MECHANICAL ENGINEERING PAPER I

Time allowed: 3 hours **Maximum marks: 300**

INSTRUCTIONS

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Candidates should attempt Questions No. 1 and 5 which are compulsory, and any three of the remaining questions selecting at least one question from each Section.

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Neat sketches/diagrams may be drawn in the answer book itself wherever required.

SECTION – A

1.(a) The critical buckling load of a cast iron hollow cylindrical column 3 m in length when hinged at both the ends is equal to P kN. When the column is fixed at both the ends, its critical load increases to (P + 300) kN. If the ratio of external diameter to internal diameter is 1.25 and E = 100 GPa, determine the external diameter of the column. 12

(b) A stuntman drives a motorcycle around a circular vertical wall 30 m in diameter. The coefficient of friction between the tyre and wall is 0.6. Determine the minimum speed that will prevent sliding down the wall. Determine the angle also by which the motorcycle is inclined to the horizontal. 12

(c) A hypo-eutectoid plain c-steel is heated to 1540°C and then cooled slowly to 725°C. What is the percentage of ferrite and austenite in steel after the process? Mark the process on Iron-carbon diagram. 12

(d) An I-beam with the following dimensions is subjected to a shearing force of 20 kN.

Flange: breadth = 50 mm, thickness = 5.5 mm

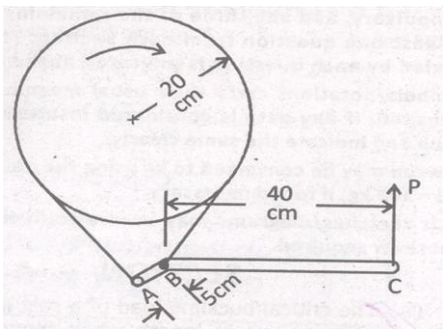
Web: depth = 109 mm, thickness = 3.5 mm

Area of cross-section = 9.4 X $10^4 mm^2$

M.I. = I_{xx} = 220 X $10^4 mm^4$.

Calculate the value of the transverse shear stress at the neutral axis *x-x* and at the top of the web. 12

(e) A band brake is used to stop a machine. The brake band is in contact with the brake drum through an angle of 250°. The coefficient of the friction is 0.3. Determine the force P required to develop the braking torque of magnitude 400 Nm. The arrangement is shown in the above figure. 12



2.(a) (i) 1. Define interference in involute gears.

2. How do you prevent interference?

3. Determine the minimum number of teeth required on a pinion, in order to avoid interference which is to gear with an equal wheel. The pressure angle is 20° and a standard addendum of 1 module for the wheel may be assumed. 2+3+10=15

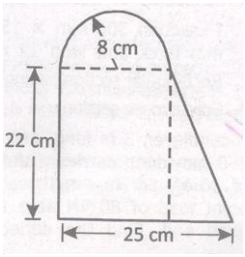
(ii) 1. Sketch the arrangement of a reverted gear train comprising of gears A and D mounted on co-axial driving and driven shafts, respectively. Gears B and C are mounted on a parallel counter shaft to mesh with gears A and D, respectively.

2. The speed ratio (driving speed + driven speed) in the reverted gear train of above arrangement is to be 14. The module pitch of gears A and B are 3.125 mm and of gears C and D are 2.5 mm. Calculate the suitable numbers of teeth for the gears. No gear is to have less than 24 teeth. The centre distance between the counter-shaft and driving shall is 200 mm. 5+10=15

(b) A cylinder having mass 40 kg is hung by means of cables AB and AC which are attached to the top of the vertical wall. The distance of points B and C on the wall from a line along the wall parallel to the axis of cylinder are 8 m and 10 m respectively. A horizontal force along the line perpendicular to the wall has been applied at the cylinder which pulls it by a distance 1.2 m away from the wall. The point A is on the cylinder and it is 10 m below BC. Determine tension in each cable and the force applied at the cylinder. 20

(c) (i) How are the thermosetting plastic products processed?

