MECHANICAL ENGINEERING

30

PAPER—I

Time Allowed : Three hours *Maximum Marks* : 300

The figures in the margin indicate full marks for the questions

Candidates should answer Question Nos. **1** and **5** which are compulsory and other **three** of the remaining questions, selecting at least **one** from each Section

Assume suitable value for any missing data if necessary

SECTION—A

1. Answer any *three* questions from the following : 20×3=60

(a) Use Castigliano's theorem to determine the maximum deflection at the tip of a cantilever beam of length L subject to a uniformly distributed load w N per unit length.

(b) With the help of a figure, explain the following reactions with respect to Fe-Fe_3C phase diagram giving details about temperature and chemical composition :

(i) Peritectic reaction

(ii) Eutectic reaction

(iii) Eutectoid reaction

(c) Derive the relationships for metal removal rate in electrochemical machining (ECM) for a pure metal and an alloy material.

(d) What do you mean by break-even analysis? What are the assumptions in break-even analysis? Define the terms break-even point, margin of safety, angle of incidence, contribution, profit-volume ratio and profit-volume chart.

2. *(a)* A project consists of nine activities starting from *A* to *I*. Draw the network of the project from the following relationships among the various activities : 20

A and *B* run simultaneously

C follows *A* and precedes *F*

D follows *A* but precedes *E*

F follows *B* but precedes *G*

G follows *F* but precedes *H*

H follows *G* but precedes *E*

G and *I* start concurrently

E and *I* terminate at the same time

(b) The planning budget of M/s PG Industry is given below :

Budgeted cost → *Particulars*	*Fixed* (₹)	*Variable* (₹)
Direct material		9,00,000
Direct labour cost		10,00,000
Factory overheads	8,00,000	3,00,000
Administrative	6,00,000	2,00,000
Overheads	6,00,000	4,00,000
Distribution cost		
Budgeted profit		8,00,000

The budgeted sale volume is 200000 units with sales price of ₹ 25. Determine the break-even profit, if —

(i) 10% increase is effected in the fixed cost;

(ii) 10% increase is effected in the variable cost;

(iii) there is an increase of 10% in sales price, which will reduce the sales volume by 5%. 40

3. *(a)* The controlling force in a spring controlled governor is 1500 N and 887.5 N when the radii of rotation of the balls are 200 mm and 130 mm respectively. The mass of each ball is 8 kg. If the controlling force curve is a straight line, determine the controlling force and the speed of rotation when the radius of rotation is 150 mm. Find also the increase in the initial tension so that the governor is isochronous. What will be the isochronous speed? 30

(b) In an epicyclic gear train, the internal wheels A and B, and the compound wheels C and D rotate independently about axis O. The wheels E and F rotate on pins fixed to the arm G. E gears with A and C, and F gears with B and D. All the wheels have same module and the number of teeth on wheels C, D, E, and F are respectively 28, 26, 18 and 18.

(i) Sketch the arrangement.

(ii) Find the number of teeth on A and B.

(iii) If the arm G makes 100 r.p.m. in clockwise direction and wheel A makes 10 r.p.m. in the counter-clockwise direction, find the speed of wheel B. 30

4. (a) The melting point of metal A is 650 °C and that of metal B is 450 °C. When A and B are alloyed together, they do not form any compound or intermetallic phase but they form an eutectic of composition 40% A and 60% B which solidifies at 300 °C. The maximum solid solubilities of B in A and A in B are respectively 20% of B and 10% of A at 300°C and remain constant from that temperature to room temperature. Assume the solvus, solidus and the liquidus lines to be straight, draw the phase diagram for the alloy system and determine —

(i) the range of solidification temperature for alloy of 15% B;

(ii) for the same alloy, the amount of phases present at 400 °C;

(iii) the amount of phases present for the alloy of 70% B at 280 °C. 40

(b) How are the crystallographic planes and directions specified in hexagonal close-packed system? With a figure, write the indices for the basal plane, one of the prismatic planes and one of the pyramidal planes. 20

