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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2022/2023

COURSE NAME	:	TURBOMACHINERY
COURSE CODE	:	BDE 40303
PROGRAMME	:	BDD
EXAMINATION DATE	:	JULY/AUGUST 2023
DURATION	:	3 HOURS
INSTRUCTION	:	1. PART A: ANSWER **TWO (2)** FROM **THREE (3)** QUESTIONS 2. PART B: ANSWER **ALL** QUESTIONS 3. THIS FINAL EXAMINATION IS CONDUCTED VIA **CLOSE BOOK** 4. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK

THIS QUESTION PAPER CONSISTS OF **EIGHT (8)** PAGES

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PART A: ANSWER TWO (2) QUESTIONS ONLY OUT OF THREE (3) QUESTIONS

Q1 (a) A model centrifugal pump with an efficiency of 88% is tested at a rotational speed of 3000 rpm and delivers 0.12 m^3/s of water against a head of 30 m. Using the similarity rules given above, determine the rotational speed, volume flow rate, and power requirement of a geometrically similar prototype at eight times the scale of the model and working against a head of 50 m

(6 marks)

(b) The compressor with the performance map shown in **Figure Q1 (b)** is tested at sea level on a stationary test bed on a day when the atmospheric temperature and pressure is 298 K and 101 kPa, respectively. When running at its design operating point, the mass flow rate through the compressor is measured as 15 kg/s and the rotational speed is 6200 rpm. Determine the mass flow rate and rotational speed when the compressor is operating at the design operating point during high altitude cruise with an inlet stagnation temperature of 236 K and an inlet stagnation pressure of 10.2 kPa. The design pressure ratio of the compressor is 22. Determine the compressor isentropic and polytropic efficiency at the design point. Hence calculate the required power input at the cruise condition. Assume throughout for air that k is 1.4 and Cp is 1005 J/(kg.K).

(14 marks)

Q2 An axial flow compressor operates based on the following data:

Table 1

Parameter	Value
Blade speed at mean blade radius, U_m	185 m/s
Blade speed at blade tip, U_t	240 m/s
Stagnation temperature rise, ΔT_0	15 K
Axial absolute velocity component, V_x	140 m/s
Work done factor, λ	0.85
Degree of reaction at mean radius, Λ	50%

For a free vortex design condition, determine:

(a) whirl component at mean rotor inlet;

(b) gas angle α_1, α_2, β_1 and β_2 at mean radius;

(c) whirl component at rotor exit; and

(d) gas angles at blade tip.

(20 marks)

Q3 Prove that the overall efficiency η_t and small stage efficiency η_p for the adiabatic expansion of a perfect gas through a turbine are related by.

$$\eta_t = (1 - \varepsilon^{\eta_p})/(1 - \varepsilon)$$

where $\varepsilon = r^{(1-k)/k}$, and r is the expansion pressure ratio, k is the ratio of specific heats. An axial flow turbine has a small stage efficiency of 86%, an overall pressure ratio of 4.5 to 1 and a mean value of k equal to 1.333. Determine the overall turbine efficiency.

(20 marks)

PART B: ANSWER ALL QUESTIONS

Q4 **Figure Q4** shows the characteristic map of a centrifugal compressor. The map presents the performance parameters which are normalized by design values, namely pressure ratio (PR/PR_{Design}), pseudo-dimensionless mass flow (MFP/MFP_{Design}) and pseudo-dimensionless speed ($\bar{N}/\bar{N}_{Design}$). The design point is also marked on the compressor map. At 80% design speed ($\bar{N}/\bar{N}_{Design}$ = 0.8), the compressor operates at the following conditions:

Table 2

Parameter	Value
Rotational speed, N	15,000 RPM
Mass flow rate, $\dot{m}$	12 kg/s
Pressure ratio, PR	2.5
Normalized pressure ratio, PR/PR_{Design}	0.7
Stagnation inlet temperature, T_{01}	297 K
Stagnation inlet pressure, P_{01}	100 kPa

Using the map and the given data, evaluate the following quantities for the compressor:

(a) design pseudo-dimensionless speed in RPM/√K;

(b) design pressure ratio;

(c) design mass flow ratein kg/s;

(d) choking mass flow rate at design speed in kg/s; and

(e) pressure ratio at surge point for 70% design speed.