(ii) Name two polymerization processes. 10



3.(a) Compute second moment of area of the plane lamina shown in the above figure about an axis parallel to the base and passing through the centroid. 20

(b) (i) A hollow shaft having an inside diameter 50% of its outer diameter is to replace a solid shaft transmitting the same power at the same speed. Calculate the percentage saving in material if the material to be used is also the same. 10

(ii) A close coiled spring has coil diameter to wire diameter ratio of 6. The spring deflects 30 mm under a load of 500 N and the maximum shear stress is not to exceed 350 MPa. Find the diameter and length of wire required. Modulus of rigidity of wire material = 80 GPa. 10

(c) Compare the main characteristics with regard to their hardening and magnetic properties of various stainless steels. 10

(d) Four masses m_1, m_2, m_3 and m_4 are 160 kg, 225 kg, 200 kg and 312 kg, respectively. The corresponding radii of rotation are 0.25 m, 0.2 m, 0.3 m and 0.25 m, respectively. The angles between the successive masses are 45°, 75° and 135°. Find the position and magnitude of the balance mass required, if its radius of rotation is 0.25 m. Presume that all masses including the balance mass rotate in the same plane. 10

4.(a) (i) Compare the flexural strengths of the following three beams of equal weight.

1. I-section 300 mm x 150 mm with flanges 20 mm thick and web 12 mm thick.
2. Rectangular section having depth twice the width.
3. Solid circular section. 15

(ii) A cantilever, 3 m long, and of symmetrical section 250 mm deep carries a uniformly distributed load of 30 kN per m run throughout, together with a point load of 80 kN at a section 12 m from the fixed end. Find the deflection at the free end. Take, E = 200 GPa and I = 54,000 cm^4. 15

(b) (i) Discuss criteria of stability for spring controlled governors. 5

(ii) The sleeve arm and the ball arm of a Hartnell governor are 9 cm and 10 cm long respectively. At mean position of the sleeve, the equilibrium speed is 300 rpm and balls rotate at the radius of 12 cm. The mass of each ball is 2 kg and the sleeve movement is ± 2 cm from the mean position. The minimum speed is 96% of the mean speed. Determine the stiffness of the spring and the maximum speed of the governor. 15

(c) A particle has initial velocity of 30 m/s towards the right at 30° with the horizontal. The retardation along horizontal axis is 1 m/s^2 and along upward vertical axis is 6 m/s^2. Determine the horizontal distance covered until the particle reached a point 30 m below its original elevation. 10

SECTION - B

5.(a) Define "tool life" and list down four methods for quantitative measurement of tool life. 12

(b) (i) With the help of an example, clarify the function of a clamp in a fixtures

(ii) Sketch a cam type damp and suggest its two applications. 12

(c) Explain how flatness of a surface is measured with an optical flat. 12

(d) Following table shows the predecessor relationship of the activities in an assembly line. The output is 200 units per day and operating time is 450 minutes per day. Using the most successors rule to assign tasks to work centre and longest work time rule as a tie breaker,

(a) Group the tasks into work centers and

(b) Compute balance efficiency, idle time and balance delay. 12

Task	*Predecessor*	*Time(sec)*
A	None	40
B	A	20
C	None	60
D	C	40
E	D	30
F	None	35
G	None	45
H	G	60
I	H	40

(e) What are the principles of motion economy related to work place? If these principles are adopted in design of work place, what will be the advantages? **12**

6.(a) (i) A hole is to be drilled in a high-strength copper alloy workpiece with a 10 mm bit at a feed of 0.2 mm/rev. The spindle speed is 500 rpm. Estimate the material removal rate and the torque required for this operation.
Take specific energy value of the work material as 1.9 w.s./mm^3. **10**

(ii) Discuss in brief the mechanism involved in grinding wheel wear. Why aluminum oxide and cubic boron nitride abrasives are suitable for grinding of steel, but silicon carbide or diamond are not? **20**

(b) (i) Explain in brief, with sketches, the pressure and vacuum gap flushing techniques used in EDM. **10**

(ii) Which one of the above will result in a more accurate cavity? Give reason. **5**

(iii) Also discuss how the gap flushing conditions may be improved while drilling small holes. **5**

(c) Find the sequence that minimizes the total elapsed time required to complete the following jobs. Each job is processed in the order ACB.

