MECHANICAL ENGINEERING Paper I

Time Allowed: Three Hours **Maximum Marks: 250**

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions:

*There are **EIGHT** questions divided in **TWO SECTIONS** and printed both in **HINDI** and in **ENGLISH** Candidate has to attempt **FIVE** questions in all.*

*Questions no. **1** and **5** are compulsory and out of the remaining, any **THREE** are to be attempted choosing at least **ONE** from each section.*

The number of marks carried by a question/part is indicated against it.

Answers must be written in the medium authorized in the Admission Certificate which must be stated clearly on the cover of this Question-cum-Answer (QCA) Booklet in the space provided. No marks will be given for answers written in a medium other than the authorized one.

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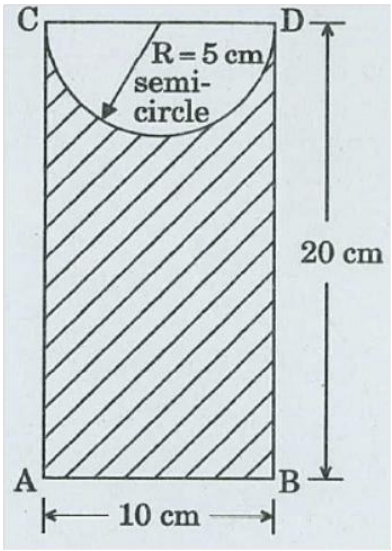
SECTION A

Q1 (a) Find the moment of inertia of the shaded area shown in the figure, about the edge AB. 10

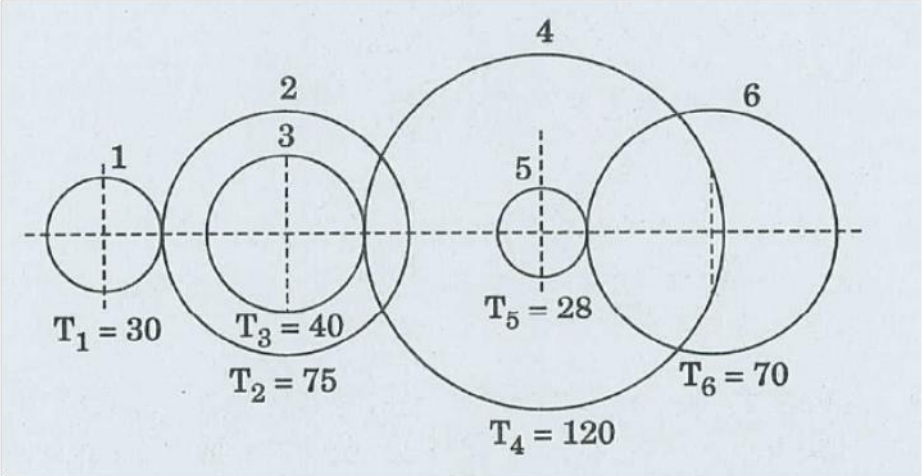


(b) A bar of steel is 50 mm in diameter and 600 mm long. A tensile load of 150 kN is found to stretch the bar by 0.23 mm. The same bar, when subjected to a torque of 1.4 kN-m is found to twist through 1°. Find the values of the four elastic constants. 10

(c) An effort of 250 N is required just to move a certain body up an inclined plane of angle 20°, the force acting parallel to the plane. If the angle of inclination of the plane is made 25°, the effort, required again, applied parallel to the plane, is found to be 280 N. Find the weight of the body and coefficient of friction. 10

(d) Write the composition of low, medium and high carbon steels and their applications. 10

(e) A compound gear train comprising the input shaft driven by a motor at 1425 rpm in clockwise direction is shown in the figure. The arrangement and the number of teeth on the gears is shown in the figure. Determine the speed of the output shaft and the direction of rotation of the output shaft.



