MECHANICAL ENGINEERING Paper I

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

INSTRUCTIONS

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

Candidates should attempt **FIVE** *questions in all. Question No,* **1** *is compulsory.*
Out of the remaining **SIX** *questions attempt any* **FOUR** *questions.*
The number of marks carried by a part of a question are indicated against it.
Answers must be written in **ENGLISH** *only.*
Assume suitable data, if necessary, and indicate the same clearly.
For air R = 0.287 *kJ/kg-K,* C_p = 1.005 *kJ/kg-K,* γ = 1.4, M = 28.97 *kg/kg-mole, Universal gas constant* R = 8.314 *kJ/kg mole-K.*
Unless otherwise mentioned, symbols and notations have their usual standard meanings.
Neat sketches may be drawn, wherever required.
Attempts of questions shall be counted in chronological 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 answer book must be clearly struck off.
A psychrometric chart is attached to this question paper for necessary use by the candidate.

1. (a) Prove the following relations 15

$$\left(\frac{\partial u}{\partial v}\right)_T = T\left(\frac{\partial p}{\partial T}\right)_v - p \text{ and } \left(\frac{\partial h}{\partial p}\right)_T = v - T\left(\frac{\partial v}{\partial T}\right)_p$$

(b) An air compressor is used to fill rapidly a 3 m^3 tank at 20° C and1atm. The filling process is governed by the law $pv^{1.4}$ = constant. The kinetic and potential energy effects are negligible. The ratio of the final to the initial mass of air in the tank is 4. Work out the following:
(i) Sketch the system and list the assumptions made
(ii) Work input to the compressor. 15

(c) Steam enters a turbine at an enthalpy of 3300 kJ/kg and a velocity of 180 m/s. The steam comes out of turbine at an enthalpy of 2700 kJ/kg with a velocity of 120 m/s. At the condition of steady state, the turbine develops work equal to 550 kJ/kg of steam flowing through the turbine. The heat transfer between the turbine and its surroundings occurs at an average temperature of 370 K. The entropy of steam at inlet and exit of turbine are 6.932 kJ/kg-K and 7.361 kJ/kg-K, respectively. Neglecting the changes in potential energy between inlet and outlet, work out the following:
(i) Sketch the system and show the process on p-v and h-s diagrams.
(ii) Calculate the rate at which entropy is produced within the turbine per kg of steam flowing. 10

2. (a) The lower calorific value of a liquid fuel at constant pressure is 44000 kJ/kg. The analysis of fuel by mass is 84% carbon and 16% hydrogen. Determine the higher calorific value at constant pressure, and the lower and higher calorific values at constant volume.
Take h_{fg} for water at 25°C as 2442 kJ/kg. 15

(b) Derive an expression for the diameter of the injector orifice to spray fuel Q cm^3/cycle/cylinder in terms of injection pressure p_{inj} (kN/m^2), combustion chamber pressure p_{cyl} (kN/m^2), density of fuel p_f(kg/cm^3) and period of injection t seconds.
Calculate the diameter of the injector orifice of a six- cylinder, 4-stroke CI engine using the following data:
Brake power = 250 kW, Engine speed = 1500 r.p.m.; BSFC = 0.3 kg/kW; Cylinder pressure = 35 bar; Injection pressure = 200 bar; Specific gravity of fuel = 0.88; Coefficient of discharge of the fuel orifice = 0.92; Duration of injection = 36° of crank angle. 15

(c) Explain the mechanism of formation of NO_x in an SI engine. Discuss the effect

of -

(i) compression ratio
(ii) air-fuel ratio
(iii) retarding spark timing
(iv) exhaust gas recirculation
(v) temperature and pressure of the inlet charge on the concentration of NO_x in the exhaust of an SI engine. 10

3. (a) A refrigerated truck carrying foodstuff is speeding on a highway at 90 km/h in a desert area where the ambient air temperature is 55 °C. The body of the truck may be modeled as a rectangular box measuring 11 m long, 4 m wide and 3 m high. Consider the boundary layer on the four walls to be turbulent and the heat transfer only from the four surfaces. The wall surfaces of the truck are maintained at 10 °C. Assume the flow to be parallel to 11m long side. The thermo-physical properties at the mean-film temperature of 32-5 °C are:
ρ = 1.165 kg/m^3, C_p = 1.005 kJ/kg-K,
k = 2.673 × 10^{-2} W/m-K,
ν = 16 × 10^{-6} m^2/s and Pr = 0.701.
Work out the following:
(i) Sketch the system and show the boundary layer development along length
(ii) Heat loss from the four surfaces
(iii) Tonnage of refrigeration needed
(iv) Power required to overcome the resistance acting on four surfaces. 15

