National Exams May 2010

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.
Candidates may use one of two calculators; a Casio or Sharp approved models.

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 pump/pipeline system is used to convey water from one reservoir with a water-surface elevation of 3.1 m to another reservoir with a water-surface elevation of 24.7 m. The pipeline has a diameter of 0.36 m, a length of 450 m, a friction factor of 0.016 and total minor loss coefficients of 2.3. The diameter the pump impeller is 0.6 m, and the pump speed is 720 rpm. The dimensionless performance characteristics of the pump are presented in the table below. In this table, C_Q is the dimensionless discharge coefficient, given by $C_Q = Q/(\omega D^3)$, C_H is the dimensionless head coefficient, given by $C_H = gH/(\omega^2 D^2)$, and e is the overall efficiency. Determine the brake power supplied to the pump.

Note: Q denotes discharge in m^3/s; H denotes head in m; D denotes impeller diameter in m; and $\omega = 2\pi N/60$, where N denotes rotational speed in rpm.

C_Q	C_H	e (%)
0.0	0.148	0.0
0.004	0.150	40.9
0.008	0.149	62.3
0.012	0.145	76.4
0.016	0.138	81.7
0.020	0.128	83.6
0.024	0.113	82.1

QUESTION #2

A centrifugal pump operating at a speed of 500 rpm is used to convey water. The impeller of the pump has an inner diameter of 0.18 m and an outer diameter of 0.35 m. The inner and outer widths of the impeller are, respectively, 0.06 m and 0.032 m. The angle associated with the absolute velocity at the inlet of the impeller is 75°. The inlet and outlet impeller-vane angles are, respectively, 30° and 45°. The vanes occupy 5% of the inlet and outlet circumferences of the impeller. The hydraulic efficiency of the pump is 88%. The brake power supplied to the pump is 4.8 kW. Determine (i) the pump discharge, (ii) the angle associated with the absolute velocity at the outlet of the impeller, (iii) the (net) pump head, (iv) the increase in the pressure head across the impeller, and (v) the overall efficiency of the pump.

Note: The difference between the elevation at the inlet of the impeller and the elevation at the outlet of the impeller can be neglected.

QUESTION #3

The speed and brake power of a radial-flow reaction water turbine operating under BEP conditions are 1000 rpm and 65 kW, respectively. The diameter of the turbine runner is 0.3 m, and the inlet angle and width of the runner vanes are 130° and 75 mm, respectively. The hydraulic and overall efficiencies of the turbine are 88% and 83%, respectively. The turbine operates with the lowest possible flow rate for the specified conditions. Neglecting the thickness of the runner vanes, determine (i) the flow rate through the turbine, (ii) the (net) turbine head, and (iii) the inlet guide vane angle.

QUESTION #4

Water is transported from a reservoir to an elevated tank by means of a pump-pipeline system. The top of the tank is open to the atmosphere and is located 26.5 m above the surface of the water in the reservoir. With respect to the discharge pipe of the system, the downstream end is attached to the top of the tank; also, the pipe length (L), the pipe diameter (D), the pipe friction factor (f) and the sum of the minor head-loss coefficients (ΣK) are, respectively, 63 m, 0.2 m, 0.018 and 1.7. With respect to the suction pipe of the system, the pipe diameter, the pipe friction factor and the sum of the minor head-loss coefficients are, respectively, 41 m, 0.3 m, 0.02 and 2.1. The centre of pump is located 3.5 m above the surface of the water in the reservoir; the *critical* cavitation parameter for the pump is 0.17; the temperature of the water in the reservoir is 20°C; and the local atmosphere pressure is 102 kPa. The head-discharge characteristics of the pump are as follows:

$$H_P = 35.9 - 130.1Q_p^2,$$

where H_P is the pump head in metres and Q_P is the pump discharge in cubic metres per second.
(a) The length of the suction pipe is 41 m. Determine (i) the pump discharge, (ii) the pump head, and (iii) the cavitation parameter of the pump. Verify that cavitation does not occur (in the pump).
(b) Determine (i) the pump discharge, (ii) the pump head, and (iii) the maximum permissible length of the suction pipe to ensure that cavitation does not occur.

QUESTION #5

An axial-flow pump operating under best-efficiency-point (BEP) conditions conveys water at a rate of 4.5 m^3/s. The pump impeller has a root diameter of 0.6 m and a blade-tip diameter of 0.9 m. The inlet and outlet impeller-blade angles are, respectively, 30° and 35°. The hydraulic and overall efficiencies of the pump are, respectively, 90% and 85%. Determine (i) the pump speed (in rpm), (ii) the theoretical pump head, and (iii) the brake power supplied to the pump.

QUESTION #6

A centrifugal pump with a *dimensionless* specific speed (in revolutions) of 0.0728 is used to transport water from one reservoir to another reservoir. The pump operates at a speed of 1,200 rpm and a hydraulic efficiency of 93% under BEP conditions, and it has the following head-discharge characteristics:

$$H = 97.5 - 130.3Q^2,$$

where H is head in metres and Q is discharge in cubic metres per second. The inlet diameter and width of the pump impeller are, respectively, 0.24 m and 0.048 m. The outlet diameter and width of the pump impeller are, respectively, 0.5 m and 0.035 m.
(a) Using an iterative procedure (or otherwise), determine the (net) pump head.
(b) Neglecting the thickness of the impeller vanes, determine the inlet and outlet impeller-vane angles.
Note: The dimensionless specific of a pump (in rev) is given by: $N_S = nQ^{1/2}/(gH)^{3/4}$, where n is in rev/s, Q is in m^3/s, g is in m/s^2 and H is in m.

QUESTION #7

The power developed by an axial-flow reaction gas turbine is 765 kW, and the axial velocity in the turbine is 70 m/s. The turbine rotor has hub and tip diameters of 1.02 m and 1.15 m, respectively. At the inlet of the rotor, the absolute temperature is 824 K, the absolute pressure is 270 kPa and the angle between the absolute flow velocity and the peripheral rotor velocity (α_1) is 20°. At the outlet of the rotor, the absolute temperature is 813.5 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 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.