CCE(M)/MCH–I/10/2024

MECHANICAL ENGINEERING

(PAPER—I)

Time : 3 hours] [Full Marks : 250

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

(i) There are **eight** questions divided in **two Sections**.

(ii) Candidate has to attempt **five** questions in all.

(iii) Question Nos. **1** and **5** are compulsory and out of the remaining, **three** are to be attempted choosing at least **one** question from each Section.

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

(v) Word limit in questions, wherever specified, should be adhered to.

(vi) 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.

SECTION—A

1. Answer *any* **five** of the following questions : 10×5=50

(a) What is fit? Briefly explain different types of fits with suitable examples.

(b) Explain the necessity of heat treatment for steels. Describe the process of quenching.

(c) In an orthogonal machining with a single point cutting tool of rake angle 10°, the uncut chip thickness and the chip thickness are 0.125 mm and 0.22 mm, respectively. Using Merchant's first solution for the condition of minimum cutting force, find out the coefficient of friction at the chip tool interface.

(d) A single degree of freedom system having mass 1 kg and stiffness 10 kN/m initially at rest is subjected to an impulse force of magnitude 5 kN for 10^{-4} seconds. Find out the amplitude of the resulting free vibration.

(e) A flywheel of a steam engine weighs 2000 N and has a radius of gyration of 76 cm. The starting torque of the steam engine is 130 kg-m and is assumed to be constant. Determine the angular acceleration of the flywheel along with the speed and kinetic energy after 10 s.

(f) Show that for a beam subjected to pure bending, the neutral axis coincides with the centroid of the cross-section.

(g) A particle is projected at such an angle with the horizontal that the horizontal range is four times the greatest height attained by the particle. Find the angle of the projection.

2. Answer the following questions :

(a) In a tensile test on a steel specimen 12 mm in diameter and 14 cm long between gauge points, the elongation was found to be 5.89×10^{-3} cm when a load of 1000 N was applied. In a torsion test on the same specimen, the angle of twist was found to be 0.47° on a length of 14 cm under a twisting moment of 100 N-m. Find out the values of Young's modulus, modulus of rigidity and Poisson's ratio. 20

(b) A bolt is under an axial thrust of 9.6 kN together with a transverse force of 4.8 kN. Calculate its diameter according to —

(i) maximum principal stress theory;

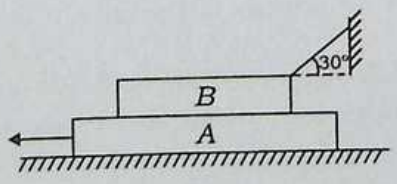
(ii) maximum shear stress theory.

Assume a factor of safety = 3, Yield strength of material of bolt = 270 N/mm^2 and Poisson's ratio = 0.3. 15

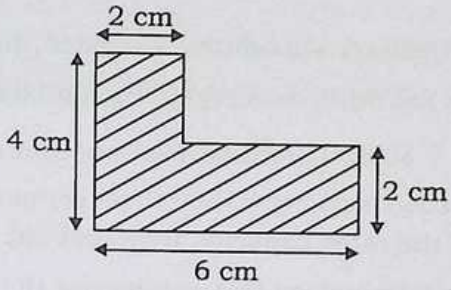
(c) Derive an expression for the major and minor principal stresses on an oblique plane when the body is subjected to direct stresses in two mutually perpendicular directions accompanied by a shear stress. 15

3. Answer the following questions :

(a) Two blocks *A* and *B* of weight 4 kN and 2 kN, respectively are in the equilibrium position as shown in the figure. Assuming that the coefficient of friction between two blocks as well as between block and floor is 0.25. Find the force required to move the block *A*. 20



(b) Locate the centroid of the shaded area. 15



(c) Find the moment of inertia of a rectangle having dimensions a and b with respect to a diagonal. 15

4. Answer the following questions :

(a) Discuss the working of ultrasonic machining along with its application, advantages and disadvantages. 20

(b) What are the functions of the dielectric fluid and servo system in electro-discharge machining? 15

(c) Electrochemical machining operations are performed with tungsten as the tool and copper and aluminium as two different workpiece materials. Properties of copper and aluminium are given in the table below. 15

Material	Atomic mass	Valency	Density (g/cm^3)
Copper	63	2	9
Aluminium	27	3	2.7

Ignore over potentials and assume that current efficiency is 100% for both the workpiece materials. Under identical conditions, if the material removal rate of copper is 100 mg/s, then find out the material removal rate of aluminium.

