amplitude. Free Vibrations When a system is disturbed, it starts vibrating and keeps on vibrating thereafter without the action of external force. Such vibrations are called free vibrations. Natural Frequency When a system executes free vibrations which are undamped, the frequency of such a system is called natural frequency. Forced Vibrations The vibrations of the system under the influence of an external force are called forced vibrations. The frequency of forced vibrations is equal to the forcing frequency. Resonance When frequency of the exciting force is equal to the natural frequency of the system it is called resonance. Under such conditions the amplitude of vibration builds up dangerously. Degree of Freedom The degree of freedom of a vibrating body or system implies the number of independent coordinates which are required to define the motion of the body or system at given instant.

3.2 Basic Elements and lumping of parameters

The elements constituting a lumped parameter vibratory system are : The Mass The mass is assumed to be rigid and concentrated at the centre of gravity. The Spring It is assumed that the elasticity is represented by a helical spring. When deformed it stores energy. The energy stored in the spring is given by wherek is stiffness of the spring. The force at the spring is given by F= k x The springs work as energy restoring element. They are treated massless. The Damper In a vibratory system the damper is an element which is responsible for loss of energy in the system. It converts energy into heat due to friction which may be either sliding friction or viscous friction. A vibratory system stops vibration because of energy conversion by damper. There are two types of dampers. Viscous Damper A viscous damper consists of viscous friction which converts energy into heat due to this. For this damper, force is proportional to the relative velocity. Fd α relative velocity (v) Fd = cv wherec is constant of proportionality and it is called coefficient of damping. The coefficient of viscous damping is defined as the force in 'N' when velocity is 1 m/s.

3.3 Degree of Freedom

The number of independent coordinates required to completely define the motion of a system is known as degree of freedom of the system.

FREE VIBRATION OF LONGITUDINAL, TRANSVERSE AND TORSIONAL SYSTEMS OF SINGLE DEGREE OF FREEDOM

Longitudinal Vibration: When the particles of the shaft or disc moves parallel to the axis of the shaft, then the vibrations known as longitudinal vibrations. Transverse Vibration: When the particles of the shaft or disc moves approximately perpendicular to the axis of the shaft, then the vibrations known as transverse vibrations. Torsional Vibration: When the particles of the shaft or disc move in a circle about the axis of the shaft, then the vibrations known as torsional vibration

3.4 Free Vibration

When a system is subjected to an initial disturbance and then left free to vibrate on its own, the resulting vibrations are referred to as free vibrations . **Free vibration** occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and then letting go or hitting a tuning fork and letting it ring. The mechanical system will then vibrate at one or more of its "natural frequencies" and damp down to zero.

3.5 Equation Of Motion

In physics, **equations of motion** are **equations** that describe the behavior of a physical system in terms of its **motion** as a function of time. ... If the **dynamics** of a system is known, the **equations** are the solutions for the differential **equations** describing the **motion** of the **dynamics**.

3.6 Natural Frequency

Natural Frequency (fn) **Frequency** of free vibration of the system. Expressed in Hz or rad/sec. Amplitude The maximum displacement of a vibrating body from its equilibrium position.

3.7 Damping

It is the resistance to the motion of a vibrating body. The vibrations associated with this resistance are known as damped vibrations.

3.8 Types of Damping

(1) Viscous damping (2) Dry friction or coulomb damping (3) Solid damping or structural damping (4) Slip or interfacial damping.

3.9 Damped Vibration

The vibrations associated with this resistance are known as damped vibrations.

3.10 Critical Speed Of Shaft

The **critical speed** is the theoretical angular **velocity** which excites the natural frequency of a rotating object, such as a **shaft**. As the **speed** of rotation approaches the objects natural frequency, the object begins to resonate which dramatically increases systemic vibration**.**

UNIT -IV
FORCED VIBRATION AND TORSIONAL VIBRATION

4.1 RESPONSE TO PERIODIC FORCING

The equation of motion is written in the form: mx cx kx F cosωt + + = 0 && & (1) Note that F0 is the amplitude of the driving force and ω is the driving (or forcing) frequency, not to be confused with ωn. Equation (1) is a non-homogeneous, 2nd order differential equation. This will have two solutions: the homogeneous (F0=0) and the particular (the periodic force), with the total response being the sum of the two responses. The homogeneous solution is the free vibration problem from last chapter. We will assume that the particular solution is of the form: x t A t A t p ( ) = 1 sinω + 2 cosω (2) Thus the particular solution is a steady-state oscillation having the same frequency ω as the exciting force and a phase angle, as suggested by the sine and cosine terms.

4.2 HARMONIC FORCING

Harmonic excitation refers to a sinusoidal external **force** of a certain frequency applied to a system. ... Resonance occurs when the external excitation has the same frequency as the natural frequency of the system. It leads to large displacements and can cause a system to exceed its elastic range and fail structurally.

4.3 Forcing Caused by Unbalance

unbalanced forces are not equal, and they always cause the motion of an object to change the speed and/or direction that it is moving.

- When two unbalanced forces are exerted in opposite directions, their combined force is equal to the difference between the two forces.
- The magnitude and direction of the net force affects the resulting motion
- This combined force is exerted in the direction of the larger force
- For example, if two students push on opposite sides of a box sitting on the floor, the student on the left pushes with less force (small arrow) on the box than the student on the right side of the box (long arrow).

4.4 Support Motion

In case of locomotives or vehicles, the wheels act as base or support for the system. The wheels can move vertically up and down on the road surface during the motion of the vehicle. At the same time there is relative motion between the wheels and the chassis. So chassis is having motion relative to the wheels and the wheels are having motion relative to the road surface. The amplitude of vibration in case of support motion depends on the speed of the vehicle and the nature of road surface. The vibration measuring instruments are designed on the support motion approach.

