ENGINEERING TRIPOS PART IIB
ELECTRICAL AND INFORMATION SCIENCES TRIPOS PART II

Friday 25 April 2003 9 to 10.30

Module 4A11

TURBOMACHINERY II

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

All questions carry the same number of marks.

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

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

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1 A linear transonic turbine cascade is designed to have an exit isentropic Mach number $M_{2,is}$ = 1.2. The cascade is shown diagrammatically in Fig. 1. The main cascade parameters are:

Pitch/Axial Chord ratio = 1.0	Inlet Mach number $M_1 = 0.2$
Inlet flow angle $\beta_1 = 0°$	Outlet blade metal angle $\chi_2 = 70°$
Inlet stagnation pressure p_{01} = 101330 Pa	Inlet stagnation temperature T_{01} = 288.15 K
$\gamma = 1.4$	R = 287.0 J/kgK

(a) By assuming that the flow through the cascade is isentropic, determine:

(i) the deviation angle at the cascade exit; [25%]

(ii) the Zweifel coefficient Z of the cascade. For axial turbomachines:

$$Z = \frac{\text{actual tangential blade force}}{\text{"ideal" tangential blade force}}$$

and the "ideal" blade force is given by the expression $[C_x\,(p_{01} - p_2)]$ [25%]

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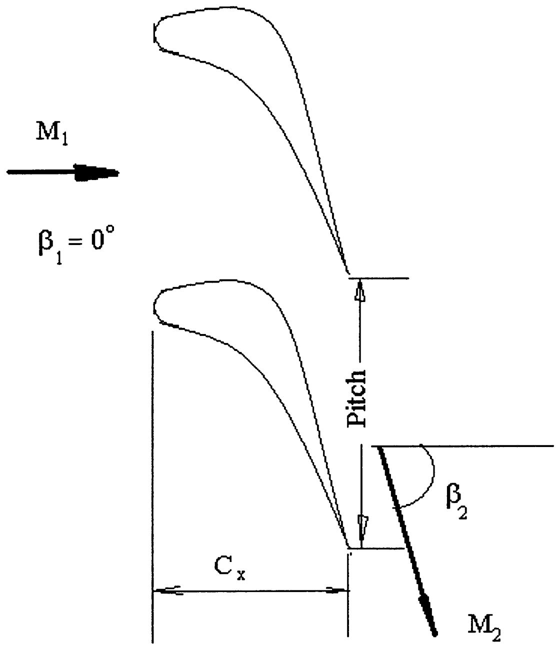

Fig. 1

(b) The performance of a stationary cascade can be measured by its stagnation pressure ratio $\sigma = p_{02}/p_{01}$. For this cascade $\sigma = 0.95$. Determine the deviation angle and Zweifel coefficient of the cascade with the loss included. The isentropic Mach number at the exit from the cascade is unchanged. Comment on the differences in the deviation and Zweifel coefficient. [30%]

(c) Develop an expression relating the Zweifel coefficient to the variables σ, M_2, γ, β_2 and the pitch to chord ratio, for the case of axial inlet flow. When the geometry is fixed and the exit Mach number and stagnation pressure ratio are held constant, find the value of the exit flow angle that corresponds to the maximum Zweifel coefficient. [20%]

2 (a) Starting from the radial momentum equation in a duct,

$$\frac{\partial p}{\partial r} = \frac{\rho V_\theta^2}{r}$$

show that the Simple Radial Equilibrium Equation as applicable to turbomachinery flow may be expressed as:

$$\frac{\partial h_0}{\partial r} - T\frac{\partial s}{\partial r} = V_m \frac{\partial V_m}{\partial r} + \frac{V_\theta}{r}\frac{\partial (rV_\theta)}{\partial r}$$

State any assumptions made and explain the physical meaning of each term in the equation. [40%]

(b) An axial compressor stage with cylindrical hub and casing profiles has an axial flow at inlet to and at exit from the stage. At the rotor exit there is a free vortex distribution of swirl velocity and there is no spanwise variation in the component of axial velocity. It is observed that there is a radial variation of stage reaction.

Assuming no variation of loss along the span of the rotor,

(i) use the Simple Radial Equilibrium Equation to explain the cause of the radial distribution of reaction, and sketch the distribution. [10%]

(ii) if the reaction at the mid-span is 0.6 and the reaction at the hub is 0.2, what is the radius ratio $r_{hub} / r_{ca\sin g}$? [20%]

(iii) low reaction at the hub generally causes high loss. Without the use of lean or sweep, suggest two possible methods for increasing the reaction near the hub. It may be assumed that there are no constraints on the hub and casing lines or the number of blade rows. [20%]

(c) Explain which terms must be added to the Simple Radial Equilibrium Equation to permit calculation of streamline curvature effects on radial quasi-orthogonal lines. What term must be added if the flow passes through a blade row that is not radially stacked? [10%]

3 (a) Several numerical methods are available for the calculation of blade-blade flows on a stream surface. Describe the different methods. Particular emphasis should be placed on the advantages and disadvantages of each method. [40%]

(b) When using a panel method calculation to analyse a cascade of axial turbine blades with zero swirl at inlet, the circulation on each blade is found to be:

$$\Gamma = 2.75\ V_x\, s$$

where Γ is the total circulation, V_x is the inlet axial velocity and s is the blade pitch.

(i) What is the swirl velocity induced at a far upstream location by the vortices representing the cascade? [15%]

(ii) What procedure would be used to correct for this induced swirl velocity? [10%]

(c) How can blade lean be used to control the secondary flow in a low aspect ratio turbine stator? Indicate which way the blade must be leant and the re-distribution of the flow that results from the blade lean. [35%]

END OF PAPER