SECTION—B

5. Answer *any* **five** of the following questions : 10×5=50

(a) Prove that the shear stress distribution across a rectangular section is parabolic.

(b) What are ceramic materials? Explain briefly the properties and application of ceramic materials.

(c) State how the properties of alloy steels are affected by the following alloying elements :

Nickel, Chromium, Manganese, Vanadium, Tungsten, Silicon, Carbon

(d) A manufacturer has the following data regarding a product :

Fixed cost per month = ₹ 50,000, Variable cost per unit = ₹ 200, Selling price per unit = ₹ 300, Production capacity = 1500 units per month. If the production is carried out at 80% of the rated capacity, then find out the monthly profit.

(e) Develop a figure of gear terminology and summarize the following :

(i) Pitch circle, *(ii)* Addendum and Dedendum, *(iii)* Circular pitch, *(iv)* Diametral pitch and *(v)* Module

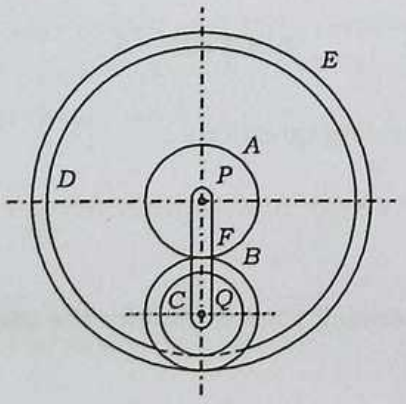
(f) A single point cutting tool with 0° rake angle is used in an orthogonal machining process. At a cutting speed of 180 m/min the thrust force is 490 N. If the coefficient of friction between the tool and the chip is 0.7, find out the power consumption of the machining operation.

(g) Differentiate between the flywheel and a governor. An engine's maximum fluctuation of kinetic energy has been calculated to be 2600 J. Assuming that the engine runs at an average speed of 200 r.p.m., find a flywheel's moment of inertia to keep the speed fluctuation within ±0.5%.

6. Answer the following questions :

(a) Differentiate between a machine and a mechanism. Evaluate the relative velocity equation of a rigid link about a fixed centre with a neat sketch. Categorize and illustrate the three types of constrained motion. 20

(b) A compound epicyclic gear having gears *A*, *D* and *E* are free to rotate on the axis *P*. The compound gears *B* and *C* rotate together on the axis *Q* at the end of arm *F*. All the gears have equal pitch. The number of external teeth on the gears *A*, *B* and *C* are 18, 45 and 21 respectively. The gears *D* and *E* are annular. The gear *A* rotates at 90 r.p.m. in the anti-clockwise direction and the gear *D* rotates at 450 r.p.m. clockwise. Evaluate the speed and direction of the arm and gear *E*. 15



(c) What is 'whirling speed' of shafts? What are the factors that affect it and how to avoid? Consider a shaft of length 1.2 m and diameter 20 mm is fixed at one end and free at the other. The density of the shaft material is 7800 kg/m^3 and Young's modulus (E) is 200×10^9 N/m^2. Find the whirling speed (first critical speed) of the shaft. 15

7. Answer the following questions :

(a) A firm uses a turning centre, a milling centre and a grinding machine to produce two parts. The table below provides the machining time required for each part and the maximum machining time available on each machine. The profit per unit on parts I and II are ₹ 40 and ₹ 100 respectively. Find out the maximum profit per week of the firm. 20

Type of Machine	Machining time required for the machine part (minutes)		Maximum machining time available per week (minutes)
	I	II	
Turning Center	12	6	6000
Milling Center	4	10	4000
Grinding machine	2	3	1800

(b) What are quality circles? Enumerate Total Quality Management (TQM) principles. How does TQM differ from Total Quality Circles? 15