(20 marks)

Q5 A small inward radial-flow gas turbine, comprising a ring of nozzle blades, a radial-vaned rotor and an axial diffuser, operates at the nominal design point with a total-to-total efficiency of 0.90. At turbine entry, the stagnation pressure and temperature of the gas are 400 kPa and 1140 K. The flow leaving the turbine is diffused to a pressure of 100 kPa and has negligible final velocity. Given that the flow is just choked at nozzle exit, determine the impeller peripheral speed and the flow outlet angle from the nozzles. The gas specific heat ratio, *k*, and the gas constant, R, are 1.333 and 287 J/(kg °C) respectively.

(20 marks)

Q6 A Pelton wheel operates at 16 m/s bucket velocity with water ($\rho_{water} = 1000$ kg/m^3) being supplied at a rate of 0.8 m^3/s and a head of 45 m. The water jet is deflected in the bucket by 160°. Taking the velocity coefficient (Cv) to be 0.98 and neglecting the losses in the bucket, determine.

(a) jet velocity;

(b) tangential velocity component at bucket exit;

(c) power developed by turbine; and

(d) efficiency of turbine.

(20 marks)

- END OF QUESTION -

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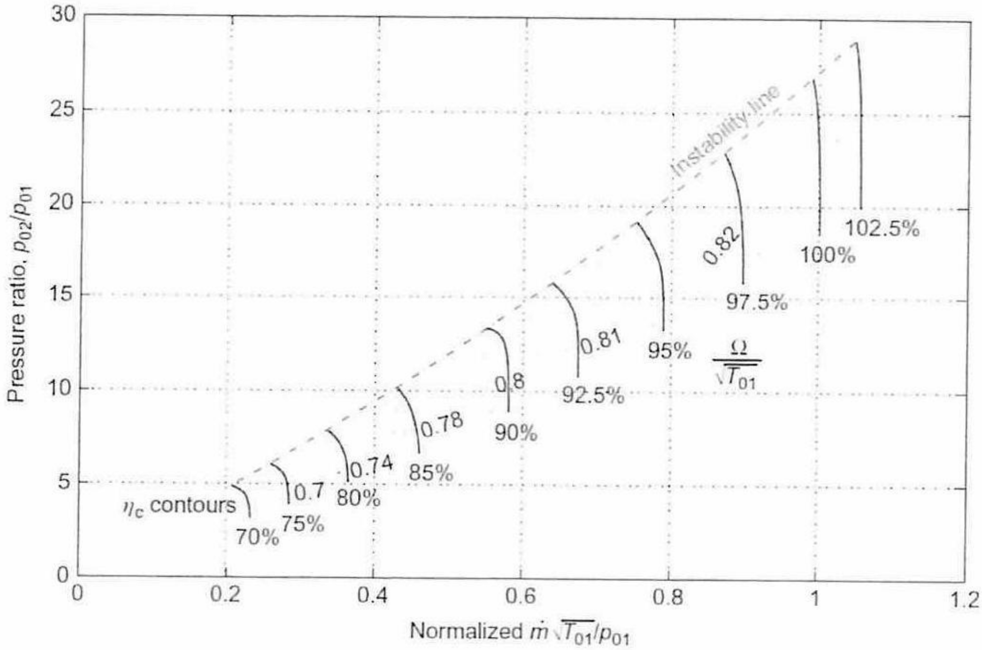

Figure Q1 (b)

