ENGINEERING TRIPOS   PART IIB

Monday 6 May 2013   9.30 to 11

Module 4A3

TURBOMACHINERY 1

Answer not more than ***two*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Attachments: Compressible Flow Data Book (38 pages).

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1 (a) Explain why *slip* occurs in centrifugal compressors, and discuss what has the greatest influence on *slip*. [20%]

(b) Air with $\gamma = 1.4$, $c_p = 1005$ $\mathrm{Jkg^{-1}K^{-1}}$ and $R = 287.1$ $\mathrm{Jkg^{-1}K^{-1}}$ enters a centrifugal compressor at a mass flow rate of $1.0\ \mathrm{kgs^{-1}}$. The entry stagnation temperature is $300\ \mathrm{K}$ and the stagnation pressure is $105\ \mathrm{kPa}$. The rotational speed is $120{,}000\ \mathrm{rpm}$. At impeller exit, the vanes are radial and the radius is $50\ \mathrm{mm}$. The slip factor is 0.92. There is no swirl at inlet to the compressor. Determine the stagnation temperature at the exit of the impeller. [15%]

(c) At impeller exit the radial velocity is 0.3 times the tip speed. Determine the absolute flow angle, the absolute Mach number and the relative Mach number of the flow leaving the impeller. Sketch the velocity triangle at this location. [25%]

(d) The total-to-total efficiency of the impeller is 91 percent. Determine the stagnation pressure at impeller exit and hence the axial width of the impeller. You may ignore the thickness of the blades. [25%]

(e) Compare the pressure rise characteristics of a centrifugal and an axial compressor. Comment on their application in aero propulsion engines. [15%]

2 (a) Show that for an axial flow compressor stage with constant axial velocity, the stage loading coefficient, ψ, varies with flow coefficient, ϕ, according to

$$\psi = 1 - \phi\left(\tan\alpha_1 - \tan\alpha_{2,rel}\right)$$

where α_1 is the absolute inlet angle to the rotor, and $\alpha_{2,rel}$ is the relative angle at rotor exit. [15%]

(b) Using this equation, sketch the ideal and real pressure rise versus flow rate characteristic for a low speed axial compressor stage. [10%]

(c) A multistage axial flow compressor is to be designed with repeating stages which have identical velocity triangles.

(i) The flow coefficient is 0.65 , the stage loading coefficient is 0.38 and the inlet flow angle, $\alpha_1 = 18°$. Calculate the remaining flow angles and draw the velocity triangles for a stage. [25%]

(ii) The difference between the actual stagnation enthalpy rise and the isentropic value is given by

$$\Delta h_0 = 0.5\zeta\left(V_{1,rel}^2 + V_2^2\right)$$

The loss coefficient, $\zeta = 0.05$, $V_{1,rel}$ is the relative velocity at rotor inlet and V_2 is the absolute velocity at stator inlet. Use this relationship to find the total-to-total isentropic efficiency of each stage. If the blade speed is 220 ms^{-1} and inlet stagnation temperature is 300 K , calculate the stagnation pressure rise of the first stage. The working fluid is air with ratio of specific heats $\gamma = 1.4$ and specific heat capacity at constant pressure $c_p = 1005$ Jkg^{-1}K^{-1} . [25%]

(iii) If a 6-stage machine were to be built with this design, what would be the overall pressure rise and overall isentropic efficiency? You should assume that the polytropic efficiency of the whole machine may be taken as the isentropic efficiency of a single stage. [25%]

(TURN OVER

3 A simple gas generator, shown in Fig. 3 , drives a power turbine mounted on a separate shaft. At its design point the simple gas generator operates with the following parameters:

Stagnation temperature at compressor inlet	T_{02} = 300 K
Stagnation pressure ratio of compressor	P_{03}/P_{02} = 12
Stagnation temperature at turbine inlet	T_{04} = 1300 K
Air mass flow rate	$\dot{m}$ = 100 kgs^{-1}

The polytropic efficiency of the compressor and both turbines are constant and equal to 90 percent. There is no pressure drop in the combustor. The mass flow of fuel can be neglected. Use c_p = 1.005 kJ kg^{-1} K^{-1} and γ = 1.4 for air. Use c_p = 1.200 kJ kg^{-1} K^{-1} and γ = 1.3 for combustion products.

(a) The gas flow in the exhaust of the power turbine has a Mach number of 0.3. Find the stagnation pressure in the exhaust of the power turbine if the ambient pressure is 1 bar. [15%]

(b) At the design point, calculate the stagnation temperature and stagnation pressure at the inlet to the power turbine. Calculate the power output from the power turbine. [30%]

(c) The vanes in the turbine of the turbojet and the vanes in the power turbine are choked. Show that the temperature rise in the compressor and the turbine inlet temperature are proportional to each other. [20%]

(d) On a cold day the temperature of the ambient air, and thus the inlet to the compressor, falls to T_{02} = 245 K . What should the turbine inlet temperature T_{04} be set to so that the engine operates at the design non-dimensional operating point? At this condition, calculate the power output of the power turbine. [35%]

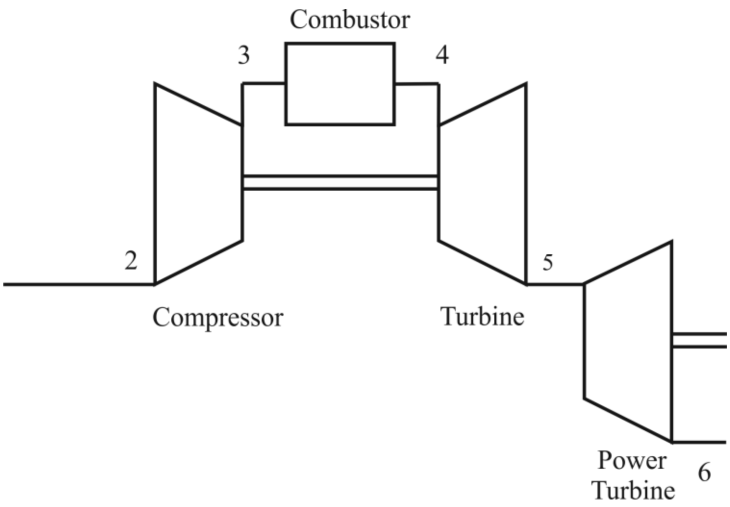

Fig. 3

END OF PAPER