(b) A flat plate solar collector with no cover plate is used to collect the solar radiation to heat water in a commercial installation. The surface emissivity of the absorber is 0.12 while its solar absorptivity is 0.95. At a given time of the day the absorber surface temperature is 130°C when the solar irradiation is 850 W/m^2, the effective sky temperature is –8°C and the ambient temperature is 27°C. Assume that the heat transfer convection coefficient for the calm dry condition is given by

$$h = 0.23(T_S - T_\infty)^{4/3} \text{ W/m}^2\text{-K}$$

where T_S is the surface temperature and T_∞ is free-stream ambient temperature. Assume steady-state condition, bottom surface is well insulated and the absorber surface is diffuse. Work out the following:
(i) Sketch the system and show the control volume
(ii) The useful heat removal rate in W/m^2 from the collector
(iii) The efficiency of collector
(iv) Comment on the results. 15

(c) For a solid cylinder with uniform heat generation, derive the following expression:

$$T = T_\infty + \frac{q'''_g.R}{2h} + \frac{q'''_g.R^2}{4k}\left[1 - \left(\frac{r}{R}\right)^2\right]$$ 10

4. (a) In order to keep off foodstuff in better condition, a food storage locker requires 20 tons of refrigeration. The evaporator temperature is –8°C and the condenser temperature is 30 °C. The refrigerant used in the refrigeration plant is Fr-12. This is subcooled by 5°C before entering to the expansion valve. The vapor is superheated to 6°C before leaving the evaporator coil. The compressor employed is of two cylinder, single-acting having stroke equal to 1.5 times the bore. The speed of the compressor is 900 r.p.m. The compression process may be assumed to be isentropic. Work out the following:
(i) Sketch the system and show the process on T-S and p-h diagrams
(ii) The refrigerating effect per kg of refrigerant
(iii) The mass flow rate of the refrigerant circulated
(iv) The theoretical piston displacement
(v) The power input to compressor if mechanical efficiency is 0.9.

(vi) The coefficient of performance
(vii) The bore and stroke if volumetric efficiency is 90%.
Use the following properties for the solution:
$h_1 = 356$ kJ/kg, $h_2 = 377$ kJ/kg, $h_{f3} = h_4 = 225.5$ kJ/kg, $v_1 = 0.077$ m^3/kg
where, 1, 2, 3 and 4 refer to inlet to compressor, outlet of compressor, exit of subcooler and capillary tube/ expansion valve exit respectively. 15

(b) With the help of a neat sketch, discuss the working principle of a practical vapor absorption system. Derive the expression for its coefficient of performance. 15

(c) Discuss the various loads for estimating the cooling load of an auditorium. 10

5. (a) What is the difference between the Bernoulli's equation and the steady flow energy equation? Derive the steady flow energy equation and reduce it to the Bernoulli's equation. 10

(b) Show that for sonic flow, the deviation between the compressible and incompressible flow values of the pressure coefficient of a perfect gas ($\gamma = 1.4$) is about 27.5%. 10

(c) A convergent-divergent nozzle has an exit area ratio of 2. Air enters the nozzle with a stagnation pressure of 950 kPa and a stagnation temperature of 350 K. The throat area is 490 mm2. Determine the mass flow rate, exit pressure, exit temperature, exit Mach number and exit velocity for the following conditions:
(i) Sonic velocity at the throat, diverging section acting as a nozzle.
(ii) Sonic velocity at the throat, diverging section acting as a diffuser.
Table below gives the one-D, isentropic, compressible flow functions for an ideal gas. * represents the critical values at the throat where the Mach number is unity: 20

M	M*	A/A*	P/P$_0$	T/T$_0$
0.308	0.326	200	0.936	0.9812
1.00	1.00	100	0.528	0.8333
2.197	1.717	200	0.0939	0.5089

6. (a) In a compressor, the frictional torque is T in the impeller. If the diameter is D, speed N, fluid viscosity μ and density ρ, prove using Buckingham's n-theorem of dimensional analysis that

$$T = \rho N^2 D^5 f\left[\frac{\mu}{\rho N D^2}\right]$$ 10

(b) Determine the position in which a solid cylindrical block of wood of diameter 0.3 m and length 0.4 m will float in water. Take specific gravity of wood as 0.5. 20

