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.

Answers must be written in **ENGLISH** only.

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SECTION 'A'

1. Attempt any four of the following:

(a) Discuss how single cylinder 4-stroke reciprocating engine is balanced. 10

(b) A circular rod has 5 cm diameter for a length of 0.6 m, 8 cm diameter for a length of 1.8 m and 3 cm diameter for a length of 0.25 m. A disc of mass moment of inertia 15 kg m^2 is suspended with the help of this rod such that the disc is in horizontal plane. Neglecting inertia effect of the rod, find natural frequency of torsional oscillation in Hz. Assume $G = 0.8 \times 10^{11}$ Pa. 10

(c) Compare the bending strengths of three beams of same material, same weight and same depth if one of them has solid rectangular area of 6×20 cm^2. The second beam is a hollow rectangular section having a wall thickness of 2 cm. The third beam has I-section of equal flanges having web and flange thickness equal to 2 cm. 10

(d) The load on a rod consists of an axial pull of 10 kN along with a transverse shear force of 5 kN. Determine the diameter of the rod by using the following theories of failure:

(i) Strain energy theory

(ii) Shear strain energy theory.

Elastic limit in tension is 270 N/mm^2 and a factor of safety of 3 is to be used. Poisson's ratio = 0.3. 10

(e) Explain (i) bainite, (ii) martensite. Show with a figure, the variation of hardness of martensite with % C. Discuss polycarbonate, its properties and applications. Complete the table below for surface hardening process. 10

Process	Temp °C	Case depth (mm)	Case hardness HRC	Main use
Cyaniding	---	---	---	---

2. (a) The total sleeve movement in a Hartnell type of governor is 3 cm. At mid position of sleeve, the sleeve arm which is 6 cm long, is horizontal. The length of ball arm is also 6 cm. The speed at the lowest position is 430 rpm. If the spring stiffness is 50 N/cm, find the speed in rpm at the top position of the sleeve. At mid-span the ball rotates at 10 cm radius. The mass of the ball is 1.3 kg. 10

(b) An epicyclic gear train consists of a sun gear, a stationary internal gear and three identical planet gears which are carried on a star-shaped planet carrier. The sun gear, internal gear and planet carrier have common axis. The speed of the planet carrier is one-fifth of the speed of the sun gear in the same sense. If minimum number of teeth on any gear is limited to 18, determine the number of teeth on each gear. Determine the torque to keep the internal gear stationary, if input torque at sun gear is 100 Nm. 10

(c) A machine is vibrating with an amplitude of 0.04 mm at 500 rpm. An instrument weighing 20 kg is mounted on the four isolators on the machine. Each isolator has stiffness 314 N/cm and damping factor of 392 N sec/m. Determine:
(i) amplitude of vibration of instrument, and
(ii) dynamic load on each isolator. 20

3. (a) Two planes AB and AC make an angle of 50° at point A. Plane AB is subjected to tensile stress 3 kN/cm^2 and shear stress 3 kN/cm^2 from B towards A. Plane AC is subjected to a normal stress of unknown magnitude and a shear stress of magnitude 2 kN/cm^2 from C towards A. Determine
(i) normal stress on plane AC, and
(ii) principal stresses, 15

(b) Design a suitable helical spring for a balance which is used to measure 0 to 100 kg over a scale of 80 mm. The spring is to be enclosed in a casing of 25 mm diameter. Approximate number of turns is 30. Also calculate the maximum shear stress induced. $G = 0.85 \times 10^7$ N/cm^2. 10

(c) A steel sleeve is pressed onto a solid steel shaft which has 5 cm diameter. The radial pressure between shaft and sleeve is 1800 N/cm^2 and hoop stress at the inner surface of the sleeve is 4500 N/cm^2. If an axial compressive load of 50 kN is applied to the shaft, determine change in radial pressure at the interface of shaft and sleeve. Assume $\mu = 0.3$. 15

4. (a) Prove that the packing fraction for F.C.C. structure is 0.74. Draw the phase diagram of Pb-Sn alloy and from this diagram draw cooling curve for eutectic alloy. How many atoms per mm2 are there on the (100) planes of lead (Pb radius = 0.1750 nm)? What is deformation by twinning? 20

