



**SHRI ANGALAMMAN COLLEGE OF
ENGINEERING AND TECHNOLOGY**
(An ISO 9001:2008 Certified Institution)
SIRUGANOOR, TIRUCHIRAPPALLI – 621 105



Department of Mechanical Engineering

ME1301 Dynamics of Machinery

UNIT-1 FORCE ANALYSIS

PART-A (2 Marks)

1. What is free body diagram?
2. Define static force analysis.
3. Differentiate between static and dynamic equilibrium.
4. Define applied and constraint forces.
5. Differentiate between static force analysis and dynamic force analysis.
6. Define inertia force.
7. Define inertia torque.
8. State D'Alembert's principle.
9. State the principle of superposition.
10. Define piston effort.
11. Define crank effort and crank-pin effort.
12. What is meant by turning moment diagram or crank effort diagram?
13. Explain the term maximum fluctuation of energy in fly wheel.
14. Define coefficient of fluctuation of energy.
15. Define coefficient of fluctuation of speed.
16. Define coefficient of steadiness.
17. Why flywheels are needed in forging and pressing operations?
18. What is cam dynamics?
19. Define unbalance and spring surge.
20. Define windup. What is the remedy for camshaft windup?
21. What are the effect and causes of windup?

PART-B (16 Marks)

1. For reciprocating engine, derive the expression for
 - (i) Velocity and acceleration of the piston
 - (ii) Angular velocity and angular acceleration of the connecting rod.
2. In a reciprocating engine mechanism, if the crank and connecting rod are 300mm and 1m long respectively and the crank rotates at a constant speed of 200r.p.m. Determine analytically,
 1. The crank angle at which the maximum velocity occurs
 2. Maximum velocity of piston.
 3. Derive the relevant equations. (16)
- 3 (i) Deduce the expression for the inertia force in the reciprocating force neglecting the weight of the connecting rod.
(ii) A vertical petrol engine with cylinder of 150mm diameter and 200mm strokes has a connecting rod of 350mm long. The mass is 1.6kg and the engine speed is 1800 rpm. On the expansion stroke with crank angle 30° from TDC, the gas pressure is 750KPa. Determine the net thrust on the piston and connecting rod, torque on crank. (8+8)
4. (i) Define coefficient of fluctuation of speed and coefficient of fluctuation of energy.
(ii) The radius of gyration of a fly wheel is 1meter and fluctuation of speed is not to exceed 1% of the mean speed of the flywheel. If the mass of the flywheel is 3340kg and the steam develops 150KW at 135rpm, then find,
 1. Max fluctuation of energy
 2. Coeff of fluctuation of energy (4+12)
5. The length of crank and connecting rod of a horizontal reciprocating engine are 150mm and 600mm respectively. The crank makes an angle of 60 deg with the inner dead center and revolves at a uniform speed of 300 rpm. Find
 1. Velocity and acceleration at the mid point of the connecting rod
 2. Angular velocity and angular acceleration of the connecting rod.
6. The length and connecting rod of a horizontal reciprocating engine are 200mm and 1 meter respectively. The crank is rotating at 400 rpm. When the crank has turned 30° from the inner dead center, the difference of pressure between cover end and piston rod is 0.4 N/mm^2 . If the mass of the reciprocating parts is 100Kg and a cylinder bore is 0.4meters. Calculate