(c) Describe the working principle of a Pitot tube with the help of a neat sketch and explain how it can be used to measure the stagnation pressure. 10

7. (a) In an open-cycle gas turbine plant, the air enters at 15°C and 1 bar, and is compressed in a compressor to a pressure ratio of 15. The air from the exit of compressor is first heated in a heat exchanger which is 75% efficient by turbine exhaust gas and then in a combustor to a temperature of 1600 K. The same gas expands in a two-stage turbine such that the expansion work is maximum. The exhaust gas from h.p. turbine is reheated to 1500 K and then expands to l.p. turbine. The isentropic efficiencies of compressor and turbine may be taken as 86% and 88% respectively. The mechanical efficiencies for compressor and turbine are 97% each. The alternator efficiency is 98%. The output of turbo-alternator is 250 MW. Work out the following:
(i) Sketch the system and show the process on T-S diagram.
(ii) The cycle thermal efficiency
(iii) The work ratio
(iv) The specific power output
(v) The mass flow rate of air. 15

(b) A centrifugal pump is required to lift 9100 lit/s of water against a head of 6 m while running at 500 r.p.m. The velocity of flow through the wheel is 2 m/s and the manometric efficiency is 60%. The angle of vane tip with the direction of motion is 150°. Work out the following:
(i) Sketch an impeller of centrifugal pump and draw the velocity triangle.
(ii) The diameter of impeller
(iii) The width of impeller 15

(c) Discuss the factors affecting stage pressure ratio in an axial flow compressor. Draw the velocity distribution through a blade passage. 10

8. (a) What is the purpose of steam generator control? With the help of sketches, discuss the various methods of steam generator control. 15

(b) Discuss the need of governing of steam turbine. With the help of a sketch, discuss the working principle of hydromechanical speed governing loop. List the various speed governors used in practice. 15

(c) With the help of a sketch, discuss the working principle of boiling water reactor and explain in brief the function of main elements. 10

MECHANICAL ENGINEERING Paper II

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

INSTRUCTIONS

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

Candidate should attempt **FIVE** *questions in all. Question No.* **1** *in Section* **A** *is compulsory.*

Out of the remaining, attempt **TWO** *from Section-***B** *and* **TWO** *from Section—***C**.

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

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

Unless other-wise mentioned, symbols and notations have their usual standard meanings.

Neat sketches may be drawn, wherever required.

All parts and sub-parts of a question are to be attempted together in the answer book.

Attempts of questions shall be counted in chronological 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 answer book must be clearly struck off.

SECTION—A

1. Answer all 20 parts of the question each part carries 2 marks.

(a) At a point in a loaded structure, a pure shear stress state of $\tau = \pm 400$ MPa prevails on two given planes at right angles, (i) What would be the state of stress across the planes of an element taken at ±45° to the given planes? (ii) What are the magnitudes of these stresses?

(b) A coil spring of stiffness 'k' is cut to two halves and these two springs are assembled in parallel to support a heavy machine. What is the combined stiffness provided by these two springs in the modified arrangement?

(c) What is the value of Euler's buckling load for an axially loaded pin-ended (hinged at both ends) strut of length 'l' and flexural rigidity 'EI'? What would be the order of Euler's buckling load carrying capacity of a similar strut but fixed at both ends in terms of the load carrying capacity of the earlier one?

(d) Suggest most suitable and cheapest material for the following:-
(i) Body of screw jack (ii) Belts (iii) Piston rings (iv) Rivets

(e) An oil ring bearing supports a shaft of diameter 95 mm which runs at 230 rpm. The maximum load on the bearing is 18 kN. Determine the bearing characteristic number for $l/d = 1.5$ and absolute viscosity 0.0225 kg/ms.

(f) Mention two best reasons why accelerometer is preferred over seismometer to measure vibration in mechanical system?

(g) The type of cam used in cam shaft of I.C. engines is of specified contour or specified motion. State it and give reasons for your answer.

(h) A six cylinder 4 stroke multicylinder in line engine is completely balanced in respect of reciprocating masses. State 4 reasons for it.

(i) Mention the names of 4 plastics which are used for bearings. Also mention four advantages which plastics offer over other materials.