Q2 (a) The equation of motion of a particle is given, acceleration 'a' in terms of time 't' as below:

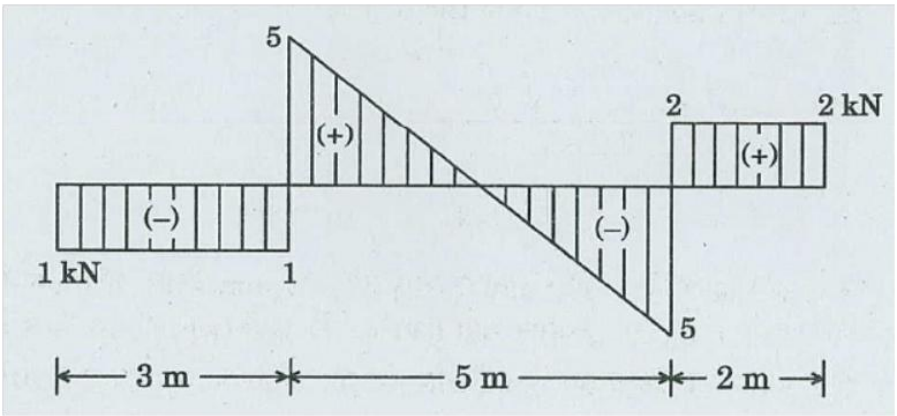
$$a = 3t^2 + 2t + 4$$

in which acceleration 'a' is in m/s^2 and time 't' is in seconds. It is observed that the velocity of the particle is 10 m/s after 4 seconds; and the displacement of the particle is 6 m after 3 seconds. Determine: 10

(i) Velocity after 6 seconds

(ii) Displacement after 5 seconds

(b) The S.F. diagram of a beam with overhangs is shown in the figure. Determine the loading on the beam and draw the B.M. diagram. 20

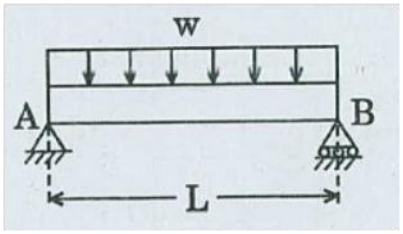


(c) What is critical cooling rate in heat treatment of steels? Write about the significance of critical cooling using TTT diagram. What are the factors affecting critical cooling rate? 20

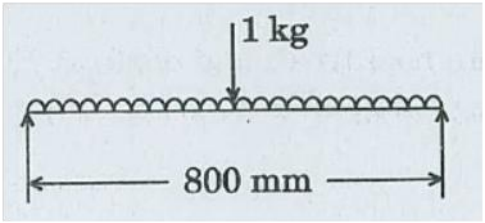
Q3 (a) At a point in a material, the stresses on two mutually perpendicular planes are 60 N/mm^2 (tensile) and 40 N/mm^2 (tensile). The shear stress across these planes is 15 N/mm^2. Find the magnitude and direction of the resultant stress on a plane making an angle of 40° with the plane of the first stress. Also find the normal and tangential stresses on this plane. 10

(b) The simply supported beam AB carries a uniformly distributed load 'w' per

unit length (figure). Determine the equation of the elastic curve and the maximum deflection of the beam. 20



(c) Determine the whirling speed of a shaft, 25 mm diameter and 800 mm long, with a mass of 1 kg placed at mid span, simply supported at the ends. The density of the shaft material is 50 g/cm^3 and Young's modulus of elasticity is 2×10^{11} N/m^2. 20



Q4 (a) What size of shaft should be used for the rotor of a 3.5 kW motor operating at 3600 rpm, if the shearing stress is not to exceed 58 MPa in the shaft? 10

(b) How do the following additives change the properties of polymers: 10

(i) Fillers
(ii) Plasticizers
(iii) Colourant
(iv) Lubricant

(c) The turning moment diagram of a multi-cylinder reciprocating engine is drawn to scale:

1 mm = 500 N-m, Y-axis and 1 mm = 4°, X-axis.