(b) Describe the following heat treatment processes:
(i) Full annealing
(ii) Process annealing
Mention some advantages of thermosets and write at least four types of such material. What are the special properties of PTFE?
What are the materials used to make porcelain? Write some important applications of oxide ceramics. 20

SECTION 'B'

5. Attempt any *four* of the following:

(a) What are the disadvantages of abrasive jet machining? Write some of its applications. Write the advantages, limitations and applications of electron beam machining. What is the safety problem connected with EBM? 10

(b) Discuss with figure the various steps required for friction welding, mentioning at least two methods of control. What is meant by low hydrogen electrode? What is the maximum output current that can be drawn at 100% duty cycle from a welding power source rated at 600 A at 60% duty cycle. 10

(c) In NC machine, what is the purpose of the parity check? What is the function of Data Processing Unit (DPU) and Control Loop Unit (CLU) of MCU. How is Feed Rate Number (FRN) expressed? What is indirect feedback? 10

(d) Prepare a flow diagram for writing the computer programme in FORTRAN for Pulse MIG welding process. 10

(e) In a four-month period, the best rainfall forecast is derived by using 40% of the rainfall for the most recent month; 30% of two months ago; 20% of three months ago; and 10% of four months ago; if the actual rainfall was as follows:

Month 1	Month 2	Month 3	Month 4
100	90	105	95

What is the rainfall forecast for Month 5? 10

6. (a) What are the functions of jig? Draw a jig to machine four holes in a plate. What are two reasons for not having drill bushings actually touching the workpiece? What is a duplex fixture? 10

(b) What is meant by interchangeable manufacture? Laser light has unique advantages for inspection. What are they? Define the terms 'roughness height', 'waviness width' and 'lay' in connection with surface irregularities. 10

(c) Discuss deep-hole drilling keeping in mind speed and feed, mentioning the technique of applying coolant. What is the main difference between rose reamer and chucking reamer? Write in short about shell reamer. 10

(d) Write four advantages of high velocity forming process. What advantages does press forging have over drop forging? Why are pure metals more easily cold worked than alloys? Compare metal spinning with press work. 10

7. (a) National Bank is considering opening a drive-in window for serving the tourists at a forest entry gate. Management estimates that tourists will arrive for banking service at the rate of 15 per hour. The teller whom it is considering to staff the window can service customers at the rate of one every three minutes. Assuming Poisson arrivals and exponential service, compute:

(i) The average utilization of the teller.
(ii) Average number in the waiting line,
(iii) Average number in the system,
(iv) Average waiting time in line.
(v) Average waiting time in the system. 25

(b) Specify the output and the cost objectives of the following organizations:

(i) A Forest Service Regional Office.
(ii) A Summer Camp for children.

For each of the organizations listed above, develop an organization chart. 15

8. (a) The daily demand for a forest product is normally distributed with a mean of 60 and a standard deviation of 7. The source of supply is reliable and maintains a constant lead time of six days. If the cost of placing the order is Rs. 10 and annual holding costs are Rs. 0.50 per unit, compute the order quantity and reorder point to satisfy 95% of the customers. Given that 95% corresponds to 1.645 standard deviation. 20

(b) The plating process for metal desk equipment painted by dipping can produce defective parts either because of too thick or too thin a plating or because of defective appearance, which shows up in surface defects. A record of twenty samples follows; construct a suitable control chart and plot the twenty samples. Is the process in control? 20

Item No.	No. of defects per unit	Item No.	No. of defects per unit
1	19	11	13
2	16	12	10
3	23	13	22
4	11	14	5
5	15	15	23
6	12	16	22
7	17	17	14
8	11	18	6
9	20	19	13
10	15	20	6

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

1. Answer any *four* parts;

(a) An imaginary engine receives heat and does work on a slowly moving piston at such rates that the cycle of operation of 1 kg of working fluid can be represented as a circle 10 cm in diameter on a p-v diagram on which 1 cm = 300 kPa and 1 cm = 0.1 m^3/kg.
Determine how much work is done by each kg of working fluid for each cycle of operation. If the heat rejected by the engine in a cycle is 1000 kJ per kg of working fluid, find the thermal efficiency of the engine. 10