SECTION—B

5. Answer any *three* questions from the following : 20×3=60

(a) (i) Differentiate between the following :

1. Lower pair and Higher pair
2. Turning pair and Sliding pair
3. Mechanism and Machine

(ii) How does a Porter governor differ from a Watt governor? What is meant by effort of a governor? Derive an expression for the same for a Porter governor. 20

(b) Derive the relationship for a flat-belt drive with usual notations :

$$\frac{T_1}{T_2} = e^{\mu\theta}$$

Define the terms involved in the above equation. On which of two wheels in an open-belt drive, θ is measured and why? 20

(c) (i) What is meant by chip reduction coefficient? Establish a relation among t_1, t_2, α and ϕ, where

t_1 = uncut chip thickness

t_2 = chip thickness

α = rake angle of tool

ϕ = shear angle

Explain the experimental determination of chip reduction coefficient.

(ii) Explain the 'minimum energy principle' as applied to machining processes and using this principle and Merchant Circle Diagram, derive the following relationship (Merchant First Solution) : 20

$$2\phi + \lambda - \alpha = \frac{\pi}{2}$$

where, ϕ = shear angle

λ = friction angle

α = rake angle of the tool

(d) (i) With reference to manual part programming in NC machine tools, define preparatory functions, absolute and incremental coordinate system group, miscellaneous functions, cutter radius compensation and canned cycle. 8

(ii) Explain each step in the following part program : 12

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N001  G92  X0  Y0  Z0
N002  G90
N003  G00  X25.0  Y25.0  Z2.0  T01  S3000  M03
N004  G01  Z-12.0  F120
N005  Y75.0
N006  X65.0
N007  G02  Y25.0  I0  J-35.0
N008  X25.0
N009  Z2.0
N010  G00  Z50.0  M05
N011  X0  Y0
N012  M30
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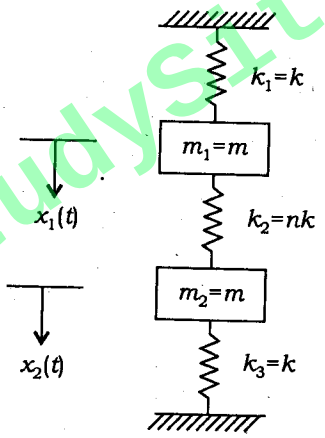
6. (a) Determine the normal and shearing stress intensities on a plane inclined at an angle θ to the axis of a bar of uniform cross-section loaded in axial tension at each end. Also, determine the magnitude and direction of the maximum shearing stress in the bar. Take P as the load, σ_x as the normal stress and A as the cross-sectional area of the bar. 40

(b) A bar of cross-section 850 mm^2 is acted upon by axial tensile forces of 60 kN applied at each end of the bar. Determine the normal and shearing stress on a plane inclined at 30° to the direction of loading. Determine also the maximum shearing stress. Solve the problems both by numerically and by using Mohr's circle. 20

7. (a) What is whirling of a shaft? What are the causes behind the whirling? How is critical speed of a shaft determined? 30

(b) Find the natural frequencies and the mode shape of a spring-mass system shown in the figure, which is constrained to move in the vertical direction only. (Take n = 1) 30



(Spring-mass system)

8. (a) How do the following parameters affect the material removal rate in ultrasonic machining (USM)? Explain how the optimum values of the above parameters are set : 30

(i) Static load on the tool

(ii) Amplitude of vibration

(iii) Frequency of vibration

(b) A metal moulder enterprise manufactures dies and gear blanks. The table below shows the resources consumed and unit profit. The management of the enterprise wants to determine the optimum number of dies and gear blanks to be manufactured to maximise the total profit. Solve the problem graphically : 30

Resources	*Dies*	*Gear blanks*	*Availability*
Metal (tonnes)	30	20	300
Labour (hr)	5	10	110
Profit	6	8	