(j) Explain the following in brief:
(i) Effect of size on the tensile strength
(ii) Effect of surface finish on endurance limit.

(k) What is the principle of resistance welding? Indicate where the resistance is maximum in spot welding operation.

(l) Sometimes the parting plane between two forging dies is not a horizontal plane, give the main reason for this design aspect, why is parting plane provided, in closed die forging?

(m) What is permeability? Permeability is more important in the basic process of sand casting than porosity. Give one important reason for this feature.

(n) Metal powders are compacted by many methods, but sintering is required to achieve which property? What is hot isostatic pressing?

(o) Cast iron with impurities of carbide requires a particular rake angle for

efficient cutting with single point tools, what is the value of this rake angle, give reasons for your answer?

(p) From the data of a pilot study, the percentage of occurrence of an activity is 60%. Find the number of observations for 95% confidence level and an accuracy of ±2%.

(q) A typical activity i-j in a CPM network has activity duration (t_{ij}) of 2.5 time units. The earlier expected time (T_E^i) and latest allowable occurrence time (T_L^i) of event i are computed as 8 and 11 units respectively. The corresponding times of event j, i.e. T_E^j and T_L^j are respectively 13.5 and 13.5 units. Find the three floats of the activity i-j.

(r) State any four basic elements of a Robot. Give one line statement for each.

(s) With the following printf ( ) statements in 'C, express
(i) how the value x = 38.4625 appears :
(i) printf ("% 7.2 f", x)
(ii) printf ("% 7.4 f", x)
(iii) printf ("% f", x)
(iv) printf ("% -7.2 f", x).

(t) What for FORTRAN commands REAL and DIMENSION are used and what are their equivalents in 'C' language?

SECTION—B

2. (a) A simply supported beam made of rolled steel joist (I- section: 450 mm × 200 mm) has a span of 5 m and it carries a central concentrated load W. The flanges are strengthened by two 300 mm × 20 mm plates, one riveted to each flange over the entire length of the flanges. The second moment of area of the joist about the principal bending axis is 35,060 cm^4. Calculate:
(i) the greatest central load the beam will carry if the bending stress in the 300 mm/20 mm plates is not to exceed 125 MPa.
(ii) the minimum length of the 300 mm plates required to restrict the maximum bending stress in the flanges of the joist to 125 MPa. 20

(b) A solid shaft is to transmit 300 kW at 120 r.p.m. If the shear stress is not to exceed 100 MPa, find the diameter of the shaft. What percent saving in weight would be obtained if this shaft were replaced by a hollow one whose internal diameter equals 0.6 of the external diameter, the length, material and maximum allowable shear stress being the same? 20

3. (a) Two gears mesh externally to provide velocity ratio 3:1. Both the gears have standard addendum and pressure angle is equal to 20°. Determine minimum number of teeth on the pinion to avoid interference. Instead of using a pinion of these number of teeth another pinion having three teeth less than the above number is to be used. Determine the minimum amount of stubbing of gear teeth in terms of module which is to be done now for this pinion. The velocity ratio is to be maintained same. 20

(b) A machine of mass 500 kg. It is supported on helical springs which deflect by 5 mm due to the weight of the machine. The machine has rotating unbalance equal to 250 kg mm. The speed of the machine is 1200 rpm. Determine the dynamic amplitude. The damping factor of the viscous damper is 0.4.
Now this machine is mounted on a larger concrete block of mass 1200 kg. The stiffness of the springs is changed such that the static deflection is still the same with the same viscous damper as in earlier case. Determine the change in the dynamic amplitude. 20

4. (a) Design a flat belt drive system for the following specifications:
Power to be transmitted = 100 kW
Pulley diameters = 0.8 m and 1 m, respectively
Centre distance between the pulleys = 3 m

Belt speed = 20 m/s
Coefficient of friction between the belt and pulleys = 0.3
Slip = 1.2% at each pulley
Friction loss at each shaft = 5%
Overload capacity = 20%
Density of leather belt material = 1000 kg/m^3
Safe stress for the belt = 2.5 MPa
Thickness of the belt = 12 to 16 mm
Take into account the effect of centrifugal tension.
Find the width and the length of the belt.
Draw a schematic diagram of the belt drive. 20