(b) Explain the principle of carburetion. Develop an expression for air-fuel ratio for a simple carburetor taking compressibility into account. 10

(c) Explain the various mechanisms of lubrication bringing out their functions. What are the various desirable properties of lubricants? Explain how additives help to achieve these. 10

(d) If a fin is thin and long and tip losses are negligible, show that the heat transfer from the Fin is given by
$$Q_0 = mkA\theta_0 \tanh(ml)$$
where $m = (hP/kA)^{1/2}$. 10

(e) For a balanced heat exchanger (R = 1), show that for counterflow arrangement 10
$$\varepsilon = \frac{\text{NTU}}{\text{NTU} + 1}$$

2. (a) An ideal gas cycle consists of three reversible processes in the following sequence—(i) constant volume pressure rise, (ii) isentropic expansion to r times the initial volume and (iii) constant pressure decrease in volume. Sketch the cycle on the P-V and T-s diagrams. Show that the efficiency of the cycle is
$$\eta_{cycle} = \frac{r^{\gamma} - 1 - \gamma(r-1)}{r^{\gamma} - 1}$$
Evaluate the cycle efficiency, when $\gamma = 4/3$ and $r = 8$. 15

(b) The following expressions for the equations of state and the specific heat Cp are obeyed by a certain gas:

$$v = \frac{RT}{P} + \alpha T^2 \text{; and } C_p = A + BT + C.p$$

where α, *A, B, C* are constants. Obtain an expression for (i) the Joule-Thomson coefficient and (ii) the specific heat C_V. 15

(c) Show that the efficiency of a reversible engine is independent of the nature or amount of the working substance going through the cycle. 10

3. (a) A petrol engine with a compression ratio of 7 uses a mixture of isooctane and hexane as fuel. The pressure and temperature at the beginning of the compression process are 1 bar and 55.22 °C respectively. If the fuel-air mixture is 19.05% rich and the maximum pressure developed is 115.26 bar, evaluate the composition of the mixture (in percentage weight).

Take, C_v = 0.717 kJ/kg-K, $(C_V)_{hexane}$ = 43 MJ/kg, $(C_V)_{isooctane}$ = 42 MJ/kg and $PV^{1.31}$ is constant for the expansion and compression processes. 20

(b) (i) Explain the stages of combustion in SI and CI engines.

(ii) Discuss the phenomenon of knock in SI and CI engines.

(iii) Discuss the important qualities of SI and CI engine fuels. How are these fuels rated? 7 + 7 + 6 = 20

4. (a) What do you mean by radiation shield? Where is it used?

Two parallel discs of 1 m diameter are situated 2 m apart in the surroundings at a temperature of 20 °C. One side of a disc has an emissivity of 0.5 and is maintained at 500 °C by electrical resistance heating and the other side is insulated. The other disc is open to radiation on both sides. Determine the equilibrium temperature of the second disc and the heat flow rate from the first disc. Take, $F_{1\text{-}2}$ =0.06 (for discs).

Discuss the effect on the solution if both sides of the second disc are perfect mirrors. 3 + 17 = 20

(b) (i) Show that for laminar flow of air (Pr = 0.714), the local and average values of Nusselt number for natural convection heat transfer from or to a vertical plate are given by Nu_x = 0.378 $Gr^{1/4}$ or $\overline{Nu}_L$ =0.504 $Gr_L^{1/4}$.

(ii) A 15 cm outer diameter steel pipe lies 2 m vertically and 8 m horizontally in a large room with an ambient temperature of 30 °C. If the pipe surface is at 250 °C and the emissivity of the steel is 0.60, calculate the total rate of heat loss from the pipe to the atmosphere. Properties of air at 140 °C are ρ = 0.854kg/m^3, C_p =1.01 kJ/kg-K, k = 0.035 W/m-K, Pr = 0.684 and ν = 27.8 × 10^{-6} m^2/s. For vertical part, use the formula

$Nu = 0.13 (Gr.Pr)^{1/3}$

and for horizontal part

$Nu = 0\text{-}53(Grd.Pr)^{1/4}$ 15 + 5 = 20

SECTION—B

5. Answer any *four* parts:

(a) With the help of a schematic diagram, describe the working of a "Benson boiler'. What are its advantages? 10

(b) How can the solar energy be used to obtain refrigeration effect? Explain with a neat and clear sketch. 10

(c) Differentiate between air-conditioning and air cooling. Whether household air-conditioners are properly named? Justify your answer. Show how air washer can be used for year-round air-conditioning. 10

(d) 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

(e) What is the pressure coefficient of a centrifugal compressor? Derive

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

where φ_2 = flow coefficient. 10

6. (a) (i) Which of the two factors (increase in the upper pressure limit and decrease in the lower pressure limit) has more adverse effect on COP of a refrigeration cycle?