The areas above and below the mean torque line are:

+ 50, 120, + 95, – 140, + 90, – 70 and + 95 mm^2,

when the engine is running at 1000 rpm. If the mean fluctuation of speed is not to exceed ± 1% of the mean speed, determine the mass of the flywheel of radius of gyration of 400 mm. 20

(d) A 110 kg machine is mounted on an elastic foundation of stiffness 2×10^6 N/m. When operating at 150 rad/s, the machine is subject to a harmonic force of magnitude 1500 N. The steady-state amplitude of the machine is measured as 1.9 mm. What is the damping ratio of the foundation? 10

SECTION B

Q5 (a) Draw and label the geometry of a single point cutting tool. Write a typical tool signature for a single point cutting tool along with the information which can be obtained from a tool signature. 10

(b) Differentiate between Tolerance and Allowance. 10

(c) (i) Define 'Standard time'.

(ii) How is the observed time converted to standard time? List the admissible allowances. 10

(d) (i) List the basic concepts of TQM.

(ii) List any five conventional QC tools. 10

(e) (i) State the basic principles of lean production.

(ii) Compare lean production with mass production. 10

Q6 (a) Calculate the current required for electrochemical machining of pure iron so as to achieve a metal removal rate of 800 mm^3/min.
Consider:
Faraday's constant (F) = 96,500
Coulombs Atomic weight of iron = 56
Valency of iron = 2
Density of iron = 7.8 g/cm^3 10

(b) (i) What is REL chart? Name closeness ratings,

(ii) The layout of a plant consisting of six departments A, B, C, D, E and F is shown below. All departments are of the same size and configuration. The material handling cost per length travel between the departments is same. The handling frequencies between the departments are given in the table:

Layout

A	C	E
B	D	F

Handling Frequencies

From \ To	A	B	C	D	E	F
A	–	0	90	160	50	0
B	–	–	70	0	100	130
C	–	–	–	320	0	0
D	–	–	–	–	180	10
E	–	–	–	–	–	40
F	–	–	–	–	–	–

Taking the distance as a unit for the departments that share boundaries with the adjacent one, should the departments C and F be interchanged in location? Justify your answer. 20

(c) (i) What statistical assumptions are made in PERT? If a particular activity has a very high variance in PERT chart, how will this affect the completion time?

(ii) A list of activities, precedence relations, and optimistic (T_0), most likely (T_m) and pessimistic (T_p) activity completion times for a secret military project are given below:

Activity Name	Predecessor Activity	Estimated Time in Days		
		T_0	T_m	T_p
A	–	4	5	6
B	A	3	4	8
C	B	1	2	3
D	A, C	3	6	8
E	D	7	8	9
F	E	4	5	7
G	C	3	4	5
H	D, E, G, I	12	13	15
I	C	1	2	4
J	G, H	1	1	1

K	F, H, J	1	6	7

Draw the activity network diagram for this project. What is the critical path for the project? What is the probability that the project will be completed (1) in 45 days, and (2) in 50 days?

[The areas under the standard normal probability distribution is attached] 20

Q7 (a) For an orthogonal turning process, calculate the shear force and kinetic coefficient of friction at chip-tool interface using the following data: 20

Chip thickness (t_c) = 0.4 mm
Width of cut (b) = 2.5 mm
Feed rate (f) = 0.2 mm/rev
Tangential cutting force (F_c) = 1100 N
Thrust force (F_t) = 290 N
Cutting speed = 2.5 m/sec
Rake angle = + 10°

(b) A company is planning to manufacture medical testing equipment. Three locations A, B and C are under consideration. The estimated fixed costs/annum and variable cost/unit at the locations are given in the table below:

Location	A	B	C
Fixed cost/Annum (in Lakh)	300	500	250
Variable cost/unit (in Rs.)	3000	2000	3500

The average sale price of the equipment may be taken to be Rs 7,000 per unit.

(i) If the projected sales volume is 18000 units per year, which location should be chosen?

