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 divided in **TWO** Sections.

Candidate has to attempt **FIVE** questions in all.

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.

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

Wherever any assumptions are made for answering a question, they must be clearly indicated.

Diagrams/Figures, wherever required, shall be drawn in the space provided for answering the question itself.

Unless otherwise mentioned, symbols and notations carry their usual standard meanings.

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.

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

SECTION—A

1. *(a)* (i) Differentiate between rotational and irrotational flows. Can there be any possibility of having zones possessing characteristics of both rotational and irrotational flows? 6

(ii) If the expression for the stream function is described by $\psi = x^3 - 3xy^2$, determine whether the flow is rotational or irrotational. Further, find out the correct expression of the velocity potential function of the following two, considering the flow is irrotational:

(1) $\phi = y^3 - 3x^2y$

(2) $\phi = -7x^3y$ 6

(b) A refrigerated truck whose dimensions are 1 2 m × 2.5 m × 3 m is to be precooled from 30°C to an average temperature of 5°C. The construction of the truck is such that a transmission heat gain occurs at the rate of 90 W/°C. If the ambient temperature is 30°C, determine how long it will take for a system with a refrigeration capacity of 10 kW to precool this truck. The density of air may be taken as 1.2 kg/m^3 and its specific heat at average temperature of 17.5°C is C_p = 1.0 kJ/kg-°C. State the assumptions, if any. 12

(c) An engine oil flows through a copper tube of 1 cm internal diameter and 0.02 cm wall thickness at the flow rate of 0.1 kg/s. Consider that the temperature of the oil at the entry is 30°C. If the oil is heated to 50°C by steam condensing at atmospheric pressure, calculate the length of the copper tube. The properties of the oil are as follows:

C_p = 1964 J/kg-K, ρ = 876 kg/m^3, k = 0.144 W/m-K,

μ = 0.210 N-s/m^2, Pr = 2870 12

(d) Explain the mechanism of NO_x formation and also the methods for its reduction in stationary gas turbine engines. 12

(e) (i) Why are higher heat transfer rates experienced in dropwise condensation than in film condensation? 6

(ii) Distinguish between nucleate boiling and film boiling. 6

2. *(a)* (i) Find the distance from the pipe wall at which the local velocity is equal to the average velocity for turbulent flow in pipe. 12

(ii) Distinguish between hydrodynamically smooth and rough boundaries. 8

(b) (i) In a closed system, 3 kg of air at initial conditions of 400 kPa and 90°C adiabatically expands until its volume is 2.5 times the initial volume and temperature becomes equal to that of surroundings. If the conditions of the surroundings are 100 kPa and 25°C, determine the following for this process:

(1) The maximum work.

(2) The change in availability.

(3) The irreversibility. 15

(ii) Prove that for an ideal gas, the slope of an isochoric line on the *T*-*s* diagram is more than that of the isobaric line. 5

(c) A square plate heater (15 cm × 15 cm) is inserted between two slabs. Slab *A* is 2 cm thick (k = 50 W/m-°C) and slab *B* is 1 cm thick (k = 0.2 W/m-°C). The outside heat transfer coefficients on side of *A* and side of *B* are 200 W/m^2-°C and 50 W/m^2-°C respectively. The temperature of surrounding air is 25°C. If the rating of heater is 1 kW, find the–

(i) maximum temperature of the system;

(ii) outer surface temperature of two slabs.

Assume steady-state heat flow. 20

3. *(a)* A centrifugal pump discharges 2000 litres/s of water developing a head of 20 m when running at 300 r.p.m. The impeller diameter at the outlet and outlet flow velocity are 1.5 m and 3.0 m/s respectively. If the blades are set back at an angle of 30° at the outlet, determine the–

(i) manometric efficiency;

(ii) power required by the pump;

(iii) minimum speed to start the pump if the inner diameter is 750 mm. 20

(b) Air flows at 12 m/s past a smooth rectangular flat plate 0.4 m wide and 3 m long. Assuming that the transition occurs at Re = 5.5 × 10^5, calculate the total drag force when–

(i) the flow is parallel to the length of the plate;

(ii) the flow is parallel to the width of the plate.

Assume, Density of air, ρ = 1.24 kg/m^3,

Kinematic viscosity, ν = 0.15 stokes 20

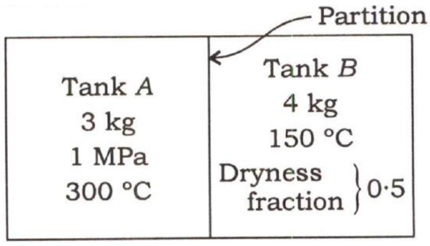
(c) Two tanks, tank *A* and tank *B*, are separated by a partition as shown in the figure. Tank *A* contains 3 kg of steam at 1 MPa and 300°C. Tank *B* contains 4 kg of saturated liquid-vapour mixture at 150°C with a dryness fraction of 0.5. The partition is removed and two fluids are allowed to mix until the thermal equilibrium and mechanical equilibrium are

acquired. If the pressure of the final state is 300 kPa, determine–

(i) the temperature of the final state;

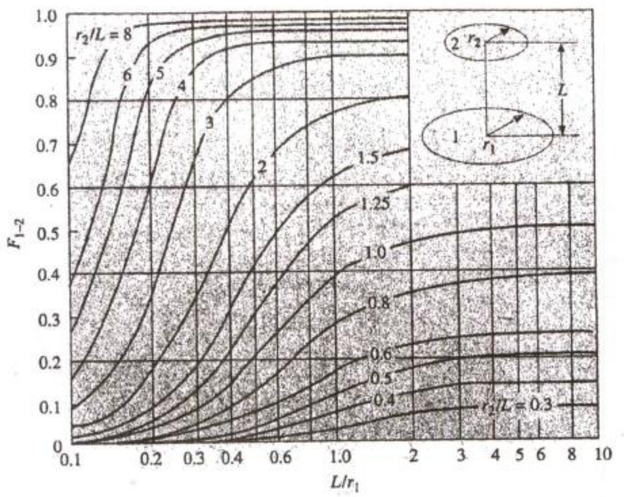
(ii) the quality of the steam at final state;

(iii) the amount of heat lost from the tanks.



[Required steam tables are attached in last Page] 20

4. *(a)* A truncated cone has top and bottom diameters of 10 cm and 20 cm respectively, and a height of 10 cm. Calculate the shape factor between the top surface and the side, and also the shape factor between the side and itself. Use the figure showing the radiation shape factor for radiation between two parallel coaxial disks:



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(b) A Francis turbine supplied through an 8.0 m diameter penstock has the following particulars:

Output power = 65000 kW
Speed = 150 r.p.m.
Hydraulic efficiency = 90%
Flow rate = 120 m^3/s
Mean diameter of turbine at entry = 5 m
Mean blade height at entry = 1.5 m
Entry diameter of draft tube = 4.5 m
Velocity in tailrace = 2.5 m/s

The static pressure head in the penstock measured just before entry to the runner is 60 m. The point of measurement is 3.2 m above the level of the tailrace. The loss in the draft tube is equivalent to 30% of the velocity head at entry to it. The exit plane of the runner is 2 m above the tailrace and the flow leaves the runner without swirl. Calculate:

(i) The overall efficiency.

(ii) The direction of flow relative to the runner at inlet.

(iii) The pressure head at entry to draft tube. 20

(c) Two containers are connected with a pipe having a closed valve. One

container contains a 5 kg mixture of 62.5% CO_2 and 37.5% O_2 on a mole basis at 30°C and 125 kPa. The second container contains 10 kg of N_2 at 15°C and 200 kPa. The valve in the pipe is opened and gases are allowed to mix. During the mixing process, 100 kJ of heat energy is supplied to the combined tank. Determine the volume of the mixture and write an energy balance equation.
[Required property tables are attached] 20

SECTION—B

5. *(a)* A six-cylinder SI engine operates on a four-stroke cycle. The bore of each cylinder is 75 mm and the stroke is 100 mm. The clearance volume per cylinder is 60 cc. At a speed of 4000 r.p.m., the fuel consumption is 18 kg/h and the torque developed is 140 N-m. Calculate the—

(i) brake thermal efficiency;

(ii) relative efficiency on the basis of brake power.

The calorific value of the fuel can be taken as 45000 kJ/kg. 12

(b) Draw the *T-s* and *h-s* diagrams for steam jet refrigeration system and write the expressions for the following:

(i) Nozzle efficiency.

(ii) Entrainment efficiency.

(iii) Compression efficiency. 12

(c) Briefly describe a natural draught cooling tower. Explain why it is hyperbolic in shape. 12

(d) Distinguish among the following:

(i) Renewable energy.

(ii) Green energy.

(iii) Clean energy.

