MECHANICAL ENGINEERING Paper I

Time Allowed: Three Hours **Maximum Marks: 200**

QUESTION PAPER SPECIFIC INSTRUCTIONS

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

There are **EIGHT** questions in all, out of which **FIVE** are to be attempted.

Question No. **1** and *5* are compulsory. Out of the remaining **SIX** questions, **THREE** are to be attempted selecting at least **ONE** question from each of the two **Sections A** and **B**.

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly. Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question/part is indicated against it.

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SECTION 'A'

1. Answer all of the following:

(a) The tooth profiles of both the gears used in a gear drive are—involute with 20° pressure angle, 12 mm module and 10 mm addendum. The pinion and the gear have 36 and 96 teeth respectively. Find the length of path of contact, arc of contact and the contact ratio. Show the path of contact with a sketch. 8

(b) The following data refer to a single-cylinder reciprocating engine:
Speed = 250 r.p.m. Stroke = 300 mm Mass of reciprocating parts = 50 kg Mass of revolving parts at 150 mm radius = 38 kg If two-thirds of reciprocating parts and all the revolving parts are to be balanced, find—
(i) the balance mass required at a radius of 410 mm;
(ii) the residual unbalance force when the crank has rotated 60° from inner dead centre. 8

(c) A cylindrical shaft, 80 mm in diameter, is subjected to a maximum bending moment of 2.5 kN-m and a twisting moment of 4.2 kN-m. Find the maximum principal stress developed in the shaft. If the yield stress of the shaft material is 380 MPa, determine the factor of safety of the shaft according to the maximum shearing stress theory of failure. 8

(d) A horizontal simply supported beam AB, 8 m long, carries a total uniformly distributed load of 300 kN. The beam is supported at A and at a point C, between A and B, where overhang BC is x. Determine the value of x, if the midpoint of the beam AB is to be a point of inflexion. 8

(e) Differentiate the characteristics of basic cubic and orthogonal crystal systems. Give at least three examples of each category of crystal system. 8

2. (a) In a quick-return motion of the crank and slotted lever type, the ratio of maximum velocities during return and forward motions is 2. If the length of stroke is 250 mm, find—
(i) the length of the slotted lever;
(ii) the ratio of times of cutting and return strokes;
(iii) the maximum cutting velocity per second if the crank rotates at 30 r.p.m. 10

(b) A punching machine carries out 5 holes per minute. Each hole of 32 mm diameter in 35 mm thick plate requires 10 N-m of energy/mm^2 of the sheared area. The punch has a stroke of 90 mm. Find the power of the motor required if the mean speed of the flywheel is 25 m/s. If the total fluctuation of speed is not to exceed 3% of the mean speed, determine the mass of the flywheel. 10

(c) A pulley of 150 mm effective diameter running at 1500 r.p.m. drives a follower of 750 mm diameter, the two shafts being parallel, 1 m apart. The belt has a mass of 0.4 kg/m and the maximum tension is to be 720 N. If $\mu = 0.4$, estimate the maximum tension difference allowing for the inertia of the belt. If the belt has a

cross-sectional area of 320 mm^2 and E for the material is 300 MPa, estimate the speed of the driven pulley at the maximum power condition and the power transmitted. Consider belt slip of 7.5%. 20

3. (a) A steel tube, 24 mm external diameter and 18 mm internal diameter, encloses a copper rod 15 mm diameter to which it is rigidly joined at each end. If at a temperature of 30 °C there is no longitudinal stress, calculate the stresses in the rod and tube, when the temperature is raised to 200 °C. Given—
for steel: E_s =210 GPa; α_s = coefficient of thermal expansion = 11×10^{-6} /°C
for copper: E_c =100 GPa; α_c = coefficient of thermal expansion = 18×10^{-6} /°C. 10

(b) A hollow cylindrical steel shaft is 1.5 m long and has inner and outer diameters equal to 40 mm and 60 mm respectively.
(i) What is the largest torque that can be applied to the shaft if the shearing stress is not to exceed 150 MPa?
(ii) What is the corresponding minimum value of the shearing stress in the shaft? 10

