EGT3
ENGINEERING TRIPOS PART IIB

Monday 25th April 2016 2:00 to 3:30 pm

Module 4A3

TURBOMACHINERY I

*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.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: Excerpt from Compressible Flow Data Book (pages 1-20 of 38 pages).
Engineering Data Book

10 minutes reading time is allowed for this paper.

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

1 (a) Explain how and why the stagnation pressure loss coefficient (as defined below) and flow angle at exit of a turbine cascade vary with exit Mach number. Use sketches to illustrate your answer. [15%]

(b) A turbine cascade has constant blade height and an inlet angle of -25° when measured from the axial direction. The cascade was tested using air with an inlet Mach number of 0.2, and exit Mach number of 1.3. The inlet stagnation to exit static pressure ratio was found to be 2.8.

(i) Find the stagnation pressure loss coefficient and exit angle at these conditions. [20%]

(ii) Neglecting the effect of stagnation pressure loss, calculate the reduction in turning relative to that at an exit Mach number of unity. If the stagnation pressure loss coefficient is halved at unity exit Mach number, comment on the error due to ignoring the total pressure loss. [20%]

(iii) Explain why supersonic exit turbines might be considered in practical applications. [10%]

(c) The exit static pressure of the cascade in part (b) is reduced until the limit load condition is reached. (The opening to pitch ratio for the cascade should be expressed as o/s).

(i) Find two independent expressions which relate the exit angle to exit Mach number at the limit load condition. [15%]

(ii) If the exit angle at limit load is 59.83°, show that the limiting exit Mach number is 1.99. [5%]

(d) The cascade in part (b) and (c) is used at the limit load condition in a single stage turbine with air as the working fluid. Under these conditions the exit to inlet total temperature ratio of the stage was found to be 0.6 and the stagnation pressure loss coefficient to be 0.2. Estimate the mechanical energy lost in the stator compared to the overall total enthalpy drop through the stage. [15%]

The definition of stagnation pressure loss coefficient for a turbine is

$$Y_p = \frac{p_{01} - p_{02}}{p_{02} - p_2}$$

where p_{01} and p_{02} are the inlet and exit stagnation pressure respectively and p_2 is the exit static pressure.

2 (a) The stage loading coefficient, ψ, the flow coefficient, ϕ, and stage reaction, Λ of a blade row are defined by the following expressions

$$\psi = \frac{\Delta h_0}{U^2} \quad , \quad \phi = \frac{V_x}{U} \quad \text{and} \quad \Lambda = \frac{\Delta h_{\text{rotor}}}{\Delta h_{\text{stage}}}$$

where U is the mean blade speed and V_x is the mean-line axial velocity of the flow.

(i) Show that for a repeating stage design that these parameters are related by the following expression

$$\psi = 2\,(1 - \Lambda - \phi \tan \alpha_1)$$

where α_1 is the absolute flow angle at stage inlet. [25%]

(ii) Explain why a repeating stage condition is often used in the preliminary design of multistage turbomachinery. [10%]

(iii) A repeating turbine stage has stage loading coefficient 1.7, flow coefficient 0.45 and stage reaction 0.5. Calculate all of the flow angles and draw the velocity triangles. [20%]

(b) The Zweifel loading coefficient for a turbine blade is defined by the following equation

$$Z = \frac{\dot{m}\,|V_{\theta 2} - V_{\theta 1}|}{c_x h\,(p_{01} - p_2)}$$

where $\dot{m}$ is the mass flow rate through the blade passage, $V_{\theta 1}$ and $V_{\theta 2}$ are the tangential flow velocities at inlet and exit, p_{01} is the inlet stagnation pressure, p_2 is the exit static pressure, c_x is the blade axial chord and h is the blade height.