Also, mention the relative environmental effects of the above. 12

(e) Describe the emission norms for Indian vehicles if they have to comply with Bharat Stage (BS) Emission Standards-VI. Mention the devices and technology introduced to meet the BS-VI norms. 12

6. *(a)* A gasoline engine has a stroke volume of 0.002 m^3 and a compression ratio of 6. At the end of the compression stroke, the pressure is 10 bar and the temperature is 400°C. Ignition is set so that the pressure rises along a straight line during combustion and attains its highest value of 30 bar after the piston has travelled (1/40) of the stroke. The charge consists of a gasoline-air mixture in proportion of 1:18 bymass. Calculate the heat lost per kg of charge during combustion. Take R = 287 J/kg-K, calorific value of the fuel = 45 MJ/kg, C_p = 1 kJ/kg. 20

(b) A room is designed for air conditioning as per the following data:

Room sensible heat gain = 30 kW

Room latent heat gain = 10 kW

Inside design conditions are: 25°C DBT and 50% RH

Outside conditions are: 40°C DBT and 27°C WBT

Bypass factor of the cooling coil = 0.10

The return air from the space is mixed with the outside air before entering the cooling coil in the ratio of 4:1 by weight. Determine the following:

(i) Apparatus dew point.
(ii) Condition of air leaving the cooling coil.
(iii) Quantity of dehumidified air.
(iv) Mass of ventilation air.
(v) Volume flow rate of fresh air.
(vi) Total refrigeration load.
[Psychrometric chart is attached] 20

(c) The angles at inlet and discharge of the blading of a 50% reaction turbine are 35° and 20° respectively. The speed of rotation is 1500 r.p.m. and at a particular stage, the mean ring diameter is 0.67 m and the steam condition is at 1.5 bar, 0.96 dry. Determine—
(i) the required height of blading to pass 3.6 kg/s of steam;
(ii) the power developed by the ring.
[Saturated steam table is attached at the end of booklet] 20

7. *(a)* The following data refer to a boiler unit consisting of an economizer, a boiler and a superheater:

Mass of water evaporated per hour = 5940 kg
Mass of coal burnt per hour = 675 kg
Lower calorific value of coal = 31600 kJ/kg
Pressure of steam at boiler stop valve = 14 bar
Temperature of feedwater entering economizer = 32°C
Temperature of feedwater leaving economizer = 115°C
Dryness fraction of steam leaving boiler and entering superheater = 0.96
Temperature of steam leaving superheater = 260°C
Specific heat of superheater steam = 2.3 kJ/kg-K

Determine the following:
(i) Percentage of heat in coal utilized in economizer, boiler and superheater.
(ii) Overall efficiency of the boiler unit.
Assume specific heat of water = 4.187 kJ/kg-K
[Saturated steam table is attached at the end of booklet] 20

(b) (i) Explain the various factors affecting anaerobic digestion process. Why do anaerobic microbes normally grow at a much lower rate than aerobic bacteria? 10

(ii) A family biogas plant is required to be designed to utilize the cow dung of five cows. The hydraulic retention time is 30 days. The temperature of the digester is to be maintained at 30 °C. The dry matter consumption per day is 2 kg. The biogas yield is 0.25 m^3/kg. The efficiency of the burner is 60%. The heat of combustion of methane is 26 MJ/m^3. The methane proportion is 70%. The density of feedstock material may be taken as 50 kg/m^3. Find (1) the volume of biogas digester and (2) its thermal power. 10

(c) (i) A refrigeration system with R-22 as refrigerant operates with an evaporating temperature of –10°C and a condensing temperature of 35°C. If the vapour leaves the evaporator saturated and is compressed isentropically, what is the COP of the cycle—(1) if saturated liquid enters the expansion device and (2) if the refrigerant entering

the expansion device is with 10% vapour?
[R-22 refrigerant chart is attached] 10

(ii) What is a liquid-to-suction heat exchanger in refrigeration and air conditioning? Illustrate the benefits of liquid-to-suction heat exchanger. 10

8. *(a)* (i) Describe the working principle of hydrogen fuel cell. Also, comment on the reversible energy conversion efficiency of fuel cells. 10

(ii) A flat plate solar collector measuring 2 m × 1.2 m has a loss resistance of 0.13 m^2K/W and a plate transfer efficiency of 0.85. The glass cover has transmittance of 0.9 and the absorptance of the plate is also 0.9. Water enters at a temperature of 35°C. The ambient temperature is 20°C and the irradiance in the plane of the collector is 750 W/m^2. Calculate the flow rate needed to produce a temperature rise of 10°C. The density of water and its specific heat at mean film temperature may be taken as 1000 kg/m^3 and 4.2 J/g-°C respectively. 10

(b) A two-pass surface condenser is required to handle the exhaust from a turbine developing 15 MW with specific steam consumption of 5 kg/kWh. The condenser vacuum is 660 mm of mercury when the barometer reads 760 mm of mercury. The mean velocity of water is 3 m/s and the water inlet temperature is 24°C. The condensate is saturated water and the outlet temperature of cooling water is 4°C less than the condensate temperature. The quality of exhaust steam is 0.9 dry. The overall heat transfer coefficient based on outer area of tubes is 4000 W/m^2-°C. The water tubes are 38.4 mm in outer diameter and 29.6 mm in inner diameter. Calculate the following:

(i) Mass of cooling water circulated in kg/min.
(ii) Condenser surface area.
(iii) Number of tubes required per pass.
(iv) Tube length.

Assume atmospheric pressure to be 760 mm of mercury or 1.01325 bar and specific heat of water = 4.187 kJ/kg-K.
[Saturated steam table is attached at the end of booklet] 20

(c) The total pressure maintained in an Electrolux refrigerator is 15 bar. The temperature obtained in the evaporator is –15°C. The quantities of heat supplied to the generator are (i) 420 kJ to dissociate one kg of vapour and (ii) 1460 kJ/kg for increasing the total enthalpy of NH_3. The enthalpy of NH_3 entering the evaporator is 330 kJ/kg. Take the following properties of NH_3 at –15°C:

Pressure = 2.45 bar
Enthalpy of vapour = 1666 kJ/kg
Specific volume = 0.5 m^3/kg
The hydrogen enters the evaporator at 25°C
Gas constant for H_2 = 4.218 kJ/kg-°C
C_p (for H_2) = 12.77 kJ/kg-°C

Find the COP of the system assuming NH_3 leaves the evaporator in saturated condition. 20

Steam Table

T	v	u	h	s	v	u	h	s	v	u	h	s
	P = 200 kPa (120.23)				P = 300 kPa (133.55)				P = 400 kPa (143.63)			
900	2.70643	3854.5	4395.8	9.4565	1.80406	3854.2	4395.4	9.2691	1.35288	3853.9	4395.1	9.1361
1000	2.93740	4052.5	4640.0	9.6563	1.95812	4052.3	4639.7	9.4689	1.46847	4052.0	4639.4	9.3360
1100	3.16834	4257.0	4890.7	9.8458	2.11214	4256.8	4890.4	9.6585	1.58404	4256.5	4890.1	9.5255
1200	3.39927	4467.5	5147.3	10.0262	2.26614	4467.2	5147.1	9.8389	1.69958	4467.0	5146.8	9.7059
1300	3.63018	4683.2	5409.3	10.1982	2.42013	4683.0	5409.0	10.0109	1.81511	4682.8	5408.8	9.8780
	P = 500 kPa (151.86)				P = 600 kPa (158.85)				P = 800 kPa (170.43)			
Sat.	0.37489	2561.2	2748.7	6.8212	0.31567	2567.4	2756.8	6.7600	0.24043	2576.8	2769.1	6.6627
200	0.42492	2642.9	2855.4	7.0592	0.35202	2638.9	2850.1	6.9665	0.26080	2630.6	2839.2	6.8158
250	0.47436	2723.5	2960.7	7.2708	0.39383	2720.9	2957.2	7.1816	0.29314	2715.5	2950.0	7.0384
300	0.52256	2802.9	3064.2	7.4598	0.43437	2801.0	3061.6	7.3723	0.32411	2797.1	3056.4	7.2372
350	0.57012	2882.6	3167.6	7.6328	0.47424	2881.1	3165.7	7.5463	0.35439	2878.2	3161.7	7.4088
400	0.61728	2963.2	3271.8	7.7937	0.51372	2962.0	3270.2	7.7078	0.38426	2959.7	3267.1	7.5715
500	0.71093	3128.4	3483.8	8.0872	0.59199	3127.6	3482.7	8.0020	0.44331	3125.9	3480.6	7.8672
600	0.80406	3299.6	3701.7	8.3521	0.66974	3299.1	3700.9	8.2673	0.50184	3297.9	3699.4	8.1332
700	0.89691	3477.5	3926.0	8.5952	0.74720	3477.1	3925.4	8.5107	0.56007	3476.2	3924.3	8.3770
800	0.98959	3662.2	4157.0	8.8211	0.82450	3661.8	4156.5	8.7367	0.61813	3661.1	4155.7	8.6033
900	1.08217	3853.6	4394.7	9.0329	0.90169	3853.3	4394.4	8.9485	0.67610	3852.8	4393.6	8.8153
1000	1.17469	4051.8	4639.1	9.2328	0.97883	4051.5	4638.8	9.1484	0.73401	4051.0	4638.2	9.0153
1100	1.26718	4256.3	4889.9	9.4224	1.05594	4256.1	4889.6	9.3381	0.79188	4255.6	4889.1	9.2049
1200	1.35964	4466.8	5146.6	9.6028	1.13302	4466.5	5146.3	9.5185	0.84974	4466.1	5145.8	9.3854
1300	1.45210	4682.5	5408.6	9.7749	1.21009	4682.3	5408.3	9.6906	0.90758	4681.8	5407.9	9.5575
	P = 1.00 MPa (179.91)				P = 1.20 MPa (187.99)				P = 1.40 MPa (195.07)			
Sat.	0.19444	2583.6	2778.1	6.5864	0.16333	2588.8	2784.8	6.5233	0.14084	2592.8	2790.0	6.4692
200	0.20596	2621.9	2827.9	6.6939	0.16930	2612.7	2815.9	6.5898	0.14302	2603.1	2803.3	6.4975
250	0.23268	2709.9	2942.6	6.9246	0.19235	2704.2	2935.0	6.8293	0.16350	2698.3	2927.2	6.7467
300	0.25794	2793.2	3051.2	7.1228	0.21382	2789.2	3045.8	7.0316	0.18228	2785.2	3040.4	6.9533
350	0.28247	2875.2	3157.7	7.3010	0.23452	2872.2	3153.6	7.2120	0.20026	2869.1	3149.5	7.1359
400	0.30659	2957.3	3263.9	7.4650	0.25480	2954.9	3260.7	7.3773	0.21780	2952.5	3257.4	7.3025
500	0.35411	3124.3	3478.4	7.7621	0.29463	3122.7	3476.3	7.6758	0.25215	3121.1	3474.1	7.6026

