National Exams December 2009

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. One of two calculators is permitted any 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

The gross head on a Francis reaction water turbine equipped with a draft tube immersed in the turbine's tailrace is 95 m. (In other words, the surface of the water in the turbine's supply reservoir is 95 m above the surface of the water in the tailrace). The flow rate in the pipeline that conveys the water ($\nu = 10^{-6}$ m^2/s) to the turbine is 3.5 m^3/s. The pipeline has a length of 550 m, a diameter of 1 m, an absolute roughness of 0.6 mm, and total minor loss coefficients amounting to 3.2. The turbine operates at a speed of 600 rpm under best-efficiency-point (BEP) conditions. The (inlet) diameter of the turbine runner is 1.2 m, the runner vanes have a height of 0.17 m and occupy 6% of the circumference of the runner, and the (inlet) guide-vane angle is 16°. Determine (i) the net turbine head, (ii) the hydraulic efficiency of the turbine, and (iii) the inlet runner-vane angle.

Note: The velocity in the tailrace can be neglected.

QUESTION #2

An axial-flow fan, which is used to provide ventilation air, operates at a speed of 540 rpm. The fan rotor has a root diameter of 0.72 m and a blade-tip diameter of 1.08 m. The angle associated with the absolute velocity at the inlet of the rotor (α_1) is 75°, and the inlet and outlet rotor-blade angles (β_1 and β_2) are, respectively, 35° and 45°. The density of the air is 1.2 kg/m^3, the brake power supplied to the fan is 1.6 kW, and the overall efficiency of the fan is 84%. Determine (i) the fan discharge, (ii) the theoretical fan head, (iii) the net fan head, and (iv) the hydraulic efficiency of the fan.

QUESTION #3

Water is transported from one reservoir with a free-surface elevation of 3.8 m to another reservoir with a free-surface elevation of 63.2 m by means of a pump/pipeline system involving two pumps connected in *parallel*. The pipeline has a diameter of 0.5 m, a length of 2,600 m and a friction factor of 0.024. The sum of the minor loss coefficients for the system is 5.72. The two pumps, pump A and pump B, have the following head-discharge characteristics:

$$H_A = 84.9 - 293.8Q_A^2,$$

and

$$H_B = 82.1 - 418.5Q_B^2,$$

where H denotes head in metres and Q denotes discharge in cubic metres per second. Determine the power supplied to the water by each pump.

QUESTION #4

A tank is filled with water from a reservoir by means of a pump/pipeline system. The head-discharge characteristics of the system are as follows:

$$H_S = 26.5 + 481.7Q_S^2,$$

where H_S is the system head in metres and Q_S is the system discharge in cubic metres per second. Also, the head loss associated with the suction pipe of the system is given by:

$$h_{LS} = 49.32Q_S^2,$$

where h_L denotes head loss in metres. The *critical* cavitation parameter for the pump is 0.17. The temperature of the water in the reservoir is 20°C. The local atmosphere pressure is 102 kPa.

(a) The centre of pump is located 3.5 m above the surface of the water in the reservoir, and the pump is operated at a speed of 2,000 rpm. At this speed, the head-discharge characteristics of the pump are as follows:

$$H_P = 30.1 + 21.6Q_P - 15.8Q_P^2,$$

where H_P is the pump head in metres and Q_P is the pump discharge in cubic metres per second. Determine (i) the pump discharge, (ii) the pump head, and (iii) the prevailing cavitation parameter for the pump. Verify that cavitation does not occur in the pump.

(b) In order to increase the pump discharge, the pump speed is increased to 2,060 rpm. Determine (i) the pump discharge, (ii) the pump head, and (iii) the maximum permissible vertical distance between the centre of pump and the surface of the water in the reservoir to ensure that cavitation does not occur.

QUESTION #5

A centrifugal pump with a *dimensionless* specific speed (in revolutions) of 0.142 operates at a speed of 960 rpm and an overall efficiency of 87% under BEP conditions. A U-tube mercury (S = 13.6) manometer is connected across the pump between the pump's suction pipe and the pump's discharge pipe. The diameter of the suction pipe is 22 cm (0.22 m) and the diameter of the discharge pipe is 16 cm (0.16 m). The reading of this manometer under operating conditions is 1.05 m (Hg). The pump impeller has a diameter of 0.3 m and an outlet width of 2.5 cm (0.025 m). The outlet impeller-vane angle is 52°.

(a) Using an iterative procedure (or otherwise), determine the pump head.

(b) Determine the brake power supplied to the pump.

(c) Neglecting the thickness of the impeller vanes, determine the hydraulic efficiency of the pump.

Note: The dimensionless specific of a pump (in revolutions) 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 #6

A reservoir supplies a gross (or static) head of 513 m to a 4-nozzle Pelton wheel (impulse) water turbine by means of a penstock with a length of 3.1 km, a diameter of 1.4 m, a friction factor of 0.034 and total minor-loss coefficients of 8.3. The nozzle diameter is 0.125 m, the nozzle velocity coefficient is 0.97, the wheel diameter is 2.1 m, the turbine speed is 400 rpm, and the overall efficiency of the turbine is 0.85.

(a) Show that

$$Q = (2gH_T)^{1/2} C_v N_n (\pi d_n^2/4),$$

where Q is the turbine discharge in m^3/s, H_T is the (net) turbine head, C_v is the nozzle velocity coefficient, N_n is the number of nozzles, and d_n is the nozzle diameter in m.

(b) With the aid of the above expression, determine (i) the turbine head, (ii) the turbine discharge, (iii) the turbine speed factor, and (iv) the brake power produced by the turbine.

QUESTION #7

Air (R = 287 J/kg·K) is compressed at a rate of 0.64 kg/s by means of an adiabatic centrifugal compressor operating under BEP conditions with an isentropic efficiency of 78% and a mechanical efficiency of 91%. The absolute pressure and temperature of the air at the inlet of the compressor casing are, respectively, 99.25 kPa and 15.2°C. The absolute pressure of the air at the outlet of the casing is 285.14 kPa. The inlet and outlet areas of the casing are, respectively, 7,830 mm^2 and 6,920 mm^2. The diameter of the impeller of the compressor is 0.18 m, and the impeller blades are radial at the outlet. It can be assumed that the air has a constant specific heat ratio (k) equal to 1.4. Determine (i) the electrical power that must be supplied to the compressor and (ii) the compressor speed (in rpm), and (iii) the temperature of the air at the outlet of the casing.

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