(ii) Show the variation of capacity factor with varying evaporator temperature in the vapour-compression system of refrigeration, the condenser pressure remaining the same.

(iii) Show the actual vapour-compression cycle on a p-h diagram and explain the various irreversibilities with the help of T-s diagram.

(iv) What is the difference between multistage refrigeration and cascade refrigeration? 4 + 4 + 8 + 4 = 20

(b) (i) Define Effective Sensible Heat Factor (ESHF). How can ADP be determined with its help?

The following data refer to a public hall:

Total sensible heat = 105 kJ/h

Total latent heat = 60000 kJ/h

The room design condition Tdb = 27 °C and φ = 60% .

The temperature rise of air (i.e., difference between the room design condition and supply air to the room) is 8 °C.

Find the SHF, show the process on the psychrometric chart and also calculate the volume of air supplied to room using approximate expression based on sensible heat and enthalpy drop.

(ii) To cut cooling loads to minimize the size of the air-conditioning plant, the energy conservation measures can help a lot. List such measures and discuss each in brief. Draw the schematic arrangement of a year-round air-conditioning system and explain its working with the help of psychrometric chart. 10 + 10 = 20

7. (a) What is a Fanno line and a Rayleigh line? Why do the end states of a normal shock lie on the Fanno line and Rayleigh line? Show these lines on a h-s diagram for various conditions. Give the physical meaning of this. 10

(b) A nozzle is designed assuming isentropic flow with an exit Mach number of 2.6. Air flows through it with a stagnation pressure and temperature of 2 MPa and 150 °C respectively. The mass flow rate is 5 kg/sec.

(i) Determine the exit pressure, temperature, area and throat area.

(ii) If back pressure at the nozzle exit is raised to 1.35 MPa, and the flow remains isentropic except for a normal shock wave, determine the exit Mach number and temperature, and the mass flow rate through the nozzle. Assume for the value of P/P_0 of 0.675, M = 0.85 and T/T_0 = 0.845 for isentropic flow. 15

(c) A centrifugal compressor with 20 m^3 of air per second at 1 bar and 15 °C is to be compressed through a pressure ratio of 1.5. The compression follows the law $pv^{1.5}$ = constant. The velocity of flow at inlet and outlet remains constant and is equal to 60 m/s.

The inlet and outlet impeller diameters are 0.6 m and 1.2 m respectively, and the speed of rotation is 5000 r.p.m.

(i) Find the blade angles at inlet and outlet of the impeller, and the angle at which the air from the impeller enters the casing.

(ii) Find the breadth of impeller blade at inlet and outlet.

It may be assumed that diffuser is not fitted and the whole pressure increase occurs in the impeller and that the blades have negligible thickness.

(iii) Sketch the velocity triangles at inlet and outlet of the impeller. 15

8. (a) Draw a neat sketch of a Heavy Water-cooled Reactor (HWR) or CANDU-type reactor power plant. Clearly show the various components. What are the advantages and disadvantages of this type of nuclear reactor over others? 10

(b) The yearly duration curve of a certain power plant can be considered a straight line from 30 MW to 10 MW. To meet this load, three turbine generator units, two rated at 15 MW each and one at 7.5 MW, are installed. Evaluate—

(i) installed capacity;
(ii) plant factor;
(iii) maximum demand;
(iv) load factor;
(iv) utilization factor. 15

(c) A turbine model of 1 : 10 develops 1.84 kW under a head of 5 m of water at 480 r.p.m. Find the power developed by the prototype under a head of 40 m. Also find the speed of the prototype. Assume efficiency of both the turbines to be same. Find and verify the specific speeds. 15