Ref. No.: Ex/ME/5/T/524I/2024

BACHELOR OF ENGINEERING IN MECHANICAL ENGINEERING
FIFTH YEAR SECOND SEMESTER - 2024

Subject: GAS TURBINE THEORY

Time: 3 hours **Full Marks:100**

Answer any FIVE questions.
All symbols carry their usual meanings.

Q.1 (a) With a neat sketch, briefly explain the working principle of a gas turbine power plant. Plot its cycle on P-*v* and T-*s* planes. (6)

(b) A gas turbine has an overall pressure ratio of 7, and the maximum temperature of the cycle is 550°C. Its ambient pressure and temperature are 1bar and 20°C, respectively. The air enters the compressor at a rate of 15 kg/s; the isentropic efficiencies of the compressor and the turbine are 80% and 83%, respectively. Neglecting changes in the kinetic energy, mass flow rate of the fuel, and all pressure losses, calculate: (14)

(i) plot the cycle on T-*s* plane,
(ii) the temperature and pressure at each node of the cycle,
(ii) the net power output, and
(iii) the cycle efficiency.

Q.2 (a) With a neat layout, present the working principle of a regenerative gas power cycle. (6)

(b) Find an expression for the thermal efficiency of an ideal regenerative gas turbine cycle. (10)

(c) Plot the variation of thermal efficiency with pressure ratio for both simple and regenerative gas turbine cycles. Hence, find a limit to the pressure ratio in order to incorporate regeneration in the cycle. (4)

Q.3 (a) How does net work output of a gas turbine cycle vary with pressure ratio? Explain with necessary T-*s* plot of the gas power cycle under different pressure ratios. (4)

(b) Show that the maximum specific net work output of a gas power cycle is $w_{net} = C_p\left(\sqrt{T_{max}} - \sqrt{T_{min}}\right)^2$. (16)

Q.4 (a) Define stagnation enthalpy. Find an expression for specific stagnation enthalpy of a flow in terms of its static enthalpy and velocity. (4)

(b) Define Mach number (M). Hence, derive the following relations (10)

$$\frac{T_0}{T} = \left(1 + \frac{\gamma - 1}{2}M^2\right)$$

$$\frac{P_0}{P} = \left(1 + \frac{\gamma - 1}{2}M^2\right)^{\frac{\gamma}{\gamma-1}}$$

$$\frac{\rho_0}{\rho} = \left(1 + \frac{\gamma - 1}{2}M^2\right)^{\frac{1}{\gamma-1}}$$

(c) An air is stagnated isentropically from a Mach number (M) of 4 and a temperature of -53°C. Find related sound velocity and corresponding flow velocity. Hence, find a value for the stagnation temperature of the flow. (C_p = 1.005kJ/kg.K and R = 0.287 kJ/kg.K) (6)

Q.5 (a) Consider an ideal regenerative gas turbine plant. Air enters its compressor at1bar and 27°C with a mass flow rate of 0.562 kg/s. It is then compressed to 4 bar. The temperature at inlet of the turbine is 927°C. Determine: (16)
(i) the net power output in kW, and
(ii) thermal efficiency of the cycle.

(b) State the reasons behind consideration of multi-stage compression and subsequent intercooling, present such processes on T-s plane. (4)

Q.6 (a) Consider a steady 1-D isentropic flow through a varying cross sectional passage. Show that the flow holds following relations: (14)

$$\frac{dA}{A} = \frac{dV}{V}(M^2 - 1)$$

$$\frac{dA}{A} = \frac{dP}{\rho V^2}(1 - M^2)$$

(b) Air is stored in a reservoir at 6 bar and 327°C. The air is then flowing isentropically through a nozzle in order to attain a sonic flow at its exit. Calculate pressure, temperature and density of the air at nozzle exit. (C_p = 1.005kJ/kg.K and R = 0.287 kJ/kg.K) (6)

Q.7 (a) Consider an axial flow compressor. Draw schematically the velocity vectors at inlet and outlet of a moving blade with proper labelling. (6)

(b) Consider an axial flow compressor. Its tip diameter is 0.9m; hub diameter is 0.85m. α_1= 28°, β_1= 56°, α_2= 56°,and β_2= 28°. Rotor speed is 5000r.p.m. Air density is 1.2 kg/m^3. Determine (i) axial velocity (C_a), (ii) maximum flow rate, and (iii) power required. (14)