Steam Table

Temp. °C T	Pressure kPa, MPa P	*Specific Volume*, m³/kg: Sat. Liquid v_f	Sat. Vapour v_g	*Internal Energy*, kJ/kg: Sat. Liquid u_f	Evap. u_{fg}	Sat. Vapour u_g	*Enthalpy*, kJ/kg: Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapour h_g	*Entropy*, kJ/kg-K: Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapour s_g
105	0.12082	0.001047	1.4194	440.00	2072.3	2512.3	440.13	2243.7	2683.8	1.3629	5.9328	7.2958
110	0.14328	0.001052	1.2102	461.12	2057.0	2518.1	461.27	2230.2	2691.5	1.4184	5.8202	7.2386
115	0.16906	0.001056	1.0366	482.28	2041.4	2523.7	482.46	2216.5	2699.0	1.4733	5.7100	7.1832
120	0.19853	0.001060	0.8919	503.48	2025.8	2529.2	503.69	2202.6	2706.3	1.5275	5.6020	7.1295
125	0.2321	0.001065	0.77059	524.72	2009.9	2534.6	524.96	2188.5	2713.5	1.5812	5.4962	7.0774
130	0.2701	0.001070	0.66850	546.00	1993.9	2539.9	546.29	2174.2	2720.5	1.6343	5.3925	7.0269
135	0.3130	0.001075	0.58217	567.34	1977.7	2545.0	567.67	2159.6	2727.3	1.6869	5.2907	6.9777
140	0.3613	0.001080	0.50885	588.72	1961.3	2550.0	589.11	2144.8	2733.9	1.7390	5.1908	6.9298
145	0.4154	0.001085	0.44632	610.16	1944.7	2554.9	610.61	2129.6	2740.3	1.7906	5.0926	6.8832
150	0.4759	0.001090	0.39278	631.66	1927.9	2559.5	632.18	2114.3	2746.4	1.8417	4.9960	6.8378
155	0.5431	0.001096	0.34676	653.23	1910.8	2564.0	653.82	2098.6	2752.4	1.8924	4.9010	6.7934
160	0.6178	0.001102	0.30706	674.85	1893.5	2568.4	675.53	2082.6	2758.1	1.9426	4.8075	6.7501
165	0.7005	0.001108	0.27269	696.55	1876.0	2572.5	697.32	2066.2	2763.5	1.9924	4.7153	6.7078
170	0.7917	0.001114	0.24283	718.31	1858.1	2576.5	719.20	2049.5	2768.7	2.0418	4.6244	6.6663
175	0.8920	0.001121	0.21680	740.16	1840.0	2580.2	741.16	2032.4	2773.6	2.0909	4.5347	6.6256
180	1.0022	0.001127	0.19405	762.08	1821.6	2583.7	763.21	2015.0	2778.2	2.1395	4.4461	6.5857
185	1.1227	0.001134	0.17409	784.08	1802.9	2587.0	785.36	1997.1	2782.4	2.1878	4.3586	6.5464
190	1.2544	0.001141	0.15654	806.17	1783.8	2590.0	807.61	1978.8	2786.4	2.2358	4.2720	6.5078
195	1.3978	0.001149	0.14105	828.36	1764.4	2592.8	829.96	1960.0	2790.0	2.2835	4.1863	6.4697
200	1.5538	0.001156	0.12736	850.64	1744.7	2595.3	852.43	1940.7	2793.2	2.3308	4.1014	6.4322
205	1.7230	0.001164	0.11521	873.02	1724.5	2597.5	875.03	1921.0	2796.0	2.3779	4.0172	6.3951
210	1.9063	0.001173	0.10441	895.51	1703.9	2599.4	897.75	1900.7	2798.5	2.4247	3.9337	6.3584
215	2.1042	0.001181	0.09479	918.12	1682.9	2601.1	920.61	1879.9	2800.5	2.4713	3.8507	6.3221
220	2.3178	0.001190	0.08619	940.85	1661.5	2602.3	943.61	1858.5	2802.1	2.5177	3.7683	6.2860

Steam Table

Pressure MPa P	Temp. °C T	Specific Volume, m³/kg: Sat. Liquid v_f	Sat. Vapour v_g	Internal Energy, kJ/kg: Sat. Liquid u_f	Evap. u_{fg}	Sat. Vapour u_g	Enthalpy, kJ/kg: Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapour h_g	Entropy, kJ/kg-K: Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapour s_g
0.275	130.60	0.001070	0.6573	548.57	1992.0	2540.5	548.87	2172.4	2721.3	1.6407	5.3801	7.0208
0.300	133.55	0.001073	0.6058	561.13	1982.4	2543.6	561.45	2163.9	2725.3	1.6717	5.3201	6.9918
0.325	136.30	0.001076	0.5620	572.88	1973.5	2546.3	573.23	2155.8	2729.0	1.7005	5.2646	6.9651
0.350	138.88	0.001079	0.5243	583.93	1965.0	2548.9	584.31	2148.1	2732.4	1.7274	5.2130	6.9404
0.375	141.32	0.001081	0.4914	594.38	1956.9	2255.13	594.79	2140.8	2735.6	1.7527	5.1647	6.9174
0.40	143.63	0.001084	0.4625	604.29	1949.3	2553.6	604.73	2133.8	2738.5	1.7766	5.1193	6.8958
0.45	147.93	0.001088	0.4140	622.75	1934.9	2557.6	623.24	2120.7	2743.9	1.8206	5.0359	6.8565
0.50	151.86	0.001093	0.3749	639.66	1921.6	2561.2	640.21	2108.5	2748.7	1.8606	4.9606	6.8212
0.55	155.48	0.001097	0.3427	655.30	1909.2	2564.5	655.91	2097.0	2752.9	1.8972	4.8920	6.7892
0.60	158.85	0.001101	0.3157	669.88	1897.5	2567.4	670.54	2086.3	2756.8	1.9311	4.8289	6.7600
0.65	162.01	0.001104	0.2927	683.55	1886.5	2570.1	684.26	2076.0	2760.3	1.9627	4.7704	6.7330
0.70	164.97	0.001108	0.2729	696.43	1876.1	2572.5	697.20	2066.3	2763.5	1.9922	4.7158	6.7080
0.75	167.77	0.001111	0.2556	708.62	1866.1	2574.7	709.45	2057.0	2766.4	2.0199	4.6647	6.6846
0.80	170.43	0.001115	0.2404	720.20	1856.6	2576.8	721.10	2048.0	2769.1	2.0461	4.6166	6.6627
0.85	172.96	0.001118	0.2270	731.25	1847.4	2578.7	732.20	2039.4	2771.6	2.0709	4.5711	6.6421
0.90	175.38	0.001121	0.2150	741.81	1838.7	2580.5	742.82	2031.1	2773.9	2.0946	4.5280	6.6225
0.95	177.69	0.001124	0.2042	751.94	1830.2	2582.1	753.00	2023.1	2776.1	2.1171	4.4869	6.6040
1.00	179.91	0.001127	0.19444	761.67	1822.0	2583.6	762.79	2015.3	2778.1	2.1386	4.4478	6.5864
1.10	184.09	0.001133	0.17753	780.08	1806.3	2586.4	781.32	2000.4	2781.7	2.1791	4.3744	6.5535
1.20	187.99	0.001139	0.16333	797.27	1791.6	2588.8	798.64	1986.2	2784.8	2.2165	4.3067	6.5233
1.30	191.64	0.001144	0.15125	813.42	1777.5	2590.9	814.91	1972.7	2787.6	2.2514	4.2438	6.4953
1.40	195.07	0.001149	0.14084	828.68	1764.1	2592.8	830.29	1959.7	2790.0	2.2842	4.1850	6.4692
1.50	198.32	0.001154	0.13177	843.14	1751.3	2594.5	844.87	1947.3	2792.1	2.3150	4.2198	6.4448
1.75	205.76	0.001166	0.11349	876.44	1721.4	2597.8	878.48	1918.0	2796.4	2.3851	4.0044	6.3895
2.00	212.42	0.001177	0.09963	906.42	1693.8	2600.3	908.77	1890.7	2799.5	2.4473	3.8935	6.3408
2.25	218.45	0.001187	0.08875	933.81	1668.2	2602.0	936.48	1865.2	2801.7	2.5034	3.7938	6.2971

