National Exams December 2008

07-Mec-A6-1, Fluid Machinery

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

2. This is an OPEN BOOK EXAM.
   calculator is permitted.

3. FIVE (5) questions constitute a complete exam paper.
   The first five questions as they appear in the answer book will be marked.

4. Each question is of equal value.

QUESTION #1

(a) A prototype reaction water turbine is required to operate at a speed of 600 rpm under a head of 55 m. In order to predict the power that this turbine would produce, a 1:4 (i.e., 25%) scale model turbine is tested under a head of 4.95 m of water. Determine the speed at which the model turbine must be operated.

(b) When the model turbine is operated at the speed found in (a), it has a flow rate of 0.428 m^3/s and a dimensionless specific speed of 0.39 (rev). Determine the power developed by the model turbine and its efficiency.

(c) Given that the efficiency of the prototype turbine, e_P, is 3% higher than that of the model turbine, e_M (i.e., $e_P = e_M + 0.03$), determine the power that will be obtained from the prototype turbine under operating conditions.

QUESTION #2

With respect to 'cavitation testing' of a water pump, the intake end of the pipe's suction pipe is immersed in a water reservoir, and the pump is located 0.7 m above the surface of the water. The temperature of the water is 20°C, and the atmospheric pressure is 101 kPa. The length, diameter, and roughness of the suction pipe are, respectively, 7.5 m, 0.15 m, and 0.15 mm, and the associated minor loss coefficient is 1.8. The head-discharge characteristics of the pump conform to the following equation:

$$H_P = 57 - 1938Q^2,$$

where H_P is the pump head in metres and Q is the pump discharge in cubic metres per second. The critical value of the cavitation parameter for the pump is 0.124. Given that cavitation is incipient under the prevailing operating conditions, determine (i) the pump discharge and (ii) the gauge pressure at the pump inlet.

Note: A trial and error procedure (involving the Moody diagram) is required.

QUESTION #3

Under best-efficiency-point (BEP) operating conditions, the speed of a Francis reaction turbine is 960 rpm and the turbine discharge is 0.748 m^3/s of water. At the inlet of the turbine runner, the runner width is a quarter of the runner diameter. The inlet guide-vane angle is 30°, and the inlet runner-vane angle is 118°. The hydraulic and overall efficiencies of the turbine are, respectively, 88% and 84%. Neglecting the thickness of the runner vanes, determine (i) the diameter of the turbine runner, and (ii) the power developed by the turbine.

QUESTION #4

A centrifugal fan operating under best-efficiency-point (BEP) conditions at a speed of 1,500 rpm supplies air to a ventilation duct at a rate of 5.9 m^3/s. The fan impeller has backward-curved vanes with an outlet vane angle of 33.5°. The outer diameter of the impeller is 0.6 m and its width is 0.2 m. The head loss within the fan is 70% of the absolute velocity head at the outlet of the fan impeller, and the overall efficiency of the fan, e, is 4% lower than its hydraulic efficiency, e_h (i.e., $e = e_h - 0.04$). Given that the thickness of the impeller vanes is negligible and that the density of the air is constant at 1.2 kg/m^3, determine (i) the head developed by the fan in millimetres of water, (ii) the hydraulic efficiency of the fan, and (iii) the power that must be supplied to the fan.

QUESTION #5

A 4-nozzle Pelton wheel impulse turbine is to be connected to a reservoir supplying a gross head of 250 m by means of a penstock with a length of 2.8 km, a friction factor of 0.032 and minor-loss coefficients amounting to 9.7. The nozzle velocity coefficient will be 0.975, and the operating speed of the turbine will be 640 rpm. Under operating conditions, the (net) turbine head should be 93% of the gross head, the turbine should produce a brake power of 8.2 MW, the overall turbine efficiency should be 0.89, and the speed (or peripheral-velocity) factor should be 0.44. Determine (i) the diameter of each nozzle, (ii) the diameter of the Pelton wheel, and (iii) the diameter of the penstock.

QUESTION #6

The power developed by an axial-flow reaction gas turbine (with a set of stator blades or nozzles and a set of rotor blades) is 730 kW. At the rotor inlet, the angle between the absolute flow velocity and the peripheral rotor velocity is 18.7°. At the rotor outlet, the absolute flow velocity is in the axial direction. The turbine rotor has hub and tip diameters of 1.015 m and 1.14 m, respectively. At the inlet of the rotor blades, the absolute temperature is 826 K and the absolute pressure is 278 kPa. At the outlet of the rotor blades, the absolute temperature is 817.5 K. The specific heat ratio and the gas constant of the gas are 1.25 and 190 J/kg·K, respectively. Determine (i) the mass flow rate through the turbine, (ii) the turbine speed in rpm, and (iii) the corresponding inlet and outlet rotor blade angles (β_1 and β_2).

Note: It can be assumed that the gas is an ideal gas with constant specific heats.

QUESTION #7

A pump is used to transport water from reservoir A to reservoirs B and C. The water surface in reservoir B is 10.5 m above that in reservoir A, and the water surface in reservoir C is 14.5 m above that in reservoir A . The head-discharge characteristics of the pump are described by the following relationship:

$$H_P = 135 - 11{,}406Q^2,$$

where H_P is the pump head in metres and Q is the pump discharge in cubic metres per second. The supply reservoir, reservoir A, is connected to the suction side of the pump by means of pipe A. This pipe has a length of 300 m, a diameter of 0.3 m, and a friction factor of 0.038; also, the sum of the minor loss coefficients associated with pipe A is 3.6. Reservoirs B and C are connected to the discharge side of the pump by means of two *branching* pipes, pipe B and pipe C. Pipe B has a length of 600 m, a diameter of 0.2 m, and a friction factor of 0.032; also, the sum of the minor loss coefficients associated with pipe B is 2.5. Pipe C has a length of 900 m, a diameter of 0.2 m, and a friction factor of 0.032; also, the sum of the minor loss coefficients associated with pipe C is 2.8.

(a) Verify that the operation point will occur (i.e., the pump head, H_P, will match the system head, H_S) when the flow rate through pipe B, Q_B, is 41% greater than the flow rate through pipe C, Q_C (i.e., $Q_B = 1.41Q_C$).

(b) Determine the power supplied by the pump.

Note: Losses between the discharge side of the pump and the *junction* of pipe B and pipe C are taken into consideration through the minor loss coefficients associated with these pipes.