(ii) How much will be the profit per year? 10

(c) The following table shows the averages ($\bar{X}$) and ranges (R) of the spindle diameters in mm for 30 sub-groups of 5 items each taken from a production line chronologically:

Sub-group	$\bar{X}$	R	Sub-group	$\bar{X}$	R	Sub-group	$\bar{X}$	R
1	45.020	0.375	11	45.600	0.275	21	45.260	0.150
2	44.950	0.450	12	45.020	0.175	22	45.650	0.200
3	45.480	0.450	13	45.320	0.200	23	45.620	0.400
4	45.320	0.150	14	45.560	0.425	24	45.480	0.225
5	45.280	0.200	15	45.140	0.250	25	45.380	0.125
6	45.820	0.250	16	45.620	0.375	26	45.660	0.350
7	45.580	0.275	17	45.800	0.475	27	45.460	0.225
8	45.400	0.475	18	45.500	0.200	28	45.640	0.375
9	45.600	0.475	19	45.780	0.275	29	45.390	0.650
10	45.680	0.275	20	45.640	0.225	30	45.290	0.350

Construct $\bar{X}$ and R-charts on the basis of the first 20 sub-groups. Check if the process continues under control for the remaining sub-groups (i.e., 21 to 30). What do you conclude? Find the process capability. 20

The value of d_2 for a sample of 5 is 2.326.

Q8 (a) The volume of a weld nugget produced by spot welding process is 80 mm^3. Welding is performed using 10000 A current. Energy required for melting of unit volume of metal is 10 J/mm^3. Assume that heat lost to the surrounding

base metal is 500 J and contact resistance is 0.0002 ohms.

Calculate the (i) time (in sec) for which the welding current is supplied, and (ii) thermal efficiency of the spot welding process if other heat losses are negligible. 10

(b) A company manufacturing washing machines establishes a relationship between the sale of washing machines and the population of the city. The market research carried out reveals the following information:

Population of the city (in lakhs)	5	7	15	22	27	36
No. of washing machines demanded (unit in hundreds)	28	40	65	80	96	130

Fit a linear regression equation and estimate the demand of washing machines for a city of population of 45 lakhs. 20

(c) A contractor has a requirement of cement that amounts to 1500 bags per day. No shortages are allowed. Cement costs Rs 400 per bag. Holding costs are Rs 0.2 per bag per day and the ordering process cost per order is Rs 150.

(i) Find the optimal lot size and the system cost per day.

(ii) If, however, the price per bag is quoted in accordance with the following schedule:

Purchase Quantity (Bags)	Price/Bag (Rs)
0 – 1999	400
2000 and above	395

Should the contractor take advantage of the quantity discount? 20

MECHANICAL ENGINEERING Paper—II

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QUESTION PAPER SPECIFIC INSTRUCTIONS

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SECTION—A

1. (a) Which is the more effective way to increase the efficiency of a Carnot engine—to increase T_1 keeping T_2 constant or to decrease T_2 keeping T_1 constant? 10

(b) What is the pressure coefficient of a centrifugal compressor? Derive that $\psi_p = 1 - \phi_2 \cot \beta_2$, where ϕ_2 = flow coefficient. 10

(c) Define effectiveness, NTU and heat capacity ratio in case of heat exchanger analysis, and also establish a relationship among them for counterflow heat exchanger. 10

(d) Derive Wien's displacement law from Planck's law of radiation. 10

(e) What are the supercharging limits of SI and CI engines? What are the modifications recommended for supercharging an IC engine? 10

2. (a) A cylindrical rod of length L insulated on its lateral surface is initially in contact at one end with a wall at temperature T_1 and at the other end with a wall at lower temperature T_2. The temperature within the rod initially varies linearly with position x according to $T(x) = T_1 - \frac{T_1 - T_2}{L} x$. The rod is insulated on its ends and eventually comes to a final equilibrium state where the temperature is T_f. Evaluate T_f in terms of T_1 and T_2, and show that the amount of entropy generated is

$$S_{gen} = mc\left[1 + \ln T_f + \frac{T_2}{T_1 - T_2} \ln T_2 - \frac{T_1}{T_1 - T_2} \ln T_1\right]$$

where c is the specific heat of the rod. 20

(b) Air flows over a surface, 2 m in length, oriented in the direction of flow and of sufficient breadth, maintained at 150 °C. The pressure is 1 atm and the bulk

air temperature is 30°C. If the air velocity is 12 m/s, find the average heat transfer coefficient.