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MECHANICAL ENGINEERING

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PAPER—II

Time Allowed : Three hours *Maximum Marks* : 300

The figures in the margin indicate full marks for the questions

Answer Question Nos. **1** and **5** which are compulsory and *any* **three** from the rest, selecting at least **one** from each Section

Assume suitable value for any missing data if necessary

SECTION—A

1. Answer any *three* questions from the following : 20×3=60

(a) *(i)* Define the terms mechanical efficiency, volumetric efficiency, specific fuel consumption and specific power output with respect to an IC engine. 8

(ii) What is meant by engine rating? Discuss the design and performance data for SI and CI engines. 6

(iii) With a figure for the system, explain the common rail fuel injection system. 6

(b) *(i)* In Kolkata, during a day in summer, a man wants to beat the heat by closing the windows and doors in his living room and keeping open the refrigerator door. Considering the room including refrigerator as a system, evaluate the situation applying the 'first law of thermodynamics'. Assume walls, windows and doors of the room are to be non-conducting. 8

(ii) A stream of gases at 7·5 bar, 750 °C and 140 m/s is passed through a turbine of a jet engine. The steam comes out of the turbine at 2·0 bar, 550 °C and 280 m/s. The process may be assumed to be adiabatic. The enthalpies of the gas at entry and exit are 950 kJ/kg and 650 kJ/kg, respectively. Determine the power capacity of the turbine if the gas flow rate is 5 kg/s. 12

(c) *(i)* Describe a simple vapour-compression refrigeration cycle with its flow diagram. 8

(ii) A cold-storage plant is required to store 20 tonnes of fish. The temperature of the fish when supplied is 25 °C. The required storage temperature of fish is – 8 °C. Specific heats of fish above and below freezing point are 2·93 kJ/kg-°C and 1·25 kJ/kg-°C, respectively. Freezing point and latent heat of fish are – 3 °C and 232 kJ/kg, respectively. If the cooling is to be achieved within 8 hours, determine the capacity of the machine. If the actual COP is one-fourth of the Carnot COP, find also the power required to run the plant. 12

(d) (i) Explain base, intermediate and peaking load as applied to a power plant. Why are the base-load power plants loaded heavily? 8

(ii) List the factors to be considered for selection of location for conventional base-load thermal power plants. What are the additional factors to be considered for a nuclear power plant? 12

2. (a) What is fouling as applied to heat exchangers? What are the effects of fouling? Explain the different categories of fouling. Derive an equation for overall heat-transfer coefficient (U_0) based on outer tube surface of a heat exchanger. Both inside and outside surfaces of the tube are fouled by deposit formation. 36

(b) Determine the overall heat-transfer coefficient based on outer surface of a brass tube with inside and outside diameters 2·5 cm and 3·34 cm, respectively with thermal conductivity of 110 W/m-°C for the following conditions : 24

The inside and outside heat-transfer coefficients are respectively 1200 W/m^2-°C and 2000 W/m^2-°C; fouling factors for the inside and outside surfaces are 0·00018 m^2-°C/W.

3. (a) Explain briefly : 20

(i) Rayleigh flow

(ii) Fanno flow

(b) A centrifugal compressor has a pressure ratio of 4/1 with an isentropic efficiency of 80% when running at 15000 rpm and inducing air at 20 °C. Guide vanes at inlet give the air a pre-whirl of 25° to the axial direction at all radii and the mean diameter of the eye is 250 mm; the absolute air velocity at inlet is 150 m/s. At exit the blades are radially inclined and the impeller tip diameter is 590 mm. Calculate the slip factor of the compressor. Take, C_p of air = 1·005 kJ/kg-K. 40

4. *(a)* Name some modern high-pressure boilers. What are the advantages of high-pressure boilers? Explain the unique features of high-pressure boilers. 30

(b) Explain the characteristic features of a BWR type nuclear reactor. How does it differ from PWR? 30