(c) What is JIT approach? State its benefits and challenges. 15

8. Answer the following questions :

(a) What is tool life? What are the main factors that influence the tool life? A tool life of 80 minutes is obtained at a speed of 30 m/min and 10 minutes at 60 m/min. Determine the tool life equation and cutting speed for 4 minutes of tool life. 20

(b) What is the difference between a jig and fixture? A taper pin of length 200 mm has a taper length of 125 mm. The smaller diameter of the taper is 25 mm and the larger diameter is 30 mm. Determine *(i)* the taper in mm/metre and degrees and *(ii)* the tailstock set over. 15

(c) What is OR model? What are its key components in reference to manufacturing system?

Solve the following LPP using graphical method : 15

Maximize $Z = 3x_1 + 2x_2$

subject to $5x_1 + x_2 \geq 10;$

$x_1 + x_2 \geq 6;$

$x_1 + 4x_2 \geq 12;$

$x_1, x_2 \geq 0$

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MECHANICAL ENGINEERING

(PAPER—II)

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SECTION—A

1. Answer *any* **five** of the following questions : 10×5=50

(a) For a closed system undergoing a polytropic reversible process, derive the expression for heat transfer.

(b) What is critical thickness of insulation? Derive the expression for critical thickness of insulation for a solid cylinder.

(c) What is the delay period or ignition lag in a C.I. engine? Mention various factors and their effects on the delay period.

(d) Explain different parts and working principle of a Cochran Boiler with a sketch.

(e) What are the factors affecting the performance of a vapour compression refrigeration system? Explain each of them.

(f) For a compressible flow through a convergent nozzle, derive the condition of pressure ratio for maximum mass flow rate through the nozzle.

(g) Explain the basic difference between conduction heat transfer and convection heat transfer.

2. Answer the following questions :

(a) 1 kg of air initially at 8 bar pressure and 380 K expands polytropically ($n = 1.2$) until the pressure is reduced to one-fifth value. Calculate —

(i) final specific volume and temperature;

(ii) change of internal energy, work done and heat interaction;

(iii) change in entropy.

Take $R = 0.287$ kJ/kgK and $\gamma = 1.4$. 20

(b) A reversible heat pump is used to maintain a temperature of 0°C in a refrigerator when it rejects the heat to the surroundings at 25 °C. If the heat removal rate from the refrigerator is 1440 kJ/min, determine the C.O.P. of the machine and the work input required. If the required input to run the pump is developed by a reversible engine which receives heat at 380 °C and rejects heat to the atmosphere, then determine the overall C.O.P. of the system. 15

(c) For a normal shock wave in air, the Mach number is 2. If the atmospheric pressure and air density are 26.5 kN/m^2 and 0.413 kg/m^3 respectively, determine the flow conditions before and after the shock wave. Take $\gamma = 1.4$. 15

3. Answer the following questions :

(a) A fluid at 25 °C flows over a flat plate with a velocity of 0.1 m/s. If the plate is 4.5 m long and is maintained at a uniform temperature of 95 °C, calculate the following using the exact solution : 20

(i) The hydrodynamic and thermal boundary layer of thickness on one side of the plate

(ii) The total drag force per unit width on one side of the plate

(iii) The local heat transfer coefficient at the trailing edge

(iv) The heat transfer rate

The properties of the fluid at mean film temperature (60 °C) are : $\rho = 956.8$ kg/m^3, $\alpha = 7.2 \times 10^{-8}$ m^2/s, $k = 0.213$ W/m°C, $\nu = 0.65 \times 10^{-4}$ m^2/s.