- (i) Inertia force (ii) Force on piston (iii) Piston effort
 (iv) Thrust on the side of the cylinder walls
 (v) Thrust in the connecting rod
 (vi) Crank effort.
7. A horizontal gas engine running at 210rpm has a bore of 220mm and a stroke of 440mm. The connecting rod is 924mm long the reciprocating parts weight 20kg. When the crank has turned through an angle of 30° from IDC, the gas pressure on the cover and the crank sides are 500KN/m^2 and 60KN/m^2 respectively. Diameter of the piston rod is 40mm. Determine,
1. Turning moment on the crank shaft
 2. Thrust on bearing
 3. Acceleration of the flywheel which has a mass of 8kg and radius of gyration of 600mm while the power of the engine is 22KW.
8. A single cylinder vertical engine has a bore of 300mm and a stroke of 400mm. The connecting rod is 1000mm long. The mass of the reciprocating parts is 140kg. On the expansion stroke with the crank at 30° from the top dead center, the gas pressure is 0.7MPa. If the runs at 250rpm, determine;
1. Net force acting on the piston
 2. resultant load on the gudgeon pin
 3. Thrust on cylinder walls
 4. The speed above which other things remaining same, gudgeon pin loads would be reversed in direction.
9. A vertical double acting steam engine has a cylinder 300mm diameter and 450mm stroke and runs at 200rpm. The reciprocating parts has a mass of 225kg and the piston rod is 50mm diameter. The connecting rod is 1.2m long. When the crank has turned 125° from IDC the steam pressure above the piston is 30KN/m^2 . calculate,
- (i) Crank-pin effort
 - (ii) The effective turning moment on the crank shaft.
10. The turning moment diagram for a petrol engine is drawn to a scale of 1mm to 629-Nm and the horizontal scale of 1mm to 1° . The turning moment repeat itself after every half revolution of the engine. The area above and below the mean torque line are 305, 710, 50, 350, 980 and 275mm^2 .
 The mass of rotating parts is 40kg at a radius of gyration of 140mm. Calculate the coefficient of fluctuation of speed if the mean speed is 1500rpm.

11. The torque delivered by a two stroke engine is represented by $T = 1000 + 300 \sin 2\theta - 500 \cos 2\theta$ N-m where θ is the angle turned by the crank from the IDC. The engine speed is 250rpm. The mass of the flywheel is 400kg and radius of gyration 400mm.

Determine (i) The power developed (ii) The total percentage fluctuation of speed (iii) The angular acceleration of flywheel when the crank has rotated through an angle of 60° from the IDC. (iv) The maximum angular acceleration and retardation of the flywheel.

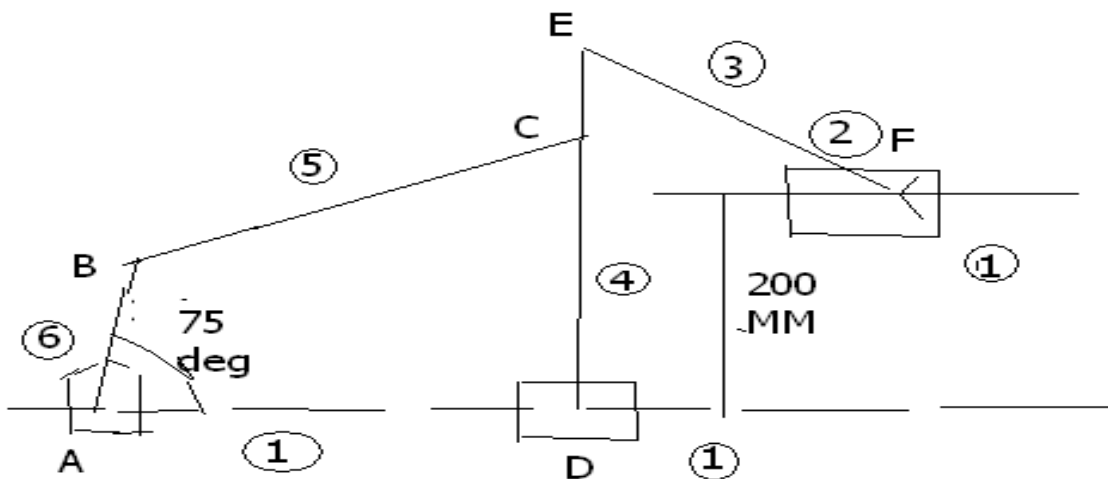
12).i) The slider of a slider crank mechanism is subjected to a force of 3000N. The crank is at 60 deg position. The length of the crank and connecting rod are 100mm and 300mm respectively. Determine the driving torque on the crank. (8)

ii) The following data refer to a horizontal reciprocating engine.