SECTION—B

5. Answer any *three* questions from the following : 20×3=60

(a) A heat pump operates between two identical bodies, which are at temperature T_1, and cools one of the bodies to a temperature $T_2 (T_1 > T_2)$. Prove that for this operation the minimum work (W) required by the heat pump is given by

$$W = C_p \left(\frac{T_1^2}{T_2^2} + T_2 - 2T_1 \right)$$

where C_p is the specific heat of the two bodies. 20

(b) An air-conditioning plant is designed to maintain a conference room for the following winter conditions :

Outdoor condition : 12 °C DBT and 10 °C WBT

Required condition : 20 °C DBT and 60% RH

Amount of air circulation : 0·3 m^3/min per person

Seating capacity of the room : 60 persons

The required condition is achieved first by heating and then by adiabatic humidifying. Determine *(i)* the heating capacity of the coil and the surface temperature required if the bypass factor of the coil is 0·4 and *(ii)* the capacity of the humidifier. Use following data, obtained from psychrometric chart : 20

Enthalpies at different state points :

h_1 = 29·3 kJ/kg, $h_2 = h_3$ = 42·3 kJ/kg

Temperature of leaving air from the coil (t_{db2}) = 24·5 °C

Specific volume (v_{s1}) = 0·817 m^3/kg

Specific humidity at states 1 and 3 of psychrometric chart are respectively 6·8 gm/kg and 8·6 gm/kg.

(c) (i) Explain the distinguishing features from which a person can identify a 2-stroke engine from a 4-stroke engine without opening the engine. 10

(ii) What is diesel knock? How does it differ from the knocking phenomenon of an SI engine? 10

(d) A mild steel tank of wall thickness 10 mm contains water at 90 °C when the atmospheric temperature is 15 °C. The thermal conductivity of mild steel is 50 W/m-K, and the heat-transfer coefficient for the inside and outside of the tank are 2800 W/m^2-K and 11 W/m^2-K, respectively. Calculate —

(i) the rate of heat loss per unit area of tank surface;

(ii) the temperature of the outside surface of the tank. 20

6. (a) A generating unit of 10 MW capacity supplies the following loads :

(i) Domestic consumer load with maximum demand of 6 MW at a load factor of 20%

(ii) Small industries load with maximum demand of 36 MW at a load factor of 50%

(iii) Streetlight load with maximum demand of 400 kW at 30% load factor

Find the overall cost of energy per kWh for each type of consumer using the following data : 40

Capital cost of the plant = ₹ 10,000·00 per year

Total running cost = ₹ 36,00000·00 per year

Annual rate of interest and depreciation on capital cost = 10%

(b) The following results were obtained during a test of an SI engine :

Indicated power = 30 kW

Brake power = 26 kW

Engine rpm = 1000

Fuel per brake-power hour = 0·25 kg

Calorific value of the fuel = 43900 kJ/kg

Calculate indicated thermal efficiency, brake thermal efficiency and mechanical efficiency of the engine. 20

7. *(a)* Define available energy and availability.Prove that for a reversible heat engine operating between two temperatures, the greater is the temperature difference, the greater is the heat rejection and greater will be the unavailable part of the energy supplied. 30

(b) 1 kg of ice at 0 °C is mixed with 12 kg of water at 27 °C. Assuming the surrounding temperature to be 15 °C, calculate the net increase in entropy and unavailable energy when the system reaches a common temperature. Take, specific heat of water = 4·18 kJ/kg-K, specific heat of ice = 2·1 kJ/kg-K and enthalpy of fusion of ice = 333·5 kJ/kg. 30

8. *(a)* Define and explain the physical significance of Prandtl number, Reynolds number and Eckert number. 24

(b) A lubricating oil of viscosity μ and thermal conductivity k fills the clearance L between two rotating cylinders, which can be regarded as two parallel plates in motion for the purpose of the analysis. Let u_0 and u_1 be the velocities of the inner and outer cylinders, respectively. Derive relations for the velocity distribution in the oil layer for *(i)* the inner and outer cylinders rotating in the same direction with $u_0 > u_1$ and *(ii)* the inner and outer cylinders rotating in the opposite direction. Also, develop a relationship for the shear stress in the fluid resulting from the rotation of the cylinders. 36

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