(b) A copper bar of cross-section 80 mm × 6 mm is working as an electric conductor. One face and both the edges of the bar are insulated. When a current of 5000 A flows through the conductor, the bar face has constant temperature of 45 °C. Determine the maximum temperature in the bar and its location. Assume, thermal conductivity of copper $k = 370$ W/m°C, resistivity of copper = 2×10^{-8} Ωm. 15

(c) 16.5 kg/s of the product at 650 °C ($c_p = 3.55$ kJ/kg °C), in a chemical plant is to be used to heat 20.5 kg/s of the incoming fluid from 100 °C ($c_p = 4.2$ kJ/kg °C). If the overall heat transfer coefficient is 0.95 kW/m^2 °C and the installed heat transfer surface is 44 m^2, calculate the fluid outlet temperatures for the counterflow and parallel flow arrangements. 15

4. Answer the following questions :

(a) A diesel engine working on a dual combustion cycle has a stroke volume of 0.0085 m^3 and a compression ratio of 15. The fuel has a calorific value of 43890 kJ/kg. At the end of the suction, the air is at 1 bar and 100 °C. The maximum pressure in the cycle is 65 bar and the air fuel ratio is 21 : 1. Find the thermal efficiency for the ideal cycle. Assume C_p = 1.0 kJ/kg K and C_v = 0.71 kJ/kg K. 20

(b) Show that the compression ratio for the maximum work to be done per kg of air in an Otto cycle between upper and lower limits of absolute temperatures T_3 and T_1 is

$$r = \left(\frac{T_3}{T_1}\right)^{\frac{1}{2(\gamma-1)}}$$

15

(c) An engine with a 200 mm cylinder diameter and 300 mm stroke works on a theoretical diesel cycle. The initial pressure and temperature of air used are 1 bar and 27 °C. The cutoff is 8% of the stroke. Determine —

(i) pressures and temperatures at all salient points;

(ii) theoretical air standard efficiency;

(iii) mean effective pressure.

Assume that the compression ratio is 15 and the working fluid is air. Consider all the conditions to be ideal. 15

SECTION—B

5. Answer *any* **five** of the following questions : 10×5=50

(a) Explain the surging and chocking of a centrifugal compressor.

(b) What is Logarithmic Mean Temperature Difference (LMTD)? Derive LMTD for a single-pass parallel flow heat exchanger.

(c) What are the merits and demerits of air and water cooling systems of IC engines?

(d) Mention three alternative fuels for IC engines. Write the advantages and disadvantages of each of them.

(e) What is compounding in a steam turbine? Explain different methods of compounding in steam turbine.

(f) What is relative humidity (ϕ)? Show that relative humidity, $\phi = 1.6\ W \frac{p_a}{p_{vs}}$.

Where p_a = partial pressure of dry air, p_{vs} = partial pressure of water vapour when air is fully saturated and W = specific humidity.

(g) Compare centrifugal and reciprocating compressors.

6. Answer the following questions :

(a) A steam power plant equipped with regenerative as well as reheat arrangements is supplied with steam to the H.P. turbine at 80 bar, 470 °C. For feed heating, a part of steam is extracted at 7 bar and the remainder of the steam is reheated to 350 °C in a reheater and then expanded in an LP turbine down to 0.035 bar. Determine — 20

(i) amount of steam bled off for feed heating;

(ii) amount of steam supplied to L.P. turbine;

(iii) heat supplied in the boiler and reheater;

(iv) cycle efficiency;

(v) power developed by the system.

The steam supplied by the boiler is 50 kg/s.

Enthalpy of steam entering HP turbine	3315 kJ/kg	Enthalpy of steam entering LP turbine	3165 kJ/kg
Enthalpy of steam entering regenerator	2716 kJ/kg	Enthalpy of steam entering condenser	2236 kJ/kg
At 7 bar, h_f = 697.1 kJ/kg			
At 0.035 bar, h_f = 101.9 kJ/kg			

(b) Superheated steam at a pressure of 10 bar and 400 °C is supplied to a steam engine. Adiabatic expansion takes place to release point at 0.9 bar and it exhausts into a condenser at 0.3 bar. Neglecting clearance, determine the following for a steam flow rate of 1.5 kg/s : 15

(i) Quality of steam at the end of expansion and the end of constant volume operation

(ii) Power developed

(iii) Specific steam consumption

(iv) Modified Rankine cycle efficiency

At 10 bar, 400 °C,
h = 3263.9 kJ/kg, v = 0.307 m^3/kg, s = 7.465 kJ/kgK
At 0.9 bar,
T_s = 96.7 °C, h_g = 2670.9 kJ/kg, s_g = 7.3954 kJ/kgK, v_g = 1.869 m^3/kg
At 0.3 bar,
h_f = 289.3 kJ/kg, v_g = 5.229 m^3/kg