Molar mass, gas constant, and critical-point properties

Substance	Formula	Molar mass, M kg/kmol	Gas constant, R kJ/kg·K*	Critical-point properties: Temperature, K	Pressure, MPa	Volume, m^3/kmol
Air	—	28.97	0.2870	132.5	3.77	0.0883
Ammonia	NH_3	17.03	0.4882	405.5	11.28	0.0724
Argon	Ar	39.948	0.2081	151	4.86	0.0749
Benzene	C_6H_6	78.115	0.1064	562	4.92	0.2603
Bromine	Br_2	159.808	0.0520	584	10.34	0.1355
n-Butane	C_4H_{10}	58.124	0.1430	425.2	3.80	0.2547
Carbon dioxide	CO_2	44.01	0.1889	304.2	7.39	0.0943
Carbon monoxide	CO	28.011	0.2968	133	3.50	0.0930
Carbon tetrachloride	CCl_4	153.82	0.05405	556.4	4.56	0.2759
Chlorine	Cl_2	70.906	0.1173	417	7.71	0.1242
Chloroform	$CHCl_3$	119.38	0.06964	536.6	5.47	0.2403
Dichlorodifluoromethane (R-12)	CCl_2F_2	120.91	0.06876	384.7	4.01	0.2179
Dichlorofluoromethane (R-21)	$CHCl_2F$	102.92	0.08078	451.7	5.17	0.1973
Ethane	C_2H_6	30.070	0.2765	305.5	4.48	0.1480
Ethyl alcohol	C_2H_5OH	46.07	0.1805	516	6.38	0.1673
Ethylene	C_2H_4	28.054	0.2964	282.4	5.12	0.1242
Helium	He	4.003	2.0769	5.3	0.23	0.0578
n-Hexane	C_6H_{14}	86.179	0.09647	507.9	3.03	0.3677
Hydrogen (normal)	H_2	2.016	4.1240	33.3	1.30	0.0649
Krypton	Kr	83.80	0.09921	209.4	5.50	0.0924
Methane	CH_4	16.043	0.5182	191.1	4.64	0.0993
Methyl alcohol	CH_3OH	32.042	0.2595	513.2	7.95	0.1180
Methyl chloride	CH_3Cl	50.488	0.1647	416.3	6.68	0.1430
Neon	Ne	20.183	0.4119	44.5	2.73	0.0417
Nitrogen	N_2	28.013	0.2968	126.2	3.39	0.0899
Nitrous oxide	N_2O	44.013	0.1889	309.7	7.27	0.0961
Oxygen	O_2	31.999	0.2598	154.8	5.08	0.0780
Propane	C_3H_8	44.097	0.1885	370	4.26	0.1998
Propylene	C_3H_6	42.081	0.1976	365	4.62	0.1810
Sulfur dioxide	SO_2	64.063	0.1298	430.7	7.88	0.1217
Tetrafluoroethane (R-134a)	CF_3CH_2F	102.03	0.08149	374.2	4.059	0.1993
Trichlorofluoromethane (R-11)	CCl_3F	137.37	0.06052	471.2	4.38	0.2478
Water	H_2O	18.015	0.4615	647.1	22.06	0.0560
Xenon	Xe	131.30	0.06332	289.8	5.88	0.1186

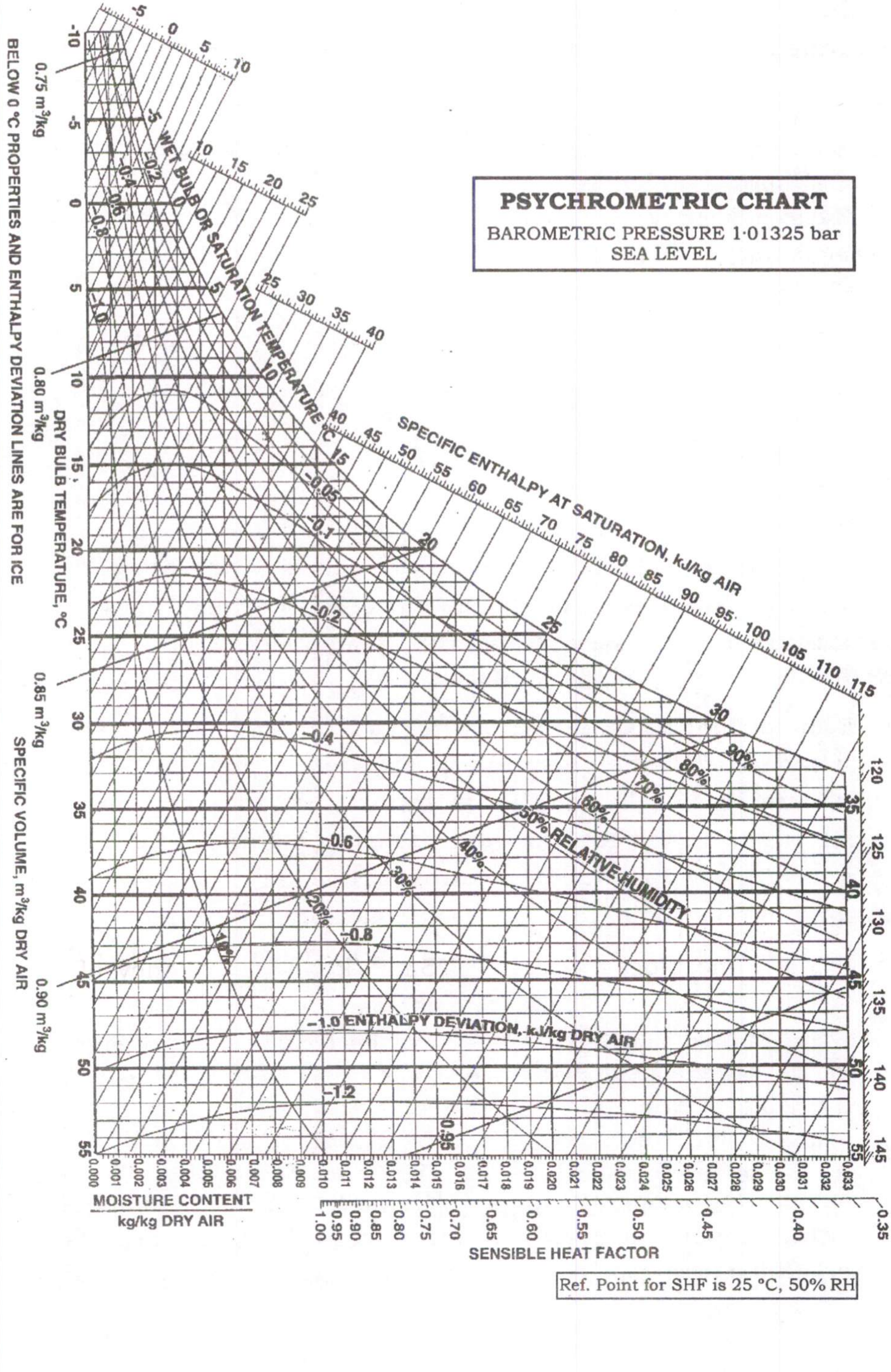
***The unit kJ/kg·K is equivalent to kPa·m^3/kg·K. The gas constant is calculated from $R=R_u/M$, where R_u=8.31447 kJ/kmol·K and M is the molar mass.**