(c) The cylinder of a hydraulic ram has 160 mm internal diameter. Find the thickness required to withstand an internal pressure of 60 MPa, if the maximum tensile stress is limited to 90 MPa and the maximum shearing stress to 80 MPa. Use Lame's formula for thick cylinders under internal pressure. 20

4. (a) A thin cylindrical shell is 5 m long, has 200 mm internal diameter and has thickness of metal 10 mm. It is filled completely with a fluid at atmospheric pressure. If an additional 25000 mm^3 fluid is pumped in, find the pressure inside the shell and hoop stress developed. Find also the changes in diameter and length. Take E = 200 MPa and $\nu = 0.3$. 10

(b) (i) What is normalizing?
(ii) Compare between normalizing and annealing of metals. 10

(c) Explain the following hardening processes used for medium carbon steel. State their advantages and disadvantages: 20
(i) Induction hardening
(ii) Flame hardening

SECTION 'B'

5. Answer all of the following:

(a) Explain the need for use of unconventional machining processes compared to the conventional ones. Name any five unconventional processes with one example of its application. Explain the basic principle of water jet machining. 8

(b) In a metal cutting experiment, the tool life was found to vary with the cutting speed in the following manner:

Cutting speed, V (in m/min)	Tool life, T (in min)
100	120
130	50

Derive Taylor's tool life equation for this operation and estimate the tool life at a speed of 2.5 m/sec. Also estimate the cutting speed for a tool life of 80 min. 8

(c) Explain, with the help of sketches, the concepts of hole basis and shaft basis in terms of assembly fit specifications. Which of the two is preferred and why? 8

(d) An aluminium rod, 6.25 mm diameter, is drawn into a wire 5.60 mm diameter. Neglecting friction between the rod and the dies, determine the drawing stress and the reduction in area when the yield stress for aluminium is 35 N/mm^2. Also calculate the tangential stress at the exit. 8

(e) What is work sampling? A pilot study shows 30% ineffective time in a job order shop which has 10 general purpose machines. A work sampling study is planned. Compute the number of observations that are required to ensure an accuracy of 5% with 95% confidence level. 8

6. (a) The table below lists 12 work elements along with their number of predecessors and time duration in minutes. Design a suitable production line consisting of appropriate number of workstations assuming cycle time of 10 min. Also compute the line efficiency, balance delay and smoothness index:

Work element	1	2	3	4	5	6	7	8	9	10	11	12
No. of predecessors	0	1	2	1	2	5	6	7	6	6	7	11
Time of completion (in min)	5	3	4	3	6	5	2	6	1	4	4	7

Write the steps used in solution. 15

(b) A company manufactures two products A and B. The manufacturing and marketing data for the two products are given below:

Department	Product A	Product B	Capacity
Welding	2.0 man-hours	2.5 man-hours	1000 man-hours
Machines	3.0 man-hours	1.5 man-hours	1200 man-hours
Assembly	1.5 man-hours	4.0 man-hours	1200 man-hours
Profit	Rs. 120/unit	Rs.100/unit	—

Find the product-mix to maximize profit, assuming that whatever is produced will be sold. 15

(c) A function $F(x)$ is defined as follows:

$$F(x) = ax^3 - bx^2 + cx - d \quad \text{if } x > 1$$
$$= 0 \quad \text{if } x = 0$$
$$= -ax^3 + bx^2 - cx + d \quad \text{if } x < 1$$

Write a FORTRAN program that reads the values of a, b, c, d, x and find the values of $F(x)$ in print. 10

7. (a) A company is engaged in the assembly of a wagon on a conveyor. 500 wagons are required per day. Production time available per day is 420 minutes. The other information is given in the table below regarding assembly steps and precedence relationships. Find the minimum number of workstations, balance delay and line efficiency: 15

Activity	Time (in sec)	Activity that must precede
A	45	—
B	11	A
C	09	B
D	50	—
E	15	D
F	12	C
G	12	C
H	12	E
I	12	E
J	08	F, G, H, I
K	09	—
Total	195	

(b) Classify the costs associated with the management of quality. A company Balance Sheet shows the following expenditure on quality control. Group them in appropriate quality cost: 10