(c) A tank fitted with convergent nozzle contains air at a temperature of 20 °C. The diameter at the outlet of the nozzle is 25 mm. Assuming adiabatic flow, find the mass flow rate of air through the nozzle to the atmosphere when the pressure in the tank is

(i) 140 kN/m^2

(ii) 300 kN/m^2

Take for air, R = 287 J/kg.K, γ = 1.4, Barometric pressure = 100 kN/m^2. 15

7. Answer the following questions :

(a) A food storage locker requires a refrigeration system of 2400 kJ/min capacity at an evaporator temperature of 263 K and a condenser temperature of 303 K. The refrigerant used is Freon-12 and is subcooled by 6 °C before entering the expansion valve and the vapour is superheated by 7 °C before leaving the evaporator coil. The compression of refrigerant is reversible adiabatic. The refrigeration compressor is a two-cylinder, single-acting with a stroke equal to 1.25 times the bore and operates at 1000 r.p.m.

Properties of Freon-12

Saturation Temp., K	Absolute pressure, bar	Sp. volume of vapour, m^3/kg	Enthalpy, kJ/kg		Entropy, kJ/kgK	
			Liquid	Vapour	Liquid	Vapour
263	2.19	0.0767	26.9	183.2	0.1080	0.7020
303	7.45	0.0235	64.6	199.6	0.2399	0.6854

Take : Liquid specific heat = 1.235 kJ/kgK, Vapour specific heat = 0.733 kJ/kgK

Determine —

(i) refrigerating effect per kg;

(ii) mass of refrigerant to be circulated per minute;

(iii) theoretical piston displacement per minute;

(iv) theoretical power required to run the compressor, in kW;

(v) heat removed through the condenser per minute;

(vi) theoretical bore and stroke of compressor. 20

(b) Explain different psychrometric processes with proper diagrams. 15

(c) A simple vapour compression plant produces 5 tonnes of refrigeration. The enthalpy values at inlet to compressor, at exit from the compressor and at exit from the condenser are 183.19, 209.41 and 74.59 kJ/kg. Calculate—

(i) the refrigerant flow rate;

(ii) the C.O.P.;

(iii) power required to drive the compressor;

(iv) the rate of heat rejection to the condenser. 15

8. Answer the following questions :

(a) In a single heater regenerative cycle, the steam enters the turbine at 30 bar, 400 °C and the exhaust pressure is 0.10 bar. The feed water heater is a direct contact type which operates at 5 bar. Find the following : 20

(i) The efficiency and steam rate of the cycle

(ii) The increase in mean temperature of heat addition, efficiency and steam rate as compared to the Rankine cycle (without regeneration)

At 30 bar, 400 °C,
h_g = 3230.9 kJ/kg, s_g = 6.921 kJ/kgK
At 5 bar,
T_s = 172 °C, h_f = 640.1 kJ/kg, h_g = 2796 kJ/kg, s_f = 1.8604 kJ/kgK, s_g = 6.8192 kJ/kgK
At 0.1 bar,
s_f = 0.649 kJ/kgK, s_g = 7.501 kJ/kgK, h_f = 191.8 kJ/kg, h_g = 2392.8 kJ/kg

(b) A gas turbine unit receives air at 1 bar and 300 K and compresses it adiabatically to 6.2 bar. The compressor efficiency is 88 %. The fuel has a heating value of 44186 kJ/kg and the fuel-air ratio is 0.017 kJ/kg of air. The turbine internal efficiency is 90%. Calculate the work of the turbine and compressor per kg of air compressed and thermal efficiency. 15

(c) Calculate the following for an industrial furnace in the form of a black body and emitting radiation at 2500 °C : 15

(i) Monochromatic emissive power at 1.2 μm length

(ii) Wavelength at which the emission is maximum

(iii) Maximum emissive power

(iv) Total emissive power

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