Mass of the reciprocating parts = 120 kg, crank length = 90 mm, engine speed = 600 rpm, connecting rod data, mass = 90kg, length between centres = 450 mm, cg distance from big end centre = 180mm, Radius of gyration about an axis through the centre of mass = 150 mm.

Determine the magnitude and direction of the inertia torque on the crankshaft, when the crank has turned 30deg from IDC.

13. For static equilibrium of the mechanism shown in the figure below, find the required Input torque. The dimensions are AB = 150mm, BC = AD = 500mm, DC = 300mm, CE = 100mm and EF = 450mm



UNIT-II BALANCING
PART-A (2 Marks)

1. What is meant by balancing of rotating masses?
2. Why rotating masses are to be dynamically balanced?
3. Define static balancing.
4. Define dynamic balancing.
5. State the conditions for static and dynamic balancing.
6. State the conditions for complete balance of several masses revolving in different planes of a shaft.
7. Why complete balancing is not possible in reciprocating engine?
8. Can a single cylinder engine be fully balanced? Why?
9. Differentiate between the unbalanced force caused due to rotating and reciprocating masses.
10. Why are the cranks of a locomotive, with two cylinders, placed at 90° to each other?
11. List the effects of partial balancing of locomotives.
12. Define swaying couple.
13. Define hammer blow with respect to locomotives.
14. What are the effects of hammer blow and swaying couple?
15. Define direct and reverse cranks.
16. what for the balancing machines are used?
17. What are different types of balancing machines?

PART-B (16 Marks)

1. A shaft is rotating at a uniform angular speed. Four masses M_1 , M_2 , and M_3 and M_4 of magnitudes 300kg, 450kg, 360kg, 390kg respectively are attached rigidly to the shaft. The masses are rotating in the same plane. The corresponding radii of rotation are 200mm, 150mm, 250mm and 300mm respectively. The angle made by these masses with horizontal are 0° , 45° , 120° and 255° respectively. Find, (i) the magnitude of balancing mass (ii) the position of balancing mass if its radius of rotation is 200mm.
2. Four masses M_1 , M_2 , M_3 , and M_4 are 200kg, 300kg, 240kg and 260kg respectively. The corresponding radii of rotation are 0.2m, 0.15m, 0.25m and 0.3m respectively and the angle between successive masses 45° Acw from the 1st mass, 75° Acw from the 2nd mass, and 135° Acw from the third mass. Find the position and magnitude of balance mass required if its radius of rotation is 0.25m.

3. The data for three rotating masses are given below:-
 $M_1=4\text{kg}$ $r_1=75\text{mm}$ $\theta_1=45^\circ$
 $M_2=3\text{kg}$ $r_2=85\text{mm}$ $\theta_2=135^\circ$
 $M_3=2.5\text{kg}$ $r_3=50\text{mm}$ $\theta_3=240^\circ$
 Determine the amount of counter mass at a radial distance of 65mm required for their static balance
4. Four masses A, B, C, and D are completely balanced masses C and D makes angles of 90° and 195° respectively with B in the same sense. The rotating masses have the following properties:
 $m_B=25\text{kg}$ $r_A=150\text{mm}$ $m_C=40\text{kg}$ $r_B=200\text{mm}$ $m_D=35\text{kg}$
 $r_C=100\text{mm}$ $r_D=180\text{mm}$ Planes B and C are 250mm apart.
 Determine (i) the mass A and its angular position
 (ii) the position of planes A and D.
5. A, B, C and D are four masses carried by a rotating shaft at radii 100mm, 125mm, 200mm and 150mm respectively. The planes in which the masses revolve are spaced 600mm apart and the masses of B, C and D are 10kg, 5kg and 4kg respectively. Find the required mass A and relative angular setting of the four masses so that the shaft be in complete balance.
6. Four masses A, B, C and D revolves at equal radii and equally spaced along a shaft. The mass B is 7kg and the radii of C and D make angles of 90° and 240° respectively with the radius of B. Find the magnitude of masses A, C and D and angular position of A. So that the system may be completely balanced.
7. A shaft carries four rotating masses A, B, C and D which are completely balanced. The masses B, C and D are 50kg, 80kg and 70kg respectively. The masses C and D make angles of 90° and 195° respectively with mass B in the same sense. The masses A, B, C and D are concentrated at radius 75mm, 100mm, 50mm and 90mm respectively. The plane of rotation of masses B and C are 250mm apart. Determine (i) the magnitude of mass A and its angular position (ii) the position of planes A and D.
8. A four cylinder vertical engine has cranks 150mm long. The plane of rotation of the first, second and fourth cranks are 400mm, 200mm and 200mm respectively from that of the third crank and their reciprocating masses are 50kg, 60kg and 50kg respectively. Find the mass of the reciprocating parts for the third cylinder and relative