SL No.	Item	Expenditure (in lakhs of Rs.)
1	Vendor quality assurance	20
2	Products returned from field	15
3	Warranty claims	04
4	Scrap	30
5	Field testing before commissioning	10
6	Rework	20
7	Receiving inspection	10
8	Downtime	10
9	Materials consumed during measurements	04
10	Quality training	10
11	Depreciation on equipment	25
		Total : 158

(c) A manufacturing company requires special gears at the rate of 300 numbers per year. Each gear costs Rs. 380. The procurement cost and inventory carrying cost are estimated to be Rs. 300 and 20% respectively. If the supplier offers a discount of Rs. 20 per gear on an order of 200 gears or more, will it be advisable to avail the discount? What should be the order quantity? 15

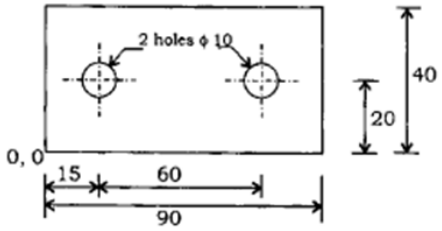
8. (a) (i) What is the difference between a jig and a fixture? Explain with the help of one example for each. 4

(ii) Explain the 3:2:1 principle of location. 8

(b) (i) Differentiate among the simple, compound and progressive dies. 6

(ii) A symmetrical cup of circular cross section with diameter 40 mm and height 60 mm with a corner radius of 2 mm is to be obtained in C20 steel of 0.6 mm thickness. Calculate the blank size for the drawn cup. Will it be possible to draw the cup in single step? 10

(c) Two holes are to be drilled with a 10 mm diameter drill on a job as shown below:



The drill rotates at 500 rpm and feed rate is 200 mm/min. How do you code the information in—

(i) fixed block format;

(ii) TAB sequential format;

(iii) word address format? 12

MECHANICAL ENGINEERING Paper II

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Assume suitable data, if necessary and indicate the same clearly.

Neat sketches may be drawn, wherever required.

Newton may be converted to kgf using the equality 1 kilonewton (1 kN) = 100 kgf, if found necessary.

All answers should be in SI units.

Take: 1 kcal = 4.187 kJ and 1 kg/cm^2 = 0.98 bar

1 bar = 10^5 pascals

Universal gas constant = 8314.6 J/kmol-K

Psychrometric chart is enclosed.

SECTION—A

Q. 1(a) Write the two statements of the Second Law of Thermodynamics and prove their equivalence. 10

Q. 1(b) When a Brayton cycle is reversed and operated as refrigerator, show that the ideal COP of such a cycle is given by

$$\text{COP} = \left[(P_2/P_1)^{\frac{\gamma-1}{\gamma}} - 1\right]^{-1}$$

where P_2 and P_1 are higher and lower pressure respectively.

Explain the physics of air refrigeration. 10

Q. 1(c) What is meant by abnormal combustion? Explain with appropriate diagrams the phenomenon of knock in S.I. Engines. 10

Q. 1(d) What are different types of combustion chambers in C.I. engines? Explain with a neat sketch, an open type indicating its merits and demerits. 10

Q. 2(a) Derive an expression for air standard efficiency of dual combustion cycle in terms of compression ratio, cut-off ratio, and ratio of specific heats. 10

Q. 2(b) (i) State the Zeroth Law of Thermodynamics and highlight its significance. 5

Q. 2(b) (ii) For an isothermal process, show that: 5

$$\int_1^2 P\,.\,dv = -\int_1^2 v\,.\,dP$$

Q. 2(c) (i) Write a brief note on alternate fuels for I.C. Engines. 5

Q. 2(c) (ii) Explain octane and cetane ratings of fuels. 5

Q. 2(d) (i) In a system executing a non flow process the work and heat per degree change of temperature are given by dW/dT = 200W-s/°C and dQ/dT = 160 J/°C. What will be the change in internal energy of the system when its temperature changes from T_1 = 55°C to T_2 = 95°C? 5