4.5 Force Transmissiblity and Amplitude Transmissiblity

the **force transmissibility**, which is defined as the ratio of the amplitude of **force** transmitted to the rigid foundation to the amplitude of the excitation **force** (at the frequency of excitation), differs from the **displacement transmissibility**

The Seat Effective **Amplitude Transmissibility** (SEAT) value is the ratio of the vibration experienced on top of the seat and the vibration that one would be exposed to when sitting directly on the vibrating floor. SEAT values have been widely used to determine the vibration isolation efficiency of a seat.

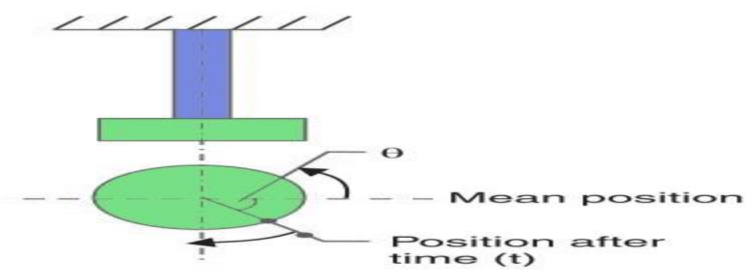
4.6 Vibration Isolation

Vibration isolation is a commonly used technique for reducing or suppressing unwanted **vibrations** in structures and machines. With this technique, the device or system of interest is **isolated** from the source of **vibration** through insertion of a resilient member or **isolator**.

4.7 Torsional system

Torsional vibration is angular vibration of an object—commonly a shaft along its axis of rotation. **Torsional** vibration is often a concern in power transmission **systems** using rotating shafts or couplings where it can cause failures if not controlled. A second effect of **torsional** vibrations applies to passenger cars.

4.8 Natural Frequency of Free Torsional Vibration



Where

- θ = Angular displacement of the shaft from the mean position after time t in radians
- *m* = Mass of the disc in kg
- *I* = Mass moment of inertia of disc in kg-m^2 = m.k^2
- *k* = Radius of gyration in metres
- *q* = Torsional stiffness of the shaft in N-m
-

- Now, let's see the body is in the equilibrium position,

- ∴ Restoring force = q.θ

UNIT -V

MECHANISMS FOR CONTROL

5.1 Governors

A centrifugal governor is a specific type of governor that controls the speed of an engine by regulating the amount of fuel (or working fluid) admitted, so as to maintain a near constant speed whatever the load or fuel supply conditions. It uses the principle of proportional control. It is most obviously seen on steam engines where it regulates the admission of steam into the cylinder(s). It is also found on internal combustion engines and variously fuelled turbines, and in some modern striking clocks.

5.2 Types Of Governors

Governors are classified based upon two different principles. These are:

1. Centrifugal governors

2. Inertia governors

5.3 Centrifugal Governors

For satisfactory performance and working a centrifugal governor should possess The following qualities. a. On the sudden removal of load its sleeve should reach at the top most position at Once. b. Its response to the change of speed should be fast. c. Its sleeve should float at some intermediate position under normal operating Conditions. d. At the lowest position of sleeve the engine should develop maximum power. e. It should have sufficient power, so that it may be able to exert the required force At the sleeve to operate the control & mechanism.

5.4 Effects of Friction

it produces heat, that helps in heating parts of any object or to warm ourselves. It also causes loss in power. It produces noise during any kind of operation. It's because of **friction** that we're able to walk, run, play, etc.

5.5 Controlling Force

When a body rotates in a circular path, there is an inward radial **force** or centripetal **force** acting on it. In case of a governor running at a steady speed, the inward **force** acting on the rotating balls is known as **controlling force**. It is equal and opposite of the centrifugal reaction.

5.6 Gyroscopes

A gyroscope is a device for measuring or maintaining orientation, based on the principles of conservation of angular momentum. A mechanical gyroscope is essentially a spinning wheel or disk whose axle is free to take any orientation. This orientation changes much less in response to a given external torque than it would without the large angular momentum associated with the gyroscope's high rate of spin. Since external torque is minimized by mounting the device in gimbals, its orientation remains nearly fixed, regardless of any motion of the platform on which it is mounted. Gyroscopes based on other operating principles also Exit, such as the electronic, microchip-packaged MEMS gyroscope devices found in consumer electronic devices, solid state ring lasers, fiber optic gyroscopes and the extremely sensitive quantum gyroscope. Applications of gyroscopes include navigation (INS) when magnetic compasses do not work (as in the Hubble telescope) or are not precise enough (as in ICBMs) or for the stabilization of flying vehicles like radio-controlled helicopters or UAVs. Due to higher precision, gyroscopes are also used to maintain direction in tunnel mining.

5.7 Gyroscopic Force And Torque

Gyroscopic motion is the tendency of a rotating object to maintain the orientation of its rotation. ... The object will resist any change in its axis of rotation, as a change in orientation will result in a change in angular momentum

A **gyroscopic torque** will result if the axis of the flywheel is rotated and it acts perpendicular to the rotor axis. The magnitude of the **torque** is the product of the flywheel rotor moment of inertia, the flywheel angular velocity and the angular velocity of the flywheel axis.

5.8 Gyroscopic stabilization

A **Gyroscopic** stabilizer is a control system that reduces tilting movement of a ship or aircraft. ... Anti-rolling **gyro**, or ship **stabilizing gyroscope**, applies force to a large **gyroscope**. **Gyroscopic** autopilot adjusts control surfaces of the aircraft.