angular position of the cranks in order that the engine may be in complete balance.

9. A four cylinder vertical engine has cranks 300mm long. The plane of rotation of the first, third and fourth cranks are 750mm, 1050mm and 1650mm respectively from that of the second crank and their reciprocating masses are 10kg, 400kg and 250kg respectively. Find the mass of the reciprocating parts for the second cylinder and relative angular position of the cranks in order that the engine may be in complete balance. (16)

10. Derive the following expression of effects of partial balancing in two cylinder locomotive engine (i) Variation of tractive force (ii) Swaying couple (iii) Hammer blow (16)

UNIT-III

FREE VIBRATION

PART-A (2 Marks)

1. What are the causes and effect of vibration?
2. Define frequency, cycle, period and free vibration.
3. What are the different types of vibrations?
4. State different method of finding natural frequency of a system.
5. What is meant by free vibration and forced vibration?
6. Define resonance.
7. What is meant by degrees of freedom in a vibrating system?
8. What is the natural frequency of simple spring mass system?
9. Determine the natural frequency of mass of 10kg suspended at the bottom of two springs (of stiffness: 5N/mm and 8N/mm) in series.
10. What is the effect of inertia on the shaft in longitudinal and transverse vibrations?
11. State the expression for the frequency of simple pendulum.
12. Give the expression for natural frequency of water, which oscillates in a 'U'tube manometer?
13. What are the different types of damping?
14. Draw the schematic diagram of a free damped vibration system and write the governing differential equation of the system.
15. Sketch the Time Vs Displacement for under-damped and over-damped systems.
16. What is the limit beyond which damping is detrimental and why?
17. What is meant by critical damping?

18. What type of motion is exhibited by a vibrating system when it is critically damped?
19. Define critical or whirling speed.
20. What are the factors that affect the critical speed of a shaft?
21. What are the causes of critical speed?
22. Differentiate between transverse and torsional vibrations.

PART-B (16 Marks)

1. Derive an expression for the natural frequency of the free longitudinal vibration by
(i) Equilibrium method (ii) Energy method (iii) Rayleigh's method
(16)
2. In a single degree of damped vibration system a suspended mass of 3.75kg makes 12 oscillations in 7 seconds when disturbed from the equilibrium position. The amplitude decreases in 18 seconds. The amplitude decreases to 0.33 of the initial value after 4 oscillations. Determine (i) the spring stiffness (ii) logarithmic decrement (iii) damping factor (iv) Damping coefficient.
(16)
3. Determine equation of motion when a liquid column vibrating in a 'U'tube by
(i) Newton's method
(ii) Energy method and hence find its natural frequency.
(16)
4. (i) Deduce the expression for the free longitudinal vibration in terms of spring stiffness, its inertia effect and suspended mass. (8)
(ii) A spring mass system has spring stiffness 's' N/m and has a mass of 'm' kg. It has the natural frequency of vibration as 12 Hz. An extra 2 kg mass is coupled to 'm' and natural frequency reduces by 2 Hz. Find the value of 's' and 'm'.
5. A vibrating system consists of a mass of 8 kg, spring of stiffness 5.6 N/m and dashpot of damping coefficient of 40 N/m/s. Find, (i) Critical damping coefficient (ii) the damping factor (iii) the natural frequency of damped vibration (iv) the logarithmic decrement (v) the ratio of two

consecutive amplitude (vi) the number of cycle after which the original amplitude is reduced to 20 percent

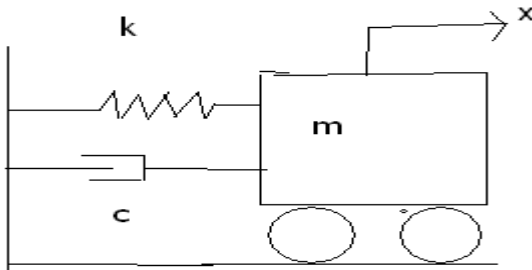
(16)

6. An instrument vibrates with a frequency of 1Hz when there is no damping. When the damping is provided, the frequency of damped vibration was observed to be 0.9Hz.