Q. 2(d) (ii) The compression ratio of an air standard Otto cycle is 8. At the beginning of compression process the pressure is 1 bar and temperature 300 K. The heat transfer to the air per cycle is 1900 kJ/kg of air. Calculate thermal efficiency and mean effective pressure. 5

Q. 3(a) The following data is given for a 4 stroke, 4 cylinder diesel engine:

Diameter of cylinder = 35 cm, Piston stroke = 40 cm, Speed = 315 rpm, I_{mep} = 7 bar, BP = 260 kW, TFC = 80 kg/hr, CV of fuel used = 43000 kJ/kg, Hydrogen content of fuel = 13% and remaining is carbon. Air consumption 30 kg/min, cooling water circulated 90 kg/min, Rise in temperature of cooling water 38°C, piston cooling oil used 45 kg/min. Rise in temperature of cooling oil 23°C, for cooling oil C_p = 2.3 kJ/kgK, exhaust gas temperature 322°C and C_p for exhaust gas 1.1 kJ/kgK, Ambient temperature 22°C, C_p for superheated steam 2 kJ/kgK and latent heat of steam 2520 kJ/kg. Find: (i) Mechanical and indicated thermal efficiency, and (ii) Draw up the heat balance sheet on minute basis. 15

Q. 3(b) Show that 2 reversible engines working between same temperature limits have the same efficiency. 10

Q. 3(c) With neat sketches explain the cooling systems used in I.C. engines. Why cooling is required in I.C. engines? 8

Q. 3(d) What are the objects of supercharging in I.C. engines? Explain thermodynamic cycle of supercharged I.C. engine. 7

Q. 4(a) How are the concept of entropy and unavailable energy related to each other? 7

Q. 4(b) (i) The analysis by weight of a perfect gas mixture at 20°C and 1.3 bar is 10% O_2, 70% N_2, 15% CO_2 and 5% CO. For a reference state of 0°C, 1 bar, determine (i) Partial pressure of the constituents, (ii) Gas constant of the mixture. 8

Q. 4(b) (ii) Explain mechanical efficiency, thermal efficiency, volumetric efficiency of IC engines. 6

Q. 4(b) (iii) Will an increase in volumetric efficiency increase the output of the engine? How? 4

Q. 4(c) (i) How does a perpetual motion machine of second kind violate second law of thermodynamics? 5

Q. 4(c) (ii) Two carnot engines A and B are connected in series between 2 thermal reservoirs maintained at 1000 K and 100 K respectively. Engine A receives 500 kJ of heat from the high temperature reservoir and rejects heat to engine B. Engine B takes this heat and rejects heat to the low temperature reservoir. If A and B have equal thermal efficiencies determine:

(a) Heat rejected by engine B.
(b) Temp. at which heat is rejected by A.
(c) Work done by engine A and B. 10

SECTION—B

Q. 5(a) (i) Discuss the working of "Air washer" with the help of a schematic diagram and psychrometric chart. 5

Q. 5(a) (ii) What method would you recommend for the design of heat exchangers, if exit temperatures of heat exchanger are not known? Discuss the method. Identify the parameter, which is a measure of the size of the heat exchanger. 5

Q. 5(b) What is the pressure coefficient of a centrifugal compressor? Derive:

$$\psi_p = 1 - \varphi_2 \cos \beta_2$$

where φ_2 = flow coefficient. 10

Q. 5(c) Prove that in a multistage turbine:

$$\eta_t = \eta_s \times RF$$

where η_t = overall turbine efficiency, η_s = small-stage efficiency and RF = reheat factor. 10

Q. 5(d) A 12 cm wide and 18 cm high vertical hot surface is to be cooled by a heat sink with equally spaced fins of rectangular profile. The fins are 0.1 cm thick, 18 cm long in the vertical direction, and have a height of 2.4 cm from the base. Determine the optimum fin spacing, and the rate of heat transfer by natural convection from the heat sink if the base temperature is 80°C. Properties of air at 325.5 K are:
K = 0.0279 W/m-K, $\nu = 1.82 \times 10^{-5}$ m²/s, Pr = 0.709. 10