[Use the following physical properties of air at film temperature, that is (150 + 30)/2 = 90°C:

$\rho = 0.962$ kg/m^3, $\mu = 2.131 \times 10^{-5}$ kg/m s

$k = 0.031$ W/m K, $C_p = 1.01$ kJ/kg K

$Nu = 0.332\ Re^{1/2}\ Pr^{1/3}$ for laminar flow

$Nu = 0.0296\ Re^{0.8}\ Pr^{1/3}$ for turbulent flow] 20

(c) Briefly describe the effect of volatility on the following performance characteristics of SI engine: 10

(i) Cold starting

(ii) Hot starting

(iii) Vapour lock

(iv) Evaporation loss

3. (a) A steam pipe (inner diameter = 150 mm and outer diameter = 160 mm) having thermal conductivity 58 W/m K is covered with two layers of insulation of thicknesses 30 mm and 50 mm respectively and thermal conductivities 0.18 W/m K and 0.09 W/m K respectively. The temperature of inner surface of the steam pipe is 320 °C and that of the outer surface of the insulation layers is 40 °C.

(i) Determine the quantity of heat lost per metre length of the steam pipe and layer contact temperature.

(ii) If the condition of the steam is dry and saturated, find the quality of the steam coming out of one metre pipe assuming that the quantity of steam flowing is 0.32 kg/min.

[Use the data: At 320 °C saturation temperature h_f = 1463kJ/kg, h_{fg} = 1240 kJ/kg, h_g = 2703 kJ/kg] 20

(b) An engine having a single-jet carburettor consumes 6.0 kg/h of fuel. The density of fuel is 750 kg/m^3. The level in the float chamber is 3 mm below the top of the jet when the engine is not running. The ambient conditions are:

Pressure = 1.013 bar and Temperature = 21 °C

The jet diameter is 1.2 mm and its discharge coefficient is 0.65. The discharge coefficient of air is 0.80. The air/fuel ratio is 15.3 : 1. Determine—

(i) critical air velocity;

(ii) depression at the throat in mm of H_2O;

(iii) effective throat diameter.

Neglect the compressibility of air. 20

(c) Explain the phenomenon of surging and choking in a centrifugal compressor. 10

4. (a) What is a current meter? Where is it used? Explain with the help of a neat sketch the functioning of a current meter. 10

(b) In a double-sided centrifugal compressor, the following data are given:

Overall diameter of impeller = 50 cm

Eye tip diameter = 30 cm

Eye root diameter = 15 cm

RPM = 15000

Total mass flow = 18 kg/s

Inlet total head temperature = 295 K

Total head isentropic efficiency = 78%
Power input factor = 1.04
Slip factor = 0.9

Assume that the velocity of air at inlet is 150 m/s and is axial, and remains constant across the eye annulus.

Find (i) the total head pressure ratio, (ii) the power required to drive the compressor and (iii) the inlet angles of the vanes at the root and tip of impeller eye. Draw the T-s diagram and velocity triangles. 20

(c) In a large steam power plant, a shell and tube type condenser is used which has the following data:

Heat exchange data = 2100 MW
Number of shell passes = 1
Number of tubes = 31500
Number of tube passes = 2
Diameter of each tube = 25 mm
Condensation temperature = 50 °C
Mass flow rate of cooling water = 3.4×10^4 kg/s
Heat transfer coefficient on the steam side = 11400 W/m^2 K
Inlet water temperature = 20 °C
Heat transfer coefficient on the water side = 8018 W/m^2 K

Using only e-NTU method, calculate—

(i) the outlet temperature of cooling water;
(ii) the length of tube pass.