Ideal-gas specific heats of various common gases

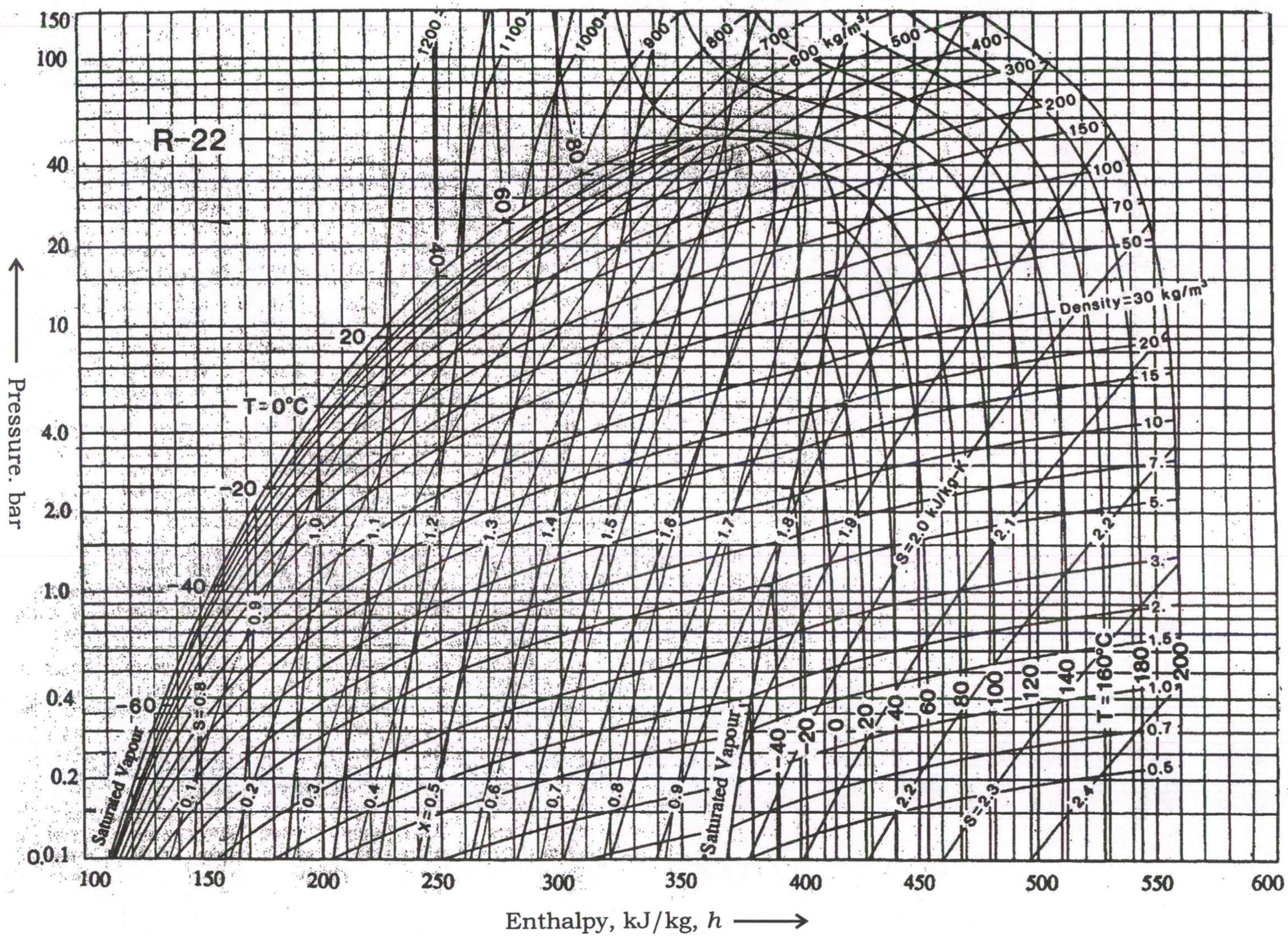
At 300 K

Gas	Formula	Gas constant, R kJ/kg·K	c_p kJ/kg·K	c_v kJ/kg·K	k
Air	—	0.2870	1.005	0.718	1.400
Argon	Ar	0.2081	0.5203	0.3122	1.667
Butane	C_4H_{10}	0.1433	1.7164	1.5734	1.091
Carbon dioxide	CO_2	0.1889	0.846	0.657	1.289
Carbon monoxide	CO	0.2968	1.040	0.744	1.400
Ethane	C_2H_6	0.2765	1.7662	1.4897	1.186
Ethylene	C_2H_4	0.2964	1.5482	1.2518	1.237
Helium	He	2.0769	5.1926	3.1156	1.667
Hydrogen	H_2	4.1240	14.307	10.183	1.405
Methane	CH_4	0.5182	2.2537	1.7354	1.299
Neon	Ne	0.4119	1.0299	0.6179	1.667
Nitrogen	N_2	0.2968	1.039	0.743	1.400
Octane	C_8H_{18}	0.0729	1.7113	1.6385	1.044
Oxygen	O_2	0.2598	0.918	0.658	1.395
Propane	C_3H_8	0.1885	1.6794	1.4909	1.126
Steam	H_2O	0.4615	1.8723	1.4108	1.327

***Note*: The unit kJ/kg·K is equivalent to kJ/kg·°C.**


PSYCHROMETRIC CHART
BAROMETRIC PRESSURE 1·01325 bar
SEA LEVEL
WET BULB OR SATURATION TEMPERATURE °C
SPECIFIC ENTHALPY AT SATURATION, kJ/kg AIR
RELATIVE HUMIDITY
ENTHALPY DEVIATION, kJ/kg DRY AIR
DRY BULB TEMPERATURE, °C
SPECIFIC VOLUME, m³/kg DRY AIR
BELOW 0 °C PROPERTIES AND ENTHALPY DEVIATION LINES ARE FOR ICE
0.75 m³/kg
0.80 m³/kg
0.85 m³/kg
0.90 m³/kg
MOISTURE CONTENT
kg/kg DRY AIR
SENSIBLE HEAT FACTOR
Ref. Point for SHF is 25 °C, 50% RH

R-22 Refrigerant Chart



Saturated Steam Pressure Table

p bar	t °C	v_f m^3/kg	v_g m^3/kg	h_f kJ/kg	h_g kJ/kg	h_{fg} kJ/kg	s_f kJ/kg-K	s_g kJ/kg-K
0.010	6.9828	.0010001	129.21	29.34	2514.4	2485.0	.1060	8.9767
0.015	13.036	.0010006	67.982	54.71	2525.5	2470.7	.1957	8.8288
0.020	17.513	.0010012	67.006	73.46	2533.6	2460.2	.2607	8.7246
0.025	21.096	.0010020	54.256	88.45	2540.2	2451.7	.3119	8.6440
0.030	24.100	.0010027	45.667	101.00	2545.6	2444.6	.3544	8.5785
0.035	26.694	.0010033	39.479	111.85	2550.4	2438.5	.3907	8.5232
0.040	28.963	.0010040	34.802	121.41	2554.5	2433.1	.4225	8.4755
0.045	31.035	.0010046	31.141	129.99	2558.2	2428.2	.4507	8.4335
0.050	32.898	.0010052	28.194	137.77	2561.6	2423.8	.4763	8.3960
0.055	34.605	.0010058	25.771	144.91	2564.7	2419.8	.4995	8.3621
0.060	36.183	.0010064	23.741	151.50	2567.5	2416.0	.5209	8.3312
0.065	37.651	.0010069	22.016	157.64	2570.2	2412.5	.5407	8.3029
0.070	39.025	.0010074	20.531	163.38	2572.6	2409.2	.5591	8.2767
0.075	40.316	.0010079	19.239	168.77	2574.9	2406.2	.5763	8.2523
0.080	41.534	.0010084	18.105	173.86	2577.1	2403.2	.5925	8.2296
0.085	42.689	.0010089	17.100	178.69	2579.2	2400.5	.6079	8.2082
0.090	43.787	.0010094	16.204	183.28	2581.1	2397.9	.6224	8.1881
0.095	44.833	.0010098	15.400	187.65	2583.0	2395.3	.6361	8.1691
0.100	45.833	.0010102	14.675	191.83	2584.8	2392.9	.6493	8.1511
0.11	47.710	.0010111	13.416	199.68	2588.1	2388.4	.6738	8.1177
0.12	49.446	.0010119	12.362	206.94	2591.2	2384.3	.6963	8.0872
0.13	51.062	.0010126	11.466	213.70	2594.0	2380.3	.7172	8.0592
0.14	52.574	.0010133	10.694	220.02	2596.7	2376.7	.7367	8.0334
0.15	53.997	.0010140	10.023	225.97	2599.2	2373.2	.7549	8.0093
0.16	55.341	.0010147	9.4331	231.59	2601.6	2370.0	.7721	7.9869
0.17	56.615	.0010154	8.9110	236.92	2603.8	2366.9	.7883	7.9658
0.18	57.826	.0010160	8.4452	241.99	2605.9	2363.9	.8036	7.9460
0.19	58.982	.0010166	8.0272	246.83	2607.9	2361.1	.8182	7.9272
0.20	60.086	.0010172	7.6498	251.45	2609.9	2358.4	.8321	7.9094
0.21	61.145	.0010178	7.3073	255.88	2611.7	2355.8	.8453	7.8925
0.22	62.162	.0010183	6.9951	260.14	2613.5	2353.3	.8581	7.8764
0.23	63.139	.0010189	6.7093	264.23	2615.2	2350.9	.8702	7.8611
0.24	64.082	.0010194	6.4467	268.18	2616.8	2348.6	.8820	7.8464
0.25	64.992	.0010199	6.2045	271.99	2618.3	2346.4	.8932	7.8323
0.26	65.871	.0010204	5.9803	275.67	2619.9	2344.2	.9041	7.8188
0.27	66.722	.0010209	5.7724	279.24	2621.3	2342.1	.9146	7.8058
0.28	67.547	.0010214	5.5788	282.69	2622.7	2340.0	.9248	7.7933
0.29	68.347	.0010219	5.3982	286.05	2624.1	2338.1	.9346	7.7812
0.30	69.124	.0010223	4.2293	289.30	2625.4	2336.1	.9441	7.7695
0.32	70.615	.0010232	4.9223	295.55	2628.0	2332.4	.9623	7.7474
0.34	72.029	.0010241	4.6504	301.48	2630.4	2328.9	.9795	7.7266
0.36	73.374	.0010249	4.4078	307.12	2632.6	2325.5	.9958	7.7070
0.38	74.658	.0010257	4.1900	312.50	2634.8	2322.3	1.0113	7.6884
0.40	75.886	.0010265	3.9934	317.65	2636.9	2319.2	1.0261	7.6709
0.45	78.743	.0010284	3.5762	329.64	2641.7	2312.0	1.0603	7.6307
0.50	81.345	.0010301	3.2402	340.56	2646.0	2305.4	1.0912	7.5947
0.55	83.737	.0010317	2.9636	350.61	2649.9	2299.3	1.1194	7.5623
0.60	85.954	.0010333	2.7318	359.93	2653.6	2293.6	1.1454	7.5327
0.65	88.021	.0010347	2.5346	368.62	2656.9	2288.3	1.1696	7.5055
0.70	89.959	.0010361	2.3647	376.77	2660.1	2283.3	1.1921	7.4804
0.75	91.785	.0010375	2.2169	384.45	2663.0	2278.6	1.2131	7.4570
0.80	93.512	.0010387	2.0870	391.72	2665.8	2274.1	1.2330	7.4352
0.85	95.152	.0010400	1.9719	398.63	2668.4	2269.8	1.2518	7.4147
0.90	96.713	.0010412	1.8692	405.21	2670.9	2265.6	1.2696	7.3954
0.95	98.204	.0010423	1.7770	411.49	2673.2	2261.7	1.2865	7.3771
1.0	99.632	.0010434	1.6937	417.51	2675.4	2257.9	1.3027	7.3598
1.1	102.32	.0010455	1.5492	428.84	2679.6	2250.8	1.3330	7.3277
1.2	104.81	.0010476	1.4281	439.36	2683.4	2244.1	1.3609	7.2984
1.3	107.13	.0010495	1.3251	449.19	2687.0	2237.8	1.3868	7.2715
1.4	109.32	.0010513	1.2363	458.42	2690.3	2231.9	1.4109	7.2465
1.5	111.37	.0010530	1.1590	467.13	2693.4	2226.2	1.4336	7.2234
1.6	113.32	.0010547	1.0911	475.38	2696.2	2220.9	1.4550	7.2017
1.7	115.17	.0010563	1.0309	483.22	2699.0	2215.7	1.4752	7.1813
1.8	116.93	.0010579	.97723	490.70	2701.5	2210.8	1.4944	7.1622
1.9	118.62	.0010594	.92900	497.85	2704.0	2206.1	1.5127	7.1440