(b) A shaft ABCD is supported at one end A and at point C. The other end D consists of a pulley which has belt tensions in the vertical direction. The distance AD is 1200 mm. AC distance is 800 mm. A spur gear having pressure angle 20° is mounted at point B which is at a distance 400 mm from A. The diameter of pulley is 450 mm and that of the gear is 300 mm. The gear is supplied power equal to 20 kW at 500 rpm by another gear at the top of it. The tension on the tight side is 3 times the tension on slack side in the belt. The combined shock and fatigue factors for bending moment and torsional moment may be taken as 1.5. The tensile strength of the material of the shaft and key is 700 MPa. Design the shaft and key for the pulley assuming factor of safety equal to 5. Assume allowance for the key way for stress as 0.75. 20

SECTION—C

5. (a) A cylinder of height 60 mm and diameter 100 mm is forged at room temperature between two flat dies. Find the die load at the end of compression to a height of 30 mm, using slab method of analysis. The yield strength of the work material is given as 120 N/mm^2 and the coefficient of friction is 0.05. Assume that volume is constant after deformation. There is no sticking. Also find the mean die pressure. 20

(b) Chvorinov and Caine gave rules for solidification time and freezing ratio for a riser. Using these rules or otherwise find the size of a cylindrical riser of height to diameter ratio as one for a steel casting of size 250 × 250 × 50 mm^3, when the casting is fed horizontally and riser is a side one. Thickness of the casting is 50 mm. For steel a = 0.10, b = 0.03 and c = 1.00. Consider it as a long bar of cross-section 250 × 50. 20

6. (a) Two steel sheets of thickness one mm are welded by resistance projection welding technique. A current of 30,000 A for 0.005 second is made to flow. The effective resistance of joint can be taken as 100 micro ohms. The joint can be considered as a cylinder of diameter 5 mm and height 1.5 mm. The density of steel is 0.00786 gm/mm^3. The heat needed for welding steel is 10 J/mm^3. Calculate the efficiency of welding. 20

(b) Prepare part program using APT language for milling the contour shown in Fig. 6(b) in a single pass.

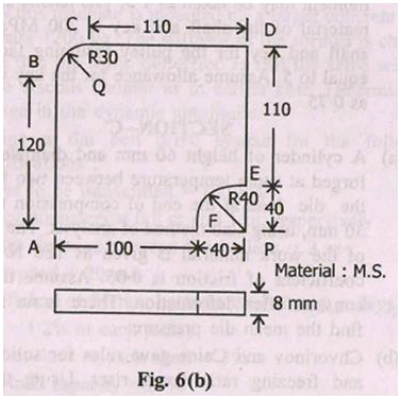

Fig. 6(b)

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7. (a) Two products A and B are to be machined on three machine tools P, Q and R. Product A takes 10 hrs on machine P, 6 hrs on machine Q and 5 hrs on machine R. The product B takes 7.5 hrs on machine P, 9 hrs on maching Q and 13 hrs on machine R. The machining time available on these machine tools P, Q, R are respectively 75 hrs, 54 hrs and 65 hrs per week. The producer contemplates profit of Rs. 60 per product A, and Rs. 70 per product B. Formulate LP model for the above problem and show the feasible region graphically/geometrically. What are the basic feasible solutions to the above problem? Estimate graphically/geometrically the optimum product mix for maximizing the profit. Explain why one of the vertices of the feasible region becomes the optimum solution point.
(Note: Graph sheet need not be used). 15

(b) An assembly of an equipment involves the tasks A to N, the precedence tasks and processing times of these tasks in minutes are given in the following table. Considering cycle time of 20 minutes at any work station, balance the assembly line and find the optimum number of work stations.
Also find the idle time at each work station.

Task	Predecessor	Duration
A	-	6
B	-	5
C	-	4
D	A	8
E	B	5
F	C	4
G	D	7
H	E	6
I	F	10
J	G	10
K	I	7
L	J, H	10
M	K	6
N	L, M	9

10

(c) Draw flow chart and write source code in FORTRAN to solve the following problems: A reciprocating engine has crank radius r and crank length 'l'. The crank is rotating with uniform angular velocity 'ω'. It is required to find the velocity and acceleration of piston at different crank positions. Also find the position of crank and piston at maximum acceleration and at acceleration nearer to zero. 15

Velocity of piston is $V_p = r\omega\left(\sin\theta + \frac{\sin 2\theta}{2n}\right)$

Acceleration of piston is $a_p = r\omega^2\left(\cos\theta + \frac{\cos 2\theta}{n}\right)$