Q. 6(a) Describe the working of a modern natural circulation boiler. Why are downcomers fewer in number and bigger in diameter, while risers are more in number and smaller in diameter? Write down the functions of preheater, reheater, economiser and superheaters and their locations. 15

Q. 6(b) (i) Compare gas turbines with steam turbines. List the applications of gas turbines and write about gas turbine fuels. 5

Q. 6(b) (ii) A simple gas turbine takes air at 1.01 bar and 15.5°C and compresses it through a pressure ratio 5 : 1, the adiabatic efficiency of compression being 85%. The gases enter the turbine at 540°C and expand to 1.01 bar, the turbine efficiency being 80%. Estimate the flow of gases in kg per second, for a net power of 1500 kW, making the following assumptions:
Fall of pressure through the combustion system is 0.07 bar, C_P for both air and combustion gases = 1.047 kJ/kgK, index of compression/expansion is 1.4. Neglect additional mass flow due to fuel. 10

Q. 6(c) Write a brief note on cooling towers based on the following points:
(i) applications
(ii) types
(iii) comparison with cooling ponds. 10

Q. 7(a) The velocity of steam leaving the nozzles of an impulse turbine is 900 m/s and the nozzle angle is 20°. The blade velocity is 300 m/s and the blade velocity coefficient is 0.7. Calculate for a mass flow of 1 kg/s and for symmetrical blading:
(i) the blade inlet angle,
(ii) driving force on the wheel,
(iii) the axial thrust,
(iv) the diagram efficiency, and
(v) power developed. 15

Q. 7(b) Explain the meaning of (i) Draft and describe briefly different draft systems, (ii) Base load and peak load. 5

Q. 7(c) A plant using R22 has an evaporator saturation temperature of -1°C and a condenser saturation temperature of 45°C. The vapour is dry saturated at entry to the compressor and is at a temperature of 75°C after compression to the condenser pressure. The compressor is a two stage centrifugal compressor, each stage having the same pressure ratio and enthalpy rise. Assuming no undercooling in the condenser, a slip factor of unity, axial flow of refrigerant into the compressor, radial flow of refrigerant at the impeller exit and using the properties of R22 given in Table 1 and 2, calculate:
(i) the coefficient of performance.
(ii) the power input required for a refrigeration capacity of 2 MW.
(iii) the diameter of the impeller in each stage when the rotational speed is 300 rev/min. 20

Table 1 Saturated Values:

Temp.	Press.		Specific enthalpy	Specific entropy		Specific volume
h_f	h_g		s_f	s_g		v_g
(0°C)	(bar)		(kJ/kg)	(kJ/kg K)		m3/kg
–1	4.816	198.83	404.99	0.996	1.753	0.0487
45	17.290	256.40	417.31	1.187	1.693	0.0133

Table 1 Saturated Values at 17.290 bar:

Temperature	Specific enthalpy	Specific entropy
0°C	(kJ/kg)	(kJ/kg K)
65	436.27	1.751
70	440.77	1.764
75	445.21	1.777

Q. 8(a) The configuration of a furnace can be approximated as an equilateral triangular duct which is sufficiently long that the end effects are negligible. The hot wall is maintained at $T_1 = 1000$ K and has an emissivity $\varepsilon_1 = 0.8$. The cold wall is at $T_2 = 500$ K and has an emissivity $\varepsilon_2 = 0.8$. The third wall is reradiating zone for which $Q_3 = 0$. Calculate the net radiation flux leaving the hot wall. 10

Q. 8(b) What is shape factor or configuration factor? Write down the reciprocity relation and prove it. 5

Q. 8(c) What are the desirable properties of a good refrigerant? List giving proper reasoning. Name few commonly used refrigerants. 10

Q. 8(d) At a particular hydro-electric power plant site, the discharge of water is 400 m^3/sec and the head is 25 m. The turbine efficiency is 88%. The generator is directly coupled to the turbine having frequency of generation of 50 cycles per second and number of poles as 24. Calculate the least numbers of turbines required if (a) a Francis turbine is used with a specific speed of 300 and (b) a Kaplan turbine is used with a specific speed of 750. 15