Saturated Steam Pressure Table

p bar	t °C	v_f m³/kg	v_g m³/kg	h_f kJ/kg	h_g kJ/kg	h_{fg} kJ/kg	s_f kJ/kg-K	s_g kJ/kg-K
2.0	120.23	.0010608	.88544	504.70	2706.3	2201.6	1.5301	7.1268
2.1	121.78	.0010623	.84590	511.28	2708.5	2197.2	1.5468	7.1105
2.2	123.27	.0010636	.80984	517.62	2710.6	2193.0	1.5627	7.0949
2.3	124.71	.0010650	.77681	523.73	2712.6	2188.9	1.5781	7.0800
2.4	126.09	.0010663	.74645	529.63	2714.5	2184.9	1.5929	7.0657
2.5	127.43	.0010675	.71844	535.34	2716.4	2181.0	1.6071	7.0520
2.6	128.73	.0010688	.69251	540.87	2718.2	2177.3	1.6209	7.0389
2.7	129.98	.0010700	.66844	546.24	2719.9	2173.6	1.6342	7.0262
2.8	131.20	.0010712	.64604	551.44	2721.5	2170.1	1.6471	7.0140
2.9	132.39	.0010724	.62513	556.50	2723.1	2166.6	1.6595	7.0023
3.0	133.54	.0010735	.60556	561.43	2724.7	2163.2	1.6716	6.9909
3.1	134.66	.0010746	.58722	566.23	2726.1	2159.9	1.6834	6.9799
3.2	135.75	.0010757	.56999	570.90	2727.6	2156.7	1.6948	6.9693
3.3	136.82	.0010768	.55376	575.46	2729.0	2153.5	1.7059	6.9589
3.4	137.86	.0010779	.53846	579.92	2730.3	2150.4	1.7168	6.9489
3.5	138.87	.0010789	.52400	584.27	2731.6	2147.4	1.7273	6.9392
3.6	139.86	.0010799	.51032	588.53	2732.9	2144.4	1.7376	6.9297
3.7	140.83	.0010809	.49736	592.69	2734.1	2141.4	1.7476	6.9205
3.8	141.78	.0010819	.48505	596.76	2735.3	2138.6	1.7574	6.9116
3.9	142.71	.0010829	.47336	600.76	2736.5	2135.7	1.7670	6.9028
4.0	143.62	.0010839	.46222	604.67	2737.6	2133.0	1.7764	6.8943
4.1	144.52	.0010848	.45162	608.51	2738.7	2130.2	1.7856	6.8860
4.2	145.39	.0010858	.44150	612.27	2739.8	2127.5	1.7945	6.8779
4.3	146.25	.0010867	.43184	615.97	2740.9	2124.9	1.8033	6.8700
4.4	147.09	.0010876	.42260	619.60	2741.9	2122.3	1.8120	6.8623
4.5	147.92	.0010885	.41375	623.16	2742.9	2119.7	1.8204	6.8547
4.6	148.73	.0010894	.40528	626.67	2743.9	2117.2	1.8287	6.8473
4.7	149.53	.0010903	.39716	630.11	2744.8	2114.7	1.8368	6.8401
4.8	150.31	.0010911	.38936	633.50	2745.7	2112.2	1.8448	6.8330
4.9	151.08	.0010920	.38188	636.83	2746.6	2109.8	1.5227	6.8260
5.0	151.84	.0010928	.37468	640.12	2747.5	2107.4	1.8604	6.8192
5.2	153.33	.0010945	.36108	646.53	2749.3	2102.7	1.8754	6.8059
5.4	154.76	.0010961	.34846	652.76	2750.9	2098.1	1.8899	6.7932
5.6	156.16	.0010977	.33671	658.81	2752.5	2093.7	1.9040	6.7809
5.8	157.52	.0010993	.32574	664.69	2754.0	2089.3	1.9176	6.7690
6.0	158.84	.0011009	.31547	670.42	2755.5	2085.0	1.9308	6.7575
6.2	160.12	.0011024	.30585	676.01	2756.9	2080.9	1.9437	6.7464
6.4	161.38	.0011039	.29681	681.46	2758.2	2076.8	1.9562	6.7357
6.6	162.60	.0011053	.28830	686.78	2759.5	2072.7	1.9684	6.7252
6.8	163.79	.0011068	.28027	691.98	2760.8	2068.8	1.9802	6.7150
7.0	164.96	.0011082	.27268	697.06	2762.0	2064.9	1.9918	6.7052
7.2	166.10	.0011096	.26550	702.03	2763.2	2061.1	2.0031	6.6956
7.4	167.21	.0011110	.25870	706.90	2764.3	2037.4	2.1041	6.6862
7.6	168.30	.0011123	.25224	711.67	2765.4	2053.7	2.0249	6.6771
7.8	169.37	.0011137	.24610	716.35	2766.4	2050.1	2.0354	6.6683
8.0	170.41	.0011150	.24026	720.94	2767.5	2046.5	2.0457	6.6596
8.2	171.44	.0011163	.23469	725.43	2768.5	2043.0	2.0558	6.6511
8.4	172.45	.0011176	.22938	729.85	2769.4	2039.6	2.0657	6.6429
8.6	173.44	.0011188	.22430	734.19	2770.4	2036.2	2.0753	6.6348
8.8	174.41	.0011201	.21945	738.45	2771.3	2032.8	2.0848	6.6269
9.0	175.36	.0011213	.21481	742.64	2772.1	2029.5	2.0941	6.6192
9.2	176.29	.0011226	.21036	746.76	2773.0	2026.2	2.1033	6.6116
9.4	177.21	.0011238	.20610	750.82	2773.8	2023.0	2.1122	6.6042
9.6	178.12	.0011250	.20201	754.81	2774.6	2019.8	2.1210	6.5969
9.8	179.01	.0011262	.19807	758.74	2775.4	2016.7	2.1297	6.5898
10.0	179.88	.0011274	.19429	762.61	2776.2	2013.6	2.1382	6.5828
10.5	182.02	.0011303	.18545	772.03	2778.0	2005.9	2.1588	6.5659
11.0	184.07	.0011331	.17738	781.12	2779.7	1998.5	2.1786	6.5497
11.5	186.05	.0011359	.16999	789.92	2781.3	1991.3	2.1977	6.5342
12.0	187.96	.0011386	.16320	798.43	2782.7	1984.3	2.2161	6.5194
12.5	189.81	.0011412	.15693	806.69	2784.1	1977.4	2.2338	6.5051
13.0	191.61	.0011433	.15113	814.70	2785.4	1970.7	2.2510	6.4913
13.5	193.35	.0011464	.14574	822.49	2786.6	1964.2	2.2676	6.4780
14.0	195.04	.0011489	.14072	830.07	2787.8	1957.7	2.2837	6.4651
14.5	196.69	.0011514	.13604	837.46	2788.9	1951.4	2.2992	6.4526