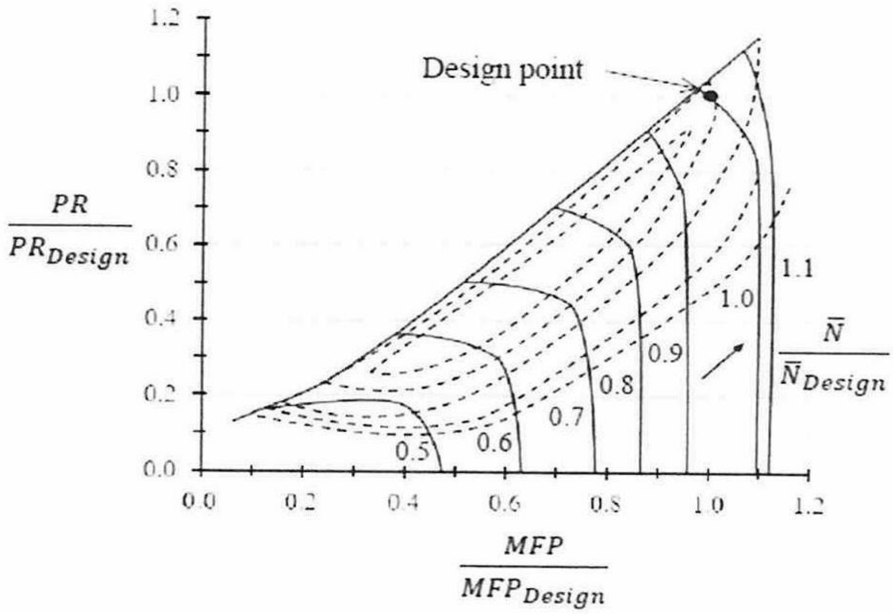

Figure Q4

FINAL EXAMINATION

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List of Formula

1. $W = \rho g Q h$

2. $C_h = \frac{g h_a}{\omega^2 D^2}$

3. $C_Q = \frac{Q}{\omega D^3}$

4. $C_P = \frac{\dot{W}}{\rho \omega^3 D^5}$

5. $\eta = \frac{\rho g Q h_a}{P}$

6. $c = \sqrt{kRT}$

7. $p = \rho R T$

8. $T_0 = T + \frac{V^2}{2} c_p$

9. Pressure ratio, $\frac{p_1}{p_2} = \left(\frac{T_1}{T_2}\right)^{k/(k-1)}$

10. $\frac{\rho_1}{\rho_2} = \left(\frac{T_1}{T_2}\right)^{1/(k-1)}$

11. $C_P = \frac{Rk}{(k-1)}$

12. Nondimensional mass flow, $\hat{m} = \frac{\dot{m}\sqrt{kRT}}{D^2 p}$

13. Nondimensional speed$= \frac{\omega D}{\sqrt{kRT}}$

14. $k = \frac{C_p}{C_v}$

15. $\frac{T_{02}}{T_{01}} = \frac{(p_{02}/p_{01})^{(\frac{k-1}{k}-1)} - 1}{\eta_c} + 1$

16. $\eta_P = \frac{k-1}{k} \frac{\ln(p_{02}/p_{01})}{\ln(T_{02}/T_{01})}$

17. $\frac{\Delta T_0}{T_{01}} = \frac{T_{02}}{T_{01}} - 1$

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List of Formula

18. Power, $P = \dot{m} C_p \Delta T_0$

19. Actual specific work, $\Delta W_x = \dot{W}_x/\dot{m} = (h_{01} - h_{02})$

20. Ideal specific work, $\Delta W_{max} = \dot{W}_{max}/\dot{m} = (h_{01} - h_{02s})$

21. Total-to-total efficiency, $\eta_{tt} = \Delta W_x/\Delta W_{max}$

22. Small stage efficiency, $\eta_p = \frac{dh_0}{dh_{0s}}$

23. $Tds = dh - \frac{dp}{\rho}$