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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER I
SESSION 2018/2019

COURSE NAME	:	TURBOMACHINERY
COURSE CODE	:	BDE 40303
PROGRAMME	:	BDD
EXAMINATION DATE	:	DECEMBER 2018 / JANUARY 2019
DURATION	:	3 HOURS
INSTRUCTIONS	:	ANSWER **ONLY FIVE (5)** FROM **SIX (6)** QUESTIONS

THIS QUESTION PAPER CONSISTS OF **FIVE (5)** PAGES

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Q1 (a) In wind turbine designs, the shaft power output (P_S) is determined to be a function of rotational speed (N), rotor diameter (D), air velocity (V), air density (ρ). Using the Buckingham-π method of dimensional analysis:

(i) derive the non-dimensional parameters that express shaft power; and

(ii) show that the parameters in (i) above can be manipulated to become the power coefficient $C_p = \frac{P_S}{\rho A V^3}$ and tip speed ratio $\lambda = \frac{DN}{V}$ respectively.

(8 marks)

(b) At 100 rpm, a radial flow turbine produces 32 kW of power under 16 m of head. A geometrically similar model of the turbine is developed and tested under the 6 m of head and was measured to produce 42 kW of power. If the model efficiency is 92%, determine:

(i) the rotational speed of the model;

(ii) the diameter ratio between the model and the prototype; and

(iii) the volume flow rate through the model.

(12 marks)

Q2 A single stage, axial-flow gas turbine has nozzle exit angle of 68°. The stagnation temperature and pressure at the turbine stage inlet is 820 °C and 4.2 bar respectively. The static pressure at the exhaust is 1.0 bar. The turbine operates at 85% total-to-static efficiency at mean blade speed of 500 m/s. The specific heat ratio and specific heat for the gas are $\gamma = 1.333$ and $C_p = 1.147$ kJ/kgK. For this turbine, evaluate:

(i) the work done by the machine;

(ii) the axial velocity through the stage;

(iii) the total-to-total efficiency; and

(iv) the turbine's degree of reaction.

(20 marks)

Q3 An axial-flow compressor is used to compress air from 1 bar and 295K through 7 reaction stages with a pressure ratio of 8. At 12000 rpm speed, each stage requires the same amount of power with 87% stage efficiency and 95% mechanical efficiency. The mean radius and blade height for the rotor is 23.0 cm and 7.5 cm respectively. The flow rate at the inlet is 12.7 m^3/s. Taking the specific heat ratio as $\gamma = 1.4$ and specific heat of air to be $C_p = 1.0$ kJ/kgK, determine:

(i) the temperature rise per stage;

(ii) the inlet and exit flow angles of the first-stage rotor;

(iii) the required total power;

(iv) the adiabatic efficiency; and

(v) the compressor efficiency.

(20 marks)

Q4 (a) A small inward-flow gas turbine operates with a total-to-total efficiency of 90% at its design point. The stagnation pressure and temperature of the gas at the nozzle inlet are 310 kPa and 1145 K respectively. The flow at the exit of the turbine is diffused to 100 kPa with negligible velocity. The specific heat and specific heat ratio for the gas are C_p = 1.147 kJ/kgK and γ = 1.333 respectively. The Mach number at the nozzle exit is 0.9. Assuming that gas enters the blade radially and that there is no whirl at the blade exit, determine:

(i) the blade tip speed at the nozzle exit; and
(ii) the flow angle at the nozzle exit.

(10 marks)

(b) **Table Q4(b)** shows the specifications of a small radial turbine. For this turbine, determine:

(i) the speed parameter (dimensionless speed);
(ii) the volume flow rate at the blade exit; and
(iii) the turbine power.

(10 marks)

Q5 (a) A centrifugal compressor operates at 16000 rpm rotational speed. Air entering the compressor at a total temperature of 20 °C and a total pressure of 1.0 bar is compressed by a pressure ratio of 4.2 between the blade inlet and exit. The radial velocity component at the blade exit is 136 m/s and the isentropic efficiency of the compressor is 82%. The flow between the blade inlet and exit is assumed to be isentropic with the specific heat ratio equal to γ = 1.4 and specific heat of C_p = 1.0 kJ/kgK. For this compressor:

(i) draw the velocity triangle at the blade exit;
(ii) calculate the slip velocity; and
(iii) determine the slip factor.

(10 marks)

(b) **Table Q5(b)** shows the specification data for a centrifugal air compressor. For this machine, evaluate:

(i) the adiabatic efficiency;
(ii) the exit air temperature; and
(iii) the required power input.

(10 marks)

Q6 (a) A Pelton wheel at a hydraulic power station runs at 305 rpm with 515 m available head. The turbine is of a single jet type with 200 mm nozzle diameter. The jet is deflected by 165 ° inside the bucket where its relative velocity is reduced by 12% through friction. The mechanical losses at the shaft is assumed to be 4% from the power supplied. For this hydraulic turbine operation, sketch the velocity triangle and determine:

(i) the water horsepower;
(ii) the net force exerted on the bucket;
(iii) the shaft power; and
(iv) the overall efficiency.

(12 marks)

(b) A Kaplan runner develops 9000 kW under a head of 5.5 m with 85% mechanical efficiency of. The speed and flow ratios are 2.08 and of 0.68 respectively. The hub diameter is 1/3 that of the runner. Determine:

(i) the diameter of the runner;
(ii) the turbine rotational speed; and
(iii) the turbine specific speed.

(8 marks)

- END OF QUESTIONS –

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Table Q4(b)

Turbine type	Radial
Rotor inlet tip diameter	92 mm
Rotor exit tip diameter	64 mm
Rotor exit hub diameter	26 mm
Absolute rotor exit to isentropic velocity ratio, C_3/C_{is}	0.447
Rotor to isentropic velocity ratio, U/C_{is}	0.707
Rotational speed	30500 rpm
Gas density at blade exit	1.75 kg/m^3

Table Q5(b)

Machine type	Centrifugal air compressor
Blade tip diameter	1.0 m
Rotational speed	5945 rpm
Air mass flow rate	28 kg/s
Static pressure ratio	2.2
Ambient pressure	1.0 bar
Ambient temperature	25 °C
Slip factor	0.90