Saturated Steam Pressure Table

p bar	t °C	v_f m³/kg	v_g m³/kg	h_f kJ/kg	h_g kJ/kg	h_{fg} kJ/kg	s_f kJ/kg-K	s_g kJ/kg-K
15.0	198.29	.0011539	.13166	844.66	2789.9	1945.2	2.3145	6.4406
15.5	199.85	.0011563	.12755	851.69	2790.8	1939.2	2.3292	6.4289
16.0	201.37	.0011586	.12369	858.56	2791.7	1933.2	2.3436	6.4175
16.5	202.86	.0011610	.12005	865.28	2792.6	1927.3	2.3576	6.4065
17.0	204.31	.0011633	.11662	871.84	2793.4	1921.5	2.3713	6.3957
17.5	205.72	.0011656	.11338	878.27	2794.1	1915.9	2.3846	6.3853
18.0	207.11	.0011678	.11032	884.57	2794.8	1910.9	2.3976	6.3751
18.5	208.47	.0011701	.10741	890.75	2795.5	1904.7	2.4103	6.3651
19.0	209.80	.0011723	.10465	896.81	2796.1	1899.3	2.4228	6.3554
19.5	211.10	.0011744	.10203	902.75	2796.7	1893.9	2.4349	6.3459
20.0	212.37	.0011766	.099536	908.59	2797.2	1888.6	2.4469	6.3367
20.5	213.63	.0011787	.097158	914.32	2797.7	1883.4	2.4585	6.3276
21.0	214.85	.0011809	.094890	919.96	2798.2	1878.2	2.4700	6.3187
21.5	216.06	.0011830	.092723	925.50	2798.6	1873.1	2.4812	6.3100
22.0	217.24	.0011850	.090652	930.95	2799.1	1868.1	2.4922	6.3015
22.5	218.41	.0011871	.088669	936.32	2799.4	1863.1	2.5030	6.2931
23.0	219.55	.0011892	.086769	941.60	2799.8	1858.2	2.5136	6.2849
23.5	220.68	.0011912	.084948	946.80	2800.1	1853.3	2.5241	6.2769
24.0	221.78	.0011932	.083199	951.93	2800.4	1848.5	2.5343	6.2690
24.5	222.87	.0011952	.081520	956.98	2800.7	1843.7	2.5444	6.2612
25.0	223.94	.0011972	.079905	961.96	2800.9	1839.0	2.5543	6.2536
25.5	225.00	.0011991	.078352	966.87	2801.2	1834.3	2.5640	6.2461
26.0	226.04	.0012011	.076856	971.72	2801.4	1829.6	2.5736	6.2387
26.5	227.06	.0012031	.075415	976.50	2801.6	1825.1	2.5831	6.2315
27.0	228.07	.0012050	.074025	981.22	2801.7	1820.5	2.5924	6.2244
27.5	229.07	.0012069	.072684	985.88	2801.9	1816.0	2.6016	6.2173
28.0	230.05	.0012088	.071389	990.48	2802.0	1811.5	2.6106	6.2104
28.5	231.01	.0012107	.070138	995.03	2802.1	1807.1	2.6195	6.2036
29.0	231.97	.0012126	.068928	999.52	2802.2	1802.6	2.6283	6.1969
29.5	232.91	.0012145	.067758	1003.96	2802.2	1798.3	2.6370	6.1903
30.0	233.84	.0012163	.066626	1008.35	2802.3	1793.9	2.6455	6.1837
31.0	235.67	.0012200	.064467	1016.99	2802.3	1785.4	2.6623	6.1709
32.0	237.45	.0012237	.062439	1025.43	2802.3	1776.9	2.6786	6.1585
33.0	239.18	.0012274	.060529	1033.70	2802.3	1768.6	2.6945	6.1463
34.0	240.88	.0012310	.058728	1041.81	2802.1	1760.3	2.7101	6.1344
35.0	242.54	.0012345	.057025	1049.76	2802.0	1752.2	2.7253	6.1228
36.0	244.16	.0012381	.055415	1057.56	2801.7	1744.2	2.7401	6.1115
37.0	245.75	.0012416	.053881	1065.21	2801.4	1736.2	2.7547	6.1004
38.0	247.31	.0012451	.052438	1072.74	2801.1	1728.4	2.7689	6.0896
39.0	248.84	.0012486	.051061	1080.13	2800.8	1720.6	2.7829	6.0789
40.0	250.33	.0012521	.049749	1087.40	2800.3	1712.9	2.7965	6.0685
40.1	251.80	.0012555	.048500	1094.56	2799.9	1705.3	2.8099	6.0583
42.0	253.24	.0012589	.047307	1101.60	2799.4	1697.8	2.8231	6.0482
43.0	254.66	.0012623	.046168	1108.54	2798.9	1690.3	2.8360	6.0383
44.0	256.05	.0012657	.045079	1115.38	2798.3	1682.9	2.8487	6.0286
45.0	257.41	.0012691	.044037	1122.11	2797.7	1675.6	2.8612	6.0191
46.0	258.75	.0012725	.043038	1128.76	2797.0	1668.3	2.8735	6.0097
47.0	260.07	.0012758	.042081	1135.31	2796.4	1661.1	2.8855	6.0004
48.0	261.37	.0012792	.041161	1141.78	2795.7	1653.9	2.8974	5.9913
49.0	262.65	.0012825	.040278	1148.16	2794.9	1646.8	2.9091	5.9824
50.0	263.91	.0012858	.039429	1154.47	2794.2	1639.7	2.9206	5.9735
51.0	265.15	.0012891	.038611	1160.69	2793.4	1632.7	2.9313	5.9648
52.0	266.37	.0012924	.037824	1166.85	2792.6	1625.7	2.9431	5.9561
53.0	267.58	.0012957	.037066	1172.93	2791.7	1618.8	2.9541	5.9476
54.0	268.76	.0012990	.036334	1178.94	2790.8	1611.9	2.9650	5.9392
55.0	269.93	.0013023	.035628	1184.89	2789.9	1605.0	2.9757	5.9309
56.0	271.09	.0013056	.034946	1190.77	2789.0	1598.2	2.9863	5.9227
57.0	272.22	.0013089	.034288	1196.59	2788.0	1591.4	2.9968	5.9146
58.0	273.35	.0013121	.033651	1202.35	2787.0	1584.7	3.0071	5.9066
59.0	274.46	.0013154	.033034	1208.05	2786.0	1578.0	3.0172	5.8986
60.0	275.55	.0013187	.032438	1213.69	2785.0	1571.3	3.0273	5.8908
61.0	276.63	.0013219	.031860	1219.28	2784.0	1564.7	3.0372	5.8830
62.0	277.70	.0013252	.031300	1224.82	2782.9	1558.0	3.0471	5.8753
63.0	278.75	.0013285	.030757	1230.31	2781.8	1551.5	3.0568	5.8677
64.0	279.79	.0013317	.030230	1235.75	2780.6	1544.9	3.0664	5.8601

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Mechanical Engineering Paper II

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 divided in **TWO** sections.*

*Candidate has to attempt **FIVE** questions in all.*

*Questions No. **1** and **5** are compulsory and out of the remaining, **THREE** are to be attempted choosing at least **ONE** question from each section.*

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

Wherever any assumptions are made for answering a question, they must be clearly indicated.

Diagrams/Figures, wherever required, shall be drawn in the space provided for answering the question itself.

Unless otherwise mentioned, symbols and notations have their usual standard meanings.

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly.

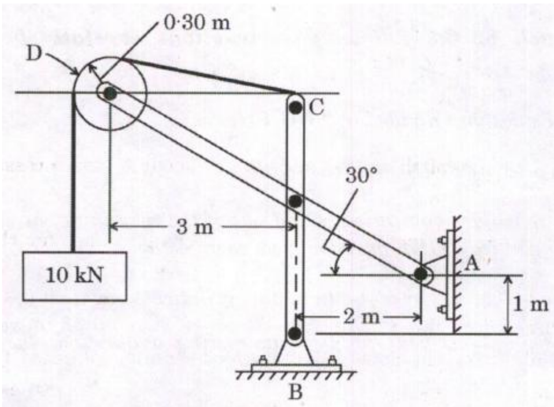
Any page or portion of the page left blank in the Question-cum-Answer (QCA) Booklet must be clearly struck off.

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

SECTION—A

Q1. (a) A circular bar *ABC*, 4 m long, is rigidly fixed at its ends *A* and *C*. The portion *AB* is 2.8 m long and of 50 mm diameter whereas *BC* is 1.2 m long and of 25 mm diameter. If the twisting moment of 700 Nm is applied at *B*, determine the values of the resisting moments at *A* and *C* and the maximum stress in each section of the shaft. For the material of the shaft $G = 80\ GN/m^2$. 12

(b) What are supporting forces for the frame? Neglect all weights except the 10 kN weight. 12

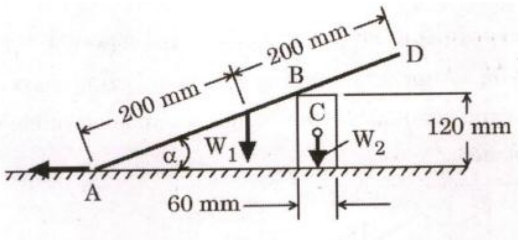


(c) An electronic instrument is to be isolated from a panel that vibrates at frequencies ranging from 25 Hz to 35 Hz. It is estimated that at least 80% vibration isolation must be achieved to prevent damage to the instrument. If the instrument weighs 85 N, find the necessary static deflection of the isolator. 12

(d) Describe all the inversions of a slider-crank mechanism. 12

(e) A structure is composed of circular members of diameter d. At a certain position along one member the loading is found to consist of a shear force of 10 kN along with an axial tensile load of 20 kN. If the elastic limit in tension of the material of the members is 300 MN/m² and there is to be a factor of safety of 3, estimate the magnitude of d required according to the maximum shear strain energy per unit volume theory. Poisson's ratio $\nu = 0.3$. 12

Q2. (a) The rod AD is pulled at A and it moves to the left. If the coefficient of dynamic friction for the rod at A and B is 0.4, what must the minimum of W_2 be to prevent the block from tipping when $\alpha = 20°$? With this value of W_2, determine the minimum coefficientof static friction between the block and the supporting plane needed to just prevent the block from sliding. Take $W_1 = 100$ N. 20

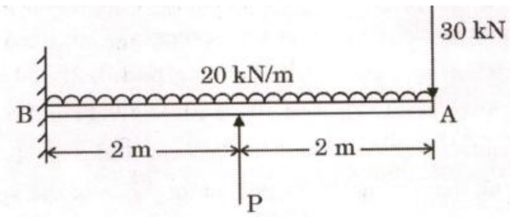


(b) (i) Define pitch point, addendum, module and pressure angle as applied to toothed gears. 8