[Properties of water at 27 °C are:
C_p = 4.18 kJ/kgK, $\mu = 855 \times 10^{-6}$ Ns/m^2, k = 0.613W/mK and Pr = 5.83]
Neglect the thermal resistance due to tube wall. 20

SECTION—B

5 (a) What do you mean by boundary layer separation? Briefly explain the various methods of controlling of boundary layer separation. 10

(b) What is the function of an economiser in a thermal power plant? Why are the economiser tubes often provided with fins on the gas side? Explain. 10

(c) What are the desirable properties of a fluid for use as a working substance in Rankine cycle based heat engine plant? Discuss with the help of T-s diagram. 10

(d) Discuss any four thermodynamic desirable properties of an ideal refrigerant. 10

(e) What is an adiabatic saturation process? Why does the enthalpy of an air-vapour mixture remain constant during this process? 10

6 (a) Explain what you mean by Fanno flow. Clearly mention the assumptions made and governing equations involved in the Fanno flow. 10

(b) A convergent-divergent nozzle receives steam at 5.0 bar, 200°C and expands isentropically into a space at 2.0 bar. Neglecting the inlet velocity, calculate the exit area required for a mass flow of 0.3 kg/ s in the following cases:

(i) When the flow is in equilibrium throughout
(ii) When the flow is supersaturated with $PV^{1.3}$ = constant

Calculate also for this supersaturated flow, the degree of supercooling and the degree of supersaturation.

Properties of steam:
At 5.0 bar and 200 °C, h = 2855.4 kJ/kg, s = 7.0592 kJ/kg K, v = 0.4249 m^3/kg
At 2.0 bar and T_{sat} =120.23 °C, h_f = 504.7 kJ/kg, h_g = 2706.7 kJ/kg, s_f = l.5301 kJ/kgK, s_g = 7.1271 kJ/kg K, v_f =0.001061 m^3/kg, v_g = 0.8857 m^3/kg 20

(c) Explain, with the help of neat sketches, vapour absorption cycle for refrigeration and also derive an expression to calculate ideal COP of it. 20

7. (a) Write a note on the off-design performance characteristics of a convergent-divergent nozzle. Plot the pressure distribution along the axis of the nozzle for different back pressures. 20

(b) A vapour compression refrigeration cycle works between pressure limits 10 bar and 3 bar. The working fluid is dry at the end of compression and there is no undercooling before the expansion valve. If refrigerant flow rate is 10 kg/min, determine—

(i) the COP;

(ii) the capacity of the refrigerator. 20

Table for properties of the refrigerant is as under:

Pressure (bar)	*Saturation Temperature* (°C)	*Liquid heat* (kJ/kg)	*Latent heat* (kJ/kg)	*Liquid entropy* (kJ/kgK)	*Vapour entropy* (kJ/kgK)
10	25	298.9	1166.94	1.1242	5.0391
3	–10	135.37	1297.68	0.5443	5.4770

(c) What is the function of a governor in a steam turbine? With the help of a neat sketch, explain the working of throttle governing. Show the process on *h-s* diagram. 10

8. (a) Air at dry-bulb temperature of 30 °C and 60% relative humidity enters a cooling coil at the rate of 250 m^3 /min.

(i) Determine the refrigeration in ton needed to bring the temperature of the air to the coil temperature of 23 °C and also the relative humidity at that condition.

(ii) If the effective surface temperature of the cooling coil or ADP is 12 °C and the by-pass factor is 0.1, determine the refrigeration in ton needed and the mass of water condensed out at the cooling coil per minute. Determine also the sensible heal factor for the process through the coil. 20

(b) Define distorted model. Explain why models nf rivers and harbours are made as distorted models. Write down the merits and demerits of distorted models. 10

(c) A cyclic steam power plant is to be designed for a steam temperature at turbine inlet of 360 °C and an exhaust pressure of 0.08 bar. After isentropic expansion of steam in the turbine, the moisture content at the turbine exhaust is not to exceed 15%. Determine the greatest allowable steam pressure at the turbine inlet, and calculate the Rankine cycle efficiency for these steam conditions. Estimate also the mean temperature of heat addition. Compare the Rankine cycle efficiency with the Carnot cycle efficiency opeidting between the mean temperature of heat addition and the condenser temperature. Neglect the pump work input.
Properties of steam :
At P = 0.08 bar and T_{sat} =41 °C, h_f = 173.88 kJ/kg, s_f = 0.5926 kJ/kg K, h_{fg} = 2403.1 kJ/kg, s_{fg} = 7.6361 kJ/kg K 20