	Processing times in hours				
Job No.	1	2	3	4	5
Machine A	5	7	6	9	5
Machine B	3	7	5	6	7
Machine C	2	1	4	5	3

Determine the sequence of the jobs, make span and idle time of machines. Illustrate the method of solution and assumptions taken. 10

7.(a) (i) What is understood by the statement "Process under statistical control"?

(ii) State the conditions when the process is considered statistically out of control on the basis of theory of runs?

(iii) What is JIT? What are its objectives and key elements? Illustrate in brief the single card Kanban and two card Kanban systems. **5+10+15=30**

(b) (i) Compare the process capabilities of Shielded Metal-Arc Welding (SMAW) and Submerged Arc Welding (SAW) processes. **15**

(ii) How thick jobs (>20 mm) may be welded by SMAW process? **5**

(c) What are the objectives of an efficient facility layout? What are the principles to be adopted to achieve these objectives? Compare product, process and cellular layout. **10**

8.(a) (i) What is the significance of (1) angle of nip, and (2) angle of bite during rolling operation? How are they related to roll friction? 10

(ii) Classify the process of extrusion with the sketches. Enumerate the conditions under which central burst may occur. Where does a 'pipe' occur? 15

(iii) What is "friction hill"? 5

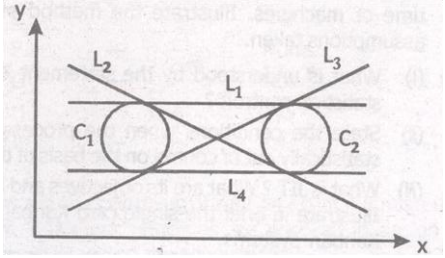
(b) (i) A firm manufactures a product whose selling price Rs. 10. It has a capacity of 10,000 units. The variable costs are Rs. 2.50per unit. The fixed costs are estimated at Rs. 30,000 up to 50 % capacity utilization, Rs. 36,000 above 50 % level, and Rs. 42,000 if the utilization is 80 % or above.

a. What will be the operating profit of the firm at 70%, 80% and 90% utilization?

b. What is the lowest level of activity at which the firm can make a profit of Rs18,000?

(ii) What is detailed work factor system of PMT? List the common areas of its application. 10 + 10 = 20

(c) In the above figure define the lines L_1, L_2, L_3 and L_4 in the APT language. 10



MECHANICAL ENGINEERING PAPER-II

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SECTION - A

1.(a) Air enters a steady flow adiabatic turbine at 1600 K and exhausts to atmosphere at 1000 K, P_{atm} = 1 bar. If the second law efficiency is 85%, what is the turbine inlet pressure? What is irreversibility during expansion process? Given, surrounding temperature is 25°C. 12

Properties of air

T, [K]	*h*, [kJ/kg]	*s*,[kJ/kg-K]
1000	1046	8.6905
1600	1757	8.1349

(b) A very long AISI 316 stainless steel (K = 14 W/m-K) rod 5 mm in diameter has one end maintained at 100°C. The surface of the rod is exposed to ambient air at 30°C with average convective heat transfer coefficient of 50 W/m^2-K. Neglecting radiation heat transfer, estimate how long the rod must be to treat it as "infinitely long" to yield a reasonable accurate estimation of heat loss. If the rod is made of copper (K = 350 W/m-K, will the length be different? How much will it be and why? Compare the heat transfer rates for both the rods. The analysis may be based on fin tip heat loss alone. 12

(c) (i) What is meant by firing order in internal combustion engines? 2

(ii) What are the firing orders used in 4 and 6 cylinder inline engines? 4

(iii) What are the three purposes of firing order in V engines? 6

(d) A boiler receives a flow of 5000 kg/hr liquid water at 5 MPa, 20°C and it adds energy to the flow to exit state of 450°C, 4.5 MPa. Determine the necessary minimum pipe flow area for inlet and outlet pipes. The velocity of water is maintained under 20 m/s. If this boiler is to operate on Moon, discuss two major design changes in this type of boiler.