(ii) Compare involute curve with cycloidal curve for the profiles of gear teeth. 12

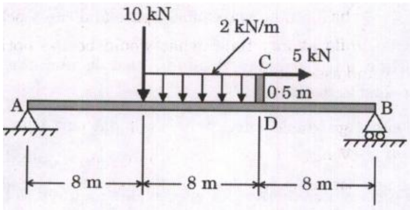
(c) A single plate clutch (both sides effective) is required to transmit 27 kW at 1600 rpm. The outer diameter of the plate is limited to 30 cm, and intensity of pressure between the plates is not to exceed 0.1 N/mm². Assuming uniform wear and a coefficient of friction 0.3, find the required inner diameter of the plates, and axial force necessary to engage the clutch. 20

Q3. (a) Find the slope and deflection at the tip of the cantilever shown in the figure. What load P must be applied upwards at mid-span to reduce the deflection by half? $EI = 20$ MN/m². 20



(b) The axes of a three-cylinder air compressor are 120° apart and their connecting rods are connected to a common crank. The length of each connecting rod is 200 mm and the stroke is 160 mm. The mass of the reciprocating parts per cylinder is 2 kg. Find the maximum primary and secondary forces acting on the frame of the compressor when running at 2500 rpm. 20

(c) A simply supported beam AB is shown in the figure. A bar CD is welded to the beam. After determining the supporting forces, sketch the shear force and bending moment diagrams and determine the maximum bending moment. 20



Q4. (a) A uniform T-section beam is 100 mm wide and 150 mm deep with flange thickness of 25 mm and a web thickness of 12 mm. If the limiting bending stresses for the material of the beam are 80 MN/m^2 in compression and 160 MN/m^2 in tension, find the maximum u.d.l. that the beam can carry over a simply supported span of 5 m. 20

(b) In a spring loaded governor of Hartnell type, the weight of each ball is 5 kg and the lift of the sleeve is 5 cm. The speed at which the governor begins to float is 250 rpm, and at this speed the radius of the ball path is 10 cm. The mean working speed of the governor is 20 times the range of speed when friction is neglected. If the lengths of ball and roller arm of the bell crank lever are 12 cm and 10 cm respectively and if the distance between the centre of pivot of bell crank lever and axis of the governor spindle is 14 cm determine the initial compression of the spring, taking into account obliquity of arms. 20

(c) (i) What are the assumptions made in the Lewis equation for beam strength? 8

(ii) A pair of spur gears with 20° full depth involute teeth consists of a 20 teeth pinion meshing with a 50 teeth gear. The pinion is mounted on a crank shaft of 5 kW engine running at 1200 rpm. The driven shaft is connected to a compressor. The pinion as well as the gear is made of steel having ultimate strength in tension equal to 500 N/mm^2. The module and face width of the gears are 4 mm and 44 mm. Assume service factor as 2. Using the velocity factor to account for the dynamic load, determine the factor of safety. Take Lewis form factor for 20 teeth equal to 0.320 and for 50 teeth equal to 0.408. Take velocity factor, $C_v = \frac{3}{3+V}$, where V is the pitch line velocity in m/s. 12

SECTION—B

Q5. (a) What is the distinction between hypoeutectoid and hypereutectoid steels? Explain the development of microstructure in a hypoeutectoid steel with the help of neatly labelled diagram. 12

(b) With the help of schematic diagram, discuss the following: 12

(i) Single manufacturing cell.

(ii) Flexible manufacturing cell.

(iii) Flexible manufacturing system.

(c) (i) Express unilateral and bilateral tolerances with the help of diagram considering normal size 24.00 mm and tolerance 0.030 mm. 6

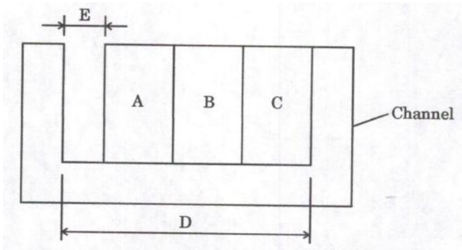
(ii) Three blocks A, B and C are to be assembled in a channel of dimension D as shown in figure. Determine the tolerance that must be assigned to D, if it is essential that the minimum gap E is not less than 0.005 mm. The dimensions of blocks are: 6

$A = 0.75 \pm 0.003$ mm

$B = 1.0 \pm 0.005$ mm

$C = 1.125 \pm 0.004$ mm

Consider basic dimension of channel $D = 2.894$ mm.



(d) (i) Why is it necessary to schedule debris sampling for wear debris? 6

(ii) Wear particles of spherical shape were found in a wear debris sample. What is the possible mode of failure for such case? Justify. 6

(e) Each unit of an item costs a company Rs. 40. Annual holding costs are 18% of unit cost for interest charges, 1% for insurance, 2% allowances for obsolescence, Rs. 2 for building overheads, Rs. 1.50 for damage and loss, and Rs. 4 miscellaneous cost. Annual demand for the item is constant at 1,000 units and each order costs Rs. 100 to place.

(i) Calculate EOQ and the total costs associated with stocking the item.

(ii) If the supplier of the item will only deliver batches of 250 units, how are the stock holding costs affected?

(iii) If the supplier relaxes his order size requirement, but the company has limited warehouse space and can stock a maximum of 100 units at any time, what would be the optimal ordering policy and associated costs? 12

Q6. (a) (i) The voltage-length characteristic of a direct current (dc) arc is given by $V = (20 + 40l)$ volts, where l is the length of the arc in cm. The power source characteristic is approximated by a straight line with an open circuit voltage = 80V and a short circuit current = 1000 amp. Determine the optimum arc length and the corresponding arc power. 12

(ii) Enlist the most common defects encountered in sand mould casting. Describe the reasons for Scab and Misrun. 8

(b) (i) Compare gray, malleable, white and modular cast irons with respect to (I) composition and heat treatment, (II) microstructure, and (III) mechanical properties. 12

(ii) Make a schematic plot showing the tensile engineering stress-strain behaviour for mild steel and label the salient points. State the reason of occurrence of two yield points in mild steel. Also, explain the following on the basis of the plot (I) Ductility, (II) Resilience, and (III) Toughness. 8

(c) (i) (I) Derive the characteristic equation for the piezoelectric accelerometer supporting a mass (M) on a spring of stiffness (K) and viscous damper with damping coefficient (C). Assume the input and output displacement to be (X_i) and (X_0) respectively.

(II) What is the amplitude ratio for a frequency response analysis assuming input displacement to be sinusoidal? 10

(ii) An accelerometer is designed with a seismic mass of 0.05 kg, a spring constant of 5000 N/m, and a damping constant of 30 NS/m. If the accelerometer is mounted to an object experiencing displacement $x_i = 5 \sin(100t)$ mm, find an expression for the steady state relative displacement of seismic mass relative to housing as a function of time $x_r(t)$. 10

Q7. (a) (i) An engine is to be designed to have a minimum reliability of 0.8 and minimum availability of 0.98 over a period of 2×10^3 hours. Determine MTTR and frequency of failures of engine. 8

(ii) Explain the mechanism of chip formation. What are the conditions that result in the formation of 12

(I) Continuous chips without built up edge,

(II) Continuous chips with built up edge,

(III) Discontinuous chips ?

(b) Explain with the working principle a suitable Non-Destructive Testing (NDT) technique to be used for detecting surface as well as fully embedded defects for a wide range of materials including polymers. Also, list the other NDT techniques with reasoning that are not suitable for inspection of above described requirements. 20

(c) (i) A 12-bit Analog-to-Digital Converter operating at a sampling rate of 5 kHz is used with a sensor. What is the size of computer memory (in bytes) required to store 20 seconds of sensor data? What will be the memory size in case a 8-bit Analog to Digital Converter is used? Why is it not possible to connect sensors such as accelerometers, strain gauges and thermocouple directly to a microprocessor or computer? 12

(ii) A CNC machine tool table is powered by a servo motor, lead screw and optical encoder. The lead screw has a pitch of 5 mm and is connected to the motor shaft with a gear ratio of 16 : 1. The optical encoder connected directly to the lead screw generates 200 pulses per revolution of the lead screw. The table moves a distance of 100 mm at a feed rate of 500 mm/min.
Determine the pulse count received by the control system to verify that the table has moved exactly 100 mm. 8

Q8. (a) An automatic door is designed to open the door when a person approaches and close automatically after five seconds. The door is operated by an electric motor-based actuator, responsible for sliding the door on rail.

(i) Explain the working mechanism assuming a microprocessor based control using a schematic diagram of the control system used. Also, specify the primary components of the control system.

(ii) If a microcontroller based system is used, what would be the merits and demerits of such system? 20

(b) (i) It is desired to measure the angular position of a motor shaft with a set-up using two Hall Sensors *A* and *B* and a permanent magnet multi-pole wheel. Explain the logic that is used for measuring the position as well as direction of the motor shaft based on states of output signals from Hall Sensors *A* and *B*. 10

(ii) With the help of a schematic diagram, explain the working principle of a resolver. How does the output for resolver differ from that of an encoder? 10

(c) What are the fundamental arm architecture of a basic robot arm on the basis of geometric work envelope? How can these fundamental arm architecture be derived from one another? What arm configurations do Gantry and SCARA robots correspond to? Also, show the geometric work envelope and arm configuration of Gantry and SCARA robots with a suitable figure. 20