Find, (i) damping factor (ii) logarithmic decrement. (16)

7. Find the equation of motion for the spring mass-dashpot system for the cases when

(i) $\zeta = 2$ (ii) $\zeta = 1$ and (iii) $\zeta = 0.3$. The mass 'm' is displaced by a distance of ($x = 30\text{mm}$) and released.



8. Between a solid mass of 0kg and the floor are kept two slabs of isolates, natural rubber and felt, in series. The natural rubber slab has a stiffness of 3000N/m and equivalent viscous damping coefficient of 100Nsec/m. The felt has a stiffness of 12000N/m and equivalent viscous damping coefficient of 330Nsec/m. Determine undamped and the damped natural frequencies of the system in vertical direction.

(16)

9. (i) A cantilever shaft 50mm diameter and 300mm long has a disc of mass 100kg at its free end. The young's modulus for the shaft material is 200GN/m². Determine the frequency of longitudinal and transverse vibration of the shaft. (10)

(ii) Explain the sketches different cases of damped vibrations. (6)

10. The barrel of a large gun recoils against a spring on firing. At the end

of the firing, a dashpot is engaged that allows the barrel to return to its original position in minimum time without oscillation. Gun barrel mass is 400kg and initial velocity of recoils 1m. Determine spring stiffness and critical damping coefficient of dashpot.

(16)

11. A steel shaft 100mm in diameter is loaded and support in shaft bearing 0.4m apart. The shaft carries three loads: first mass 12kg at the centre, second mass 10kg at a distance 0.12m from the left bearing and third mass of 7kg at a distance 0.09m from the right bearing. Find the value of the critical speed by using Dunkerley's method.

$$E=2 \times 10^{11} \text{ N/m}^2$$

(16)

UNIT-IV FORCED VIBRATION
PART-A (2 Marks)

1. Define damping ratio or damping factor.
2. Define logarithmic decrement.
3. Give equation for damping factor and damped frequency .
4. What is meant by harmonic forcing?
5. What is the relationship between frequencies of undamped and damped vibration?
6. What is meant by dynamic magnifier or magnification factor?
7. Define transmissibility.
8. Define transmissibility ratio or isolation factor.
9. What is vibration isolation?
10. Sketch the graph for MF Vs frequency ratio for different values of damping factor.
- 10a. Sketch the graph for transmissibility Vs frequency ratio for different values of damping factor.
11. Write the x_{\max} and phase angle equation for forced vibration due to Harmonic forcing.
12. Write the x_{\max} and phase angle equation for forced vibration due to Rotating unbalance.
13. Write the x_{\max} and phase angle equation for forced vibration due to Support motion.
14. Explain the terms transient vibrations and steady state vibrations.
15. What are the materials used for vibration isolation

PART-B (16 Marks)