Given properties of water:

ν_{inlet} =0.001m^3/kg; ν_{exit} = 0.0716 m^3/kg. 12

(e) Nitrogen flows in a pipe with velocity 300 m/s at 500 kPa, 300°C. What is availability with respect to an ambient at 100 kPa and 20°C? 12

2.(a) (i) Explain briefly the design and off-design characteristics of an axial flow compressor. 10

(ii) Explain the phenomena of surge and choking in centrifugal compressors. 10

(b) The volumetric heat generation rate in a cylindrical nuclear reactor fuel rod of 5 cm diameter is 5 X 10^7 W/m^3. Under steady state operating condition, the temperature

distribution in the rod is $t = 800 - 4.167 \times 10^5 r^2$.Density, specific heat and thermal conductivity of rod material are 1100 kg/m^3, 800 J/kg-K and 30 W/m-K respectively.

What are the rates of heat transfer per unit length of the rod at the centre line (axis) and at the rod surface?

If the reactor power level is suddenly increased to 10^8 W/m^3, what are the initial time rate of change of temperature at the centre line and at the surface? 20

(c) A stream of air flows in an insulated tube of constant cross-sectional area of 0.9 m^2. At a section1, the pressure is 0.6 bar, temperature is 22°C and mass velocity is 150 kg/s-m^2. The pressure in space in which tube exhausts is so low that choking condition prevails. Determine,

(i) Mach no. at section 1.

(ii) Mach no., temperature and pressure at the exit of tube,

(iii) Total force exerted in axial direction which must be exerted to hold the tube stationary.

Given, R = 287 J/kg-K; γ = 1.4

Fanno line (Adiabatic constant area flow with friction) table γ = 1.4

M	$\frac{T}{T^*}$	$\frac{e}{e^*}$	$\frac{P}{P^*}$	$\frac{P_0}{P_0{}^*}$	$\frac{I}{I^*}$	$\frac{4fL_{max}}{D}$
0.58	1.124	0.615	1.828	1.213	1.121	0.576
0.60	1.119	0.635	1.763	1.188	1.105	0.491
0.62	1.114	0.654	1.703	1.166	1.091	0.417
0.64	1.109	0.674	1.646	1.145	1.079	0.353

3.(a) A small power plant produces 25 kg/s steam at 3 MPa,600°C in the boiler. It cools the condenser with ocean water coming in at 12°C and returned at 15°C. Condenser exit is 45°C. Find

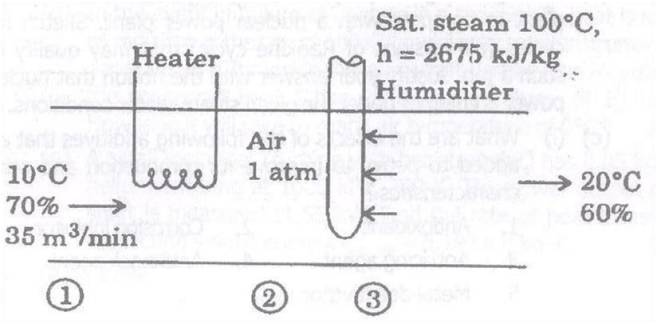
(i) Net power output.

(ii) Required mass of ocean flow water. 20

$$Given: h_{x=0}^{45^\circ C} = 188.4\ kj/kg;$$
$$V_1 = 0.001\ m^3/kg;\ P_{sat}^{45^\circ C} = 9.59\ kPa;\ ;$$
$$h_{3\ MPa}^{600^\circ C} = 3682\ kj/kg;\ S_{3\ MPa}^{600^\circ C} = 7.50\ kj/kg - K$$

(b) (i) A closed cylindrical vessel 0.2 m in diameter and 1.2 m long is filled with water upto a height of 0.8 m from the bottom. Find the speed of the vessel about its vertical axis, when the axial depth of water is zero. 10

(ii) How would you define the strength of shock wave? What do you mean by weak shock? Also find the expression for the strength of shock in terms of density ratio. 10



(c) An air-conditioning system (see figure) operates at a total pressure of 1 atm. It consists of a heating section and a humidifier that supplies wet steam (saturated) at 100°C. Air enters the heating section at 10°C and 70 percent relative humidity at the rate of 35 m^3/min. It leaves at 20°C and relative 60% relative humidity, Determine