(i) Describe how blade loading varies with blade pitch. Hence, explain the physical significance of the Zweifel coefficient, and reason for an optimum pitch to chord ratio for minimum loss. [15%]

(ii) The stator blade of part (a) (iii) is to be used with an inlet Mach number of 0.2 when the stagnation pressure loss coefficient is 0.05, and exit Mach number is 0.8. What pitch to axial chord ratio is needed to achieve a Zweifel coefficient of 0.8? [30%]

3 (a) For a fixed turbine inlet temperature to compressor inlet temperature ratio T_{03}/T_{01}, show that the compressor pressure ratio, p_{02}/p_{01}, of a twin shaft gas turbine is given by the following function

$$\pi_c = \frac{p_{02}}{p_{01}} = C\,\frac{\dot{m}\sqrt{c_{p,\text{air}}T_{01}}}{p_{01}A_1}\sqrt{\frac{c_{p,\text{air}}T_{03}}{c_{p,\text{gas}}T_{01}}}$$

where $\dot{m}$ is the inlet mass flow rate and A_1 is the inlet flow area. The layout of a twin shaft gas turbine and station notations are shown in fig. 1. You should assume the nozzle guide vane of the compressor driving turbine is choked and the specific heat $c_{p,\text{air}}$ for air and $c_{p,\text{gas}}$ for gas remain constant in the compressor and turbine respectively. State the form of the coefficient C. [30%]

(b) Show further that when the downstream power turbine guide vane is also choked, the slope of the working line on the compressor map reduces as the compressor efficiency reduces. State carefully the assumptions you are making for the derivation. [20%]

(c) Sketch a hypothetical compressor map. Illustrate how the working line would alter, as compared to the steady state operation, as the gas-turbine accelerates from idle to full speed when more turbine power is required for the acceleration. [20%]

(d) A manufacturer decided to modify an existing simple cycle gas turbine to produce half of the power. The original engine comprises a 10-stage compressor driven by a single stage axial turbine and a single stage power turbine. The blades were shortened to reduce the throughflow area to 50% of the original value. As such, the mass flow rate was halved, whilst maintaining the other cycle parameters. The clearance gaps were kept at the same absolute size.

(i) The modified gas turbine had compressor surge while accelerating close to the nominal design speed, and the exhaust gas temperature was significantly higher than before. Discuss the likely cause of the premature compressor instability. [10%]

(ii) Propose a possible remedy (or remedies) to restore the lost stability margin. [10%]

(iii) Highlight how the cycle parameters, p_{02}, T_{03} and the polytropic efficiencies of the compressor and turbine, η_{pc} and η_{pt}, might vary with the change(s) you propose. Comment on whether you would expect your proposal to return the cycle performance parameters, namely the specific work output and cycle efficiency to the original values. [10%]

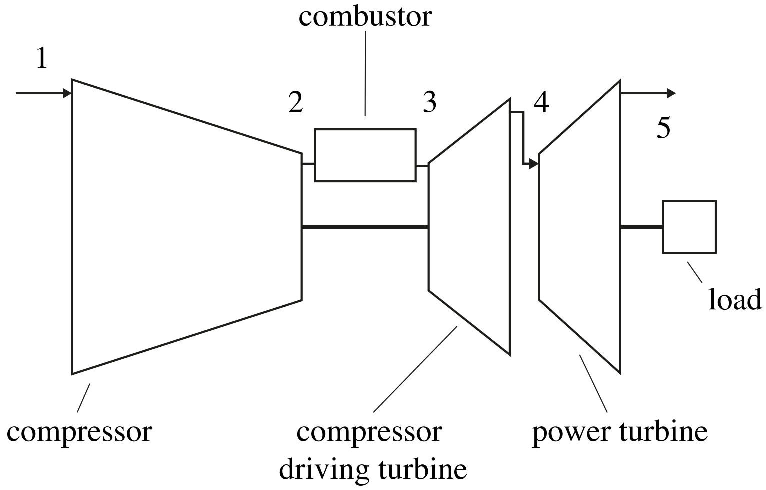

Fig. 1

END OF PAPER

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