- 1. A mass of 50kg is supported by an elastic structure of total stiffness 20kN/m. The damping ratio of the system is 0.2. A simple harmonic disturbing force acts on the mass and at any time 't seconds, the force is $60\cos 10t$ newtons. Find amplitude of the vibration and phase angle caused by the damping.**
- 2. A mass of 50kg is supported by an elastic structure of total stiffness 20kN/m. The damping ratio of the system is 0.25. A simple harmonic disturbing force acts on the mass and at any time 't seconds, the force is $75\cos 12t$ newtons. Find amplitude of the vibration and phase angle caused by the damping**
- 3. A mass of 10kg is suspended from one end of a helical spring, the other end being fixed. The stiffness of the spring is 10N/mm. The viscous damping causes the amplitude to decrease to one-tenth of the initial value in four complete oscillations. If a periodic force of $150\cos 50t$ N is applied at the mass in the vertical direction. Find the amplitude of the forced vibrations? What is its value of resonance?**
- 4. A harmonic exciting force of 25N is acting on a machine part which is having a mass of 2Kg and vibrating in viscous medium. The exciting force causes resonant amplitude of 12.5mm with a period of 0.2sec. Determine the damping coefficient.**
- 5. A body having a mass of 15kg is suspended from a spring which deflects 12mm under the weight of the mass. Determine the frequency of the free vibrations. What is the viscous damping force needed to make the motion a periodic at a speed of 1mm/s? If, when damped to this extent a disturbing force having a maximum value of 100N and vibrating at 6Hz is made to act on the body, determine the amplitude of the ultimate motion.**
- 6. A single cylinder vertical petrol engine of total mass of 200kg is mounted upon a steel chassis frame. The vertical static deflection of the frame is 2.4mm due to the weight of the engine. The mass of the reciprocating parts is 9kg and stroke of piston 160mm with S.H.M. If**

dashpot of damping coefficient of 1N/mm/s used to dampen the vibrations, calculate at steady state

(i) Amplitude of forced vibrations at 500rpm engine speed. (ii) The speed of the driving shaft at which resonance will occur.

7. A vertical single stage air compressor having a mass of 500kg is mounted on a spring having stiffness of $1.96 \times 10^5 \text{N/m}$ and dashpot with damping factor of 0.2 . The rotating parts are completely balanced and the equivalent reciprocating parts weigh 20kg . The stroke is 0.2m . Determine the dynamic amplitude of vertical motion of the excitation force if the compressor is operated at 200rpm .
8. A machine 100kg has a 20kg rotor with 0.5mm eccentricity. The mounting spring has $k = 85 \times 10^3 \text{N/m}$. The operating speed is 600rpm and the unit is constrained to move vertically. Find (i) Dynamic amplitude of machine (ii) the force transmitted to the support.
9. A single cylinder engine has an out of balance force of 500N at an engine speed of 30rpm . The total mass of engine is 150kg and it is carried on a set of total stiffness 300N/cm .
(i) Find the amplitude of steady motion of the mass and maximum oscillating force transmitted to the foundation.
(ii) If a viscous damping is interposed between the mass and the foundation the damping force 1000N at 1m/s of velocity, find the amplitude of force damped oscillation of the mass and its angle of lag with disturbing force.
10. An industrial machine weighing 445kg is supported on a spring with a static deflection of 0.5cm . If the machine has a rotating imbalance of 25kg-cm . Determine the force transmitted at 1200rpm and the dynamic amplitude at the speed.
11. The mass of an electric motor is 120kg and it runs at 1500rpm . The armature mass is 35kg and its center of gravity lies 0.5mm from axis of rotation. The motor is mounted on five springs of negligible damping. So that the force transmitted is one-eleventh of the impressed force. Assume that the mass of the motor is equally distributed among the five springs. Determine (i) the stiffness of the spring

- (ii) the dynamic force transmitted to the base at the operating speed.
- (iii) Natural frequency of system.

12. Find the stiffness of each spring when a refrigerator unit having a mass of 30kg is to be support by three springs. The force transmitted to the supporting structure is only 10% of the impressed force. The refrigerator unit operates at 420rpm.

UNIT-V MECHANISMS FOR CONTROL

PART-A (2 Marks)

1. What is the function of governor?
2. How governors are classified?
3. Differentiate between governor and fly wheel.
4. What is meant by sensitiveness of a governor?
5. What is the effect of friction on the governor?
6. Define coefficient of sensitiveness.
7. What is meant by hunting?
8. What is meant by isochronous conditions governor?
9. Give application of gyroscopic principle.
10. What is gyroscopic torque?
11. What is the effect of gyroscopic couple on rolling of ship? Why?
12. Define gyroscopic couple.
13. Write expression for gyroscopic couple.