(i) temperature and relative humidity of air when it leaves the heating section,
(ii) the rate of heat transfer to the heating section, and
(iii) The rate at which water is added to the air in the humidifying section.
Also draw skeleton Psychometric chart representation showing the process. 20

4.(a) A steel strip emerges from hot roll section of a steel mill at a constant speed of 0.1 m/s and a temperature of 500°C. The length, width and thickness of the steel strip are 10 m, 1 m and 0.003 m respectively. Air at a mean velocity and free stream temperature of 20 m/s and 20°C respectively flows transversely over the strip. Density, specific heat and emissivity of steel strip, respectively, are 7850 kg/m^3,620 J/kg and 0.7. The thermal conductivity, kinematic viscosity and Prandtl number for air at 20°C are respectively 0.044 W/m-K, 4.5 x 10^{-5} m^2/s and 0.68. Neglect the variation in strip temperature across its width and thickness.

(i) Write the governing equation for the temperature distribution along the length of the strip.
(ii) Neglecting radiation from the steel strip, derive an expression for the temperature of steel strip.
(iii) Neglecting radiation from the steel strip, calculate the steel strip temperature at the trailing edge.

The following correlation for convection heat transfer may be used:

$$\overline{Nu} = 0.037 Re_{x-l}^{0.8} Pr^{1/3}$$

Symbols have the usual meaning. 20

(b) A designer is given the job of designing a steam based power plant to compete with a nuclear power plant. Sketch five cycles (all versions of Rankine cycle) that may qualify for such a job. Justify your answer with the notion that nuclear power is cheaper under the given steam-water conditions. 20

(c) (i) What are the effects of the following additives that are added to petrol to improve its combustion and other characteristics?

1. Antioxidant;
2. Corrosion inhibitor;
3. Anti icing agent;
4. Antiknock agent
5. Metal deactivator 10

(ii) What are the measures required for the reduction of the following emissions from diesel engine?

1. Particulate Emission
2. Smoke Emission
3. NOx Emissions
4. HC Emissions
5. SOx Emissions 10

SECTION - B

5.(a) With the help of a neat sketch explain the concept of a flow net. Clearly mention the various assumptions made. Also explain the uses of flow net. 12

(b) The average friction coefficient, when an incompressible fluid flows over a stationary flat surface with free stream velocity of 10 m/s, is 0.008. The average temperature of the plate and free stream fluid temperature are respectively at 120°C and 20°C

respectively. Fluid properties known: density = 0.88 kg/m^3 and specific heat = 1001 J/kg-K, Pr = 0.65.

Estimate the average rate of heat transfer per unit area of the plate. Flow over the plate is laminar. 12

(c) (i) Draw the actual p-v diagram of a four stroke Otto cycle engine and indicate the pumping loss by hatching. 4

(ii) Explain four deviations of the actual p-v diagram from the hypothetical p-v diagram of four stroke Otto cycle engine. 8

(d) In the event of failure of heaters in a spacecraft, heat is lost by radiation at the rate of 100 kJ/hr while electronic instruments generate 75 kJ/hr inside the spacecraft. Initially the air inside the spacecraft is at 1 bar, 25°C with a volume of 10 m^3. How long it will take to reach air temperature of 0°C? 12

(e) A small expander (turbine with heat transfer) has 0.05 kg/s helium entering at 1000 kPa, 300 K. The power output on shaft is measured at 55 kW. Find the rate of heat transfer neglecting kinetic energy. $C_{P,\,He}$ = 5.193 kJ/kg-K. 12

6.(a) Derive

$$\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$$

$$\left(\frac{\partial P}{\partial T}\right)_V = \left(\frac{\partial S}{\partial V}\right)_T$$

$$\left(\frac{\partial V}{\partial T}\right)_P = \left(\frac{\partial S}{\partial P}\right)_T$$

from the first principles. Explain any assumptions needed here. 20

(b) A tubular gas heater heats air flowing at the rate of 5.5 kg/s from 20°C to 75°C using saturated steam condensing at 1.3 bar (saturation temperature, t_{sat}= 107°C). It is proposed to double the flow rate of air to heat the same for the same rise in temperature in the same gas heater. One way of doing this is to increase the condensing pressure of saturated steam. What should be the pressure needed if the overall heat transfer coefficient remains the same for both the operating conditions? Specific heat of air =1.005 kJ/kg-K.

For steam, the following pressure and the corresponding saturation temperature are known: 20

P(bar	2	3	4	5	6	7	8	9
t_{sat}(°C)	120.2	133.5	143.6	151.8	158.8	165.0	170.4	175.4

(c) (i) What is the purpose of shrouding the inlet valve in compression ignition engines? 4

(ii) With the help of cross-section figures and schematics show the shrouded inlet valve and masked cylinder head for producing net in - cylinder angular momentum viz., swirl in compression ignition engine. 12

(iii) Give two disadvantages and their effects of open combustion chambers. 4

7.(a) Draw the schematic arrangement of a simple cycle with intercooled and heat exchanger and explain briefly the working principle. Also draw the P-V and T-S diagrams of the cycle. Further, derive expressions for specific work output and the efficiency of a simple cycle with intercooled and heat exchanger. Draw their trends as a function of pressure ratio. 20

(b) Explain how the Diesel Fuel is rated by the following with their salient features:

(i) Critical Compression Ratio Method — CCR 8

(ii) Calculated Cetane Index — CQ 4

(iii) Diesel Index 8

(c) A commercial refrigerator with refrigerant 134a as the working fluid keeps a space cooled at -30°C. It rejects heat to cooling water that enters the condenser at 18°C and at the rate of 0.25 kg/s and it leaves at 26°C. The refrigerant enters the condenser at 1.2 MPa and 65°C and it leaves at 42°C. The inlet state of compressor is 60 kPa and -34°C. It gains a net heat of 450 W from the surroundings. Sketch T-S diagram and determine,

(i) refrigeration toad

(ii) COP

(iii) Theoretical maximum refrigerant toad for the same power input to the compressor.

Given Properties: $h_{-34°C}^{60\ KPa} = 230.03\ kJ/kg;$

$h_{65°C}^{1200\ KPa} = 295.16\ kJ/kg;$

$h_{42°C}^{1200\ KPa} = 111.23\ kJ/kg;\ x_{111.23}^{60\ KPa} = 0.47$

h_{water}, 18°C= 75.4 kJ/kg; h_{Water},26 ºC = 108.9 kJ/kg

8.(a) An electric furnace consisting of two flat surface heaters, top and bottom, is used to heat treat a coating that is applied to both surfaces of a thin metal plate inserted midway between the heaters. The heaters and the plate are 2 m x 2 m on a side, and each heater is separated from the plate by a distance of 0.5 m. Each heater is well insulated on its back side and has an emissivity of 0.9 at its exposed surface. The plate and side walls have emissivities of 0.6 and 0.3 respectively. Under steady operating conditions, both heaters are at 800 K while the side walls are at 400 K. View factor between the heaters and the plate is 0.62.

(i) Sketch the system and its equivalent thermal network and label all pertinent resistances and potentials.

(ii) Calculate the associated resistances and driving potentials.

(iii) Calculate the required electrical power. 20

(b) A low temperature power plant operates with a refrigerant maintaining - 20°C in the condenser, a pressure of 3 Mpa and superheat of 80°C. There is one open feedwater heater operating at 800 kPa with an exit as saturated liquid at 0°C.

(i) Sketch the schematic of this plant.

(ii) Sketch the corresponding T - S diagram.

(iii) Set up equations only to compute extraction fraction of the flow out of turbine and the turbine work per unit mass flowing through boiler.

(iv) Indicate in your answer which refrigerant properties are needed. 20

(c) Discuss briefly how the following alternate fuels considered for Compression Ignition Engines i.e., Diesel Engines compare with respect to introduction into the engine, calorific value, part load and full load operation and safety aspect:

(i) Biogas produced from cow dung, water hyacinth, algae and municipal wastes

(ii) Hydrogen Gas

(iii) Ethyl Alcohol

(iv) Cashewnut Shell Liquid (CNSL) 4 x 5 = 20