PART-B (16 Marks)

1. A porter governor has equal arms each 250mm long and pivoted on the axis of rotation. Each ball has a mass of 5kg and mass of the central load on the sleeve is 25kg. The radius of rotation of the ball is 150mm when governor is at maximum speed. Find the maximum and minimum speed and range of speed of the governor.
2. The length of the upper and lower arms of a porter governor are 200mm and 250mm respectively. Both the arms are pivoted on the axis of rotation. The central load is 150N, the weight of the each ball is 20N and the friction of the sleeve together with the resistance of the operating gear is equivalent to a force of 30N at the sleeve. If the

limiting inclinations of the upper arms to the vertical are 30° and 40° taking friction in to account. Find the range of speed of the governor.

3. Calculate the range of speed of a porter governor which has equal arms of each 200mm long and pivoted on the axis of rotation. The mass of each ball is 4kg and the central load of the sleeve is 20kg. The radius of rotation of the ball is 100mm when the governor begins to lift and 130mm when the governor is at maximum speed.
4. A Hartnell governor having a central sleeve spring and two right angled bell crank levers operates between 290rpm and 310rpm for a sleeve lift of 15mm. The sleeve and ball arms are 80mm and 120mm respectively. The levers are pivoted at 120mm from the governor axis and mass of the ball is 2.5kg. The ball arms are parallel at lowest equilibrium speed. Determine (i) load on the spring at maximum and minimum speeds and (ii) Stiffness of the spring.
5. A governor of Hartnell type has equal balls of mass 3kg, set initially at a radius of 200mm. The arms of the bell-crank lever are 110mm vertically and 150mm horizontally. Find (i) the initial compressive force on the spring at a radius of 200mm at 240rpm and (ii) the stiffness of the spring required to permit a sleeve movement of 4mm on a fluctuation of 7.5 percent in the engine speed.
6. The controlling force in a spring controlled governor is 1500N when radius of rotation is 200mm and 887.5N when radius of rotation is 130mm. The mass of each ball is 8kg. If the controlling force curve is a straight line, then find (i) Controlling force at 150mm radius of rotation (ii) Speed of the governor at 150mm radius. (iii) Increase in initial tension so that governor is isochronous. (iv) Isochronous speed.
7. In a spring controlled governor, the controlling force curve is a straight line. When the balls are 400mm apart, the controlling force is 1200N and when 200mm apart, the controlling force is 450N. Determine the speed at which the governor runs when the balls

are 250mm apart. When initial tension on the spring would be required for isochronisms and what would be the speed. Take mass of each ball to be 10kg.

8. Calculate the minimum speed of a proell governor, which has equal arms each of 200mm and are provided on the axis of rotation. The mass of each ball is 4kg and the central mass on the sleeve is 20kg. The extension arms of the lower links are each 60mm long and parallel to the axis when the minimum radius of the ball is 100mm. of load.
9. (i) Explain the effect of Gyroscopic couple on a Naval ship during pitching. (8)
(ii) Explain the effect of Gyroscopic couple on a Aeroplane. (8)
10. Each paddle wheel of a steamer have a mass of 1600kg and a radius of gyration of 1.2meters. The steamer turns to port in a circle of 160meters radius at 24Km/hr. The speed of the paddle is 90rpm. Find the magnitude and effect of the gyroscopic couple acting on the steamer.
11. The rotor of a turbine yacht rotates at 1200rpm clockwise when viewed from stern. The rotor has a mass of 750 kg and radius of gyration of 250mm. Find the maximum gyroscopic couple transmitted to the hull when yacht pitches with a maximum angular velocity of 1 rad/s. What is the effect of this couple?
12. The turbine rotor of a ship has a mass of 20 tonnes and a radius of gyration 0.75. Its speed is 2000rpm. The ship pitches 6° above and below the horizontal position. One complete oscillation takes 18 seconds and the motion is simple harmonic. Determine
 - (i) the maximum couple tending to shear the holding down bolt of the turbine
 - (ii) The maximum angular acceleration of the ship during pitching
 - (iii) The direction in which the bow will tend to turn while, if the rotation of the rotor is clockwise when locking from rear.