National Exams May 2003

98-Mec-B6, 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. Candidates may use one of two calculators, the Casio or Sharp approved models. This is an Open Book exam.

3. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked.

4. All questions are of equal value.

QUESTION #1

The power input to a centrifugal water pump operating under best-efficiency-point (BEP) conditions is 113 kW. The dimensionless performance curves for the pump are shown in Figure 1, where $C_Q = Q/(\omega D^3)$, $C_H = gH/(\omega^2 D^2)$, and e_p is the overall efficiency. The diameter of the pump impeller is 0.305 m, the outlet impeller-vane angle is 40°, and the outlet impeller-vane width is 9 mm. Determine (i) the rotational speed of the pump in rpm, (ii) the pump discharge, (iii) the pump head, and (iv) the hydraulic efficiency of the pump.

Note:

(i) Q denotes the pump discharge, H denotes the pump head, D denotes the diameter of the pump impeller, and $\omega = 2\pi N/60$, where N denotes the rotational speed of the pump in rpm.

(ii) If $C_H \times 10 = 1.0$, then $C_H = 1.0/10 = 0.1$; also, if $C_Q \times 100 = 2.0$, then $C_Q = 2.0/100 = 0.02$.

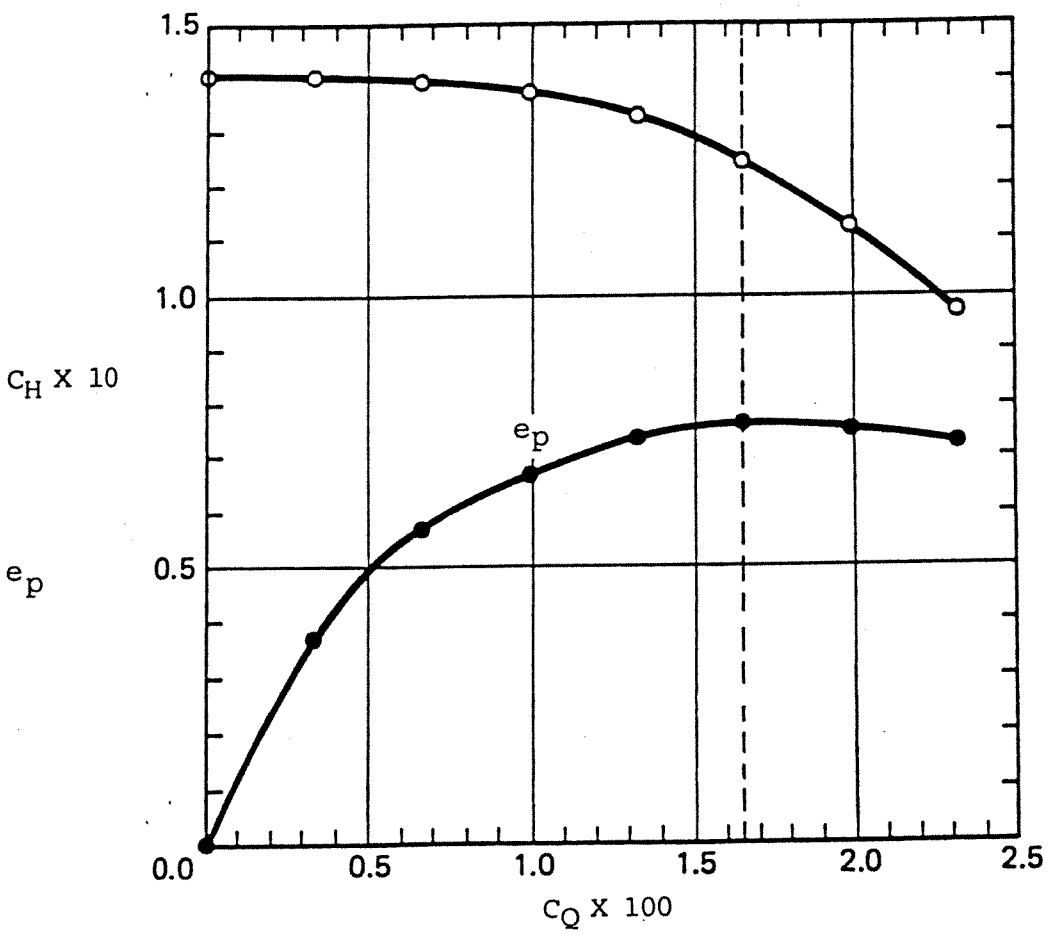

Figure 1

QUESTION #2

Water at 20°C is transported from a reservoir by means of a pump with a 10-cm-diameter suction pipe and a relatively short 8-cm-diameter discharge pipe to which a 4-cm-diameter nozzle is attached, as depicted in Figure 2 below. The friction factor and the minor loss coefficient associated with the suction pipe are, respectively, 0.035 and 1.5. The pump setting, z_s, is 3.6 m. The barometric pressure is 101 kPa. Under operating conditions, the pressure at the pump outlet, where the discharge pipe is connected, is 135 kPa (gauge), and the overall pump efficiency is 0.74. Determine (i) the pump discharge, (ii) the maximum permissible length of the suction pipe, and (iii) the corresponding power supplied to the pump. **Note**: Losses associated with the discharge pipe and nozzle are negligible. Moreover, the maximum permissible length of the suction pipe is such that cavitation can be considered to be incipient at the pump inlet when this length is used.

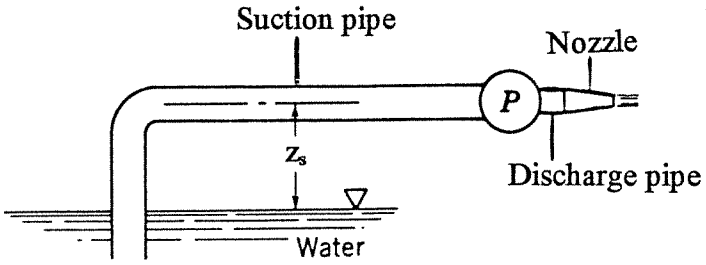

Figure 2

QUESTION #3

Water ($\nu = 10^{-6}$ m^2/s) is to be pumped through a pipeline from one reservoir with a water-surface elevation of 1 m to another reservoir with a water-surface elevation of 30 m by means of a number of identical pumps. The length, diameter, and absolute roughness of the pipeline are, respectively, 200 m, 0.3 m and 0.24 mm, and the minor head-loss coefficients amount to 3.5. The head-discharge characteristics of each pump are given by:

$$H_P = 12.9 + 35.2Q - 281.6Q^2,$$

where H_P is pump head in metres and Q is pump discharge in cubic metres per second. Determine (i) the minimum number of pumps that must be used, and (ii) the power that must be supplied to these pumps given that the overall efficiency of each pump under operating conditions is 0.77.

QUESTION #4

Air is compressed at a rate of 2,000 kilograms per hour by means of a centrifugal compressor operating at 6,400 rpm under BEP conditions with a power input of 4.5 kW. The absolute pressure and temperature of the air at the inlet of the compressor casing are, respectively, 101 kPa and 25°C. The inlet and outlet areas of the casing are 16,500 mm^2 and 8,500 mm^2, respectively. At the outlet of the compressor impeller, the diameter and width are, respectively, 250 mm and 200 mm. The absolute pressure of the air at the outlet of the casing is 107.5 kPa. Determine (i) the overall efficiency of the compressor, and (ii) the outlet impeller-vane angle.
Note: $k = 1.4$, $c_p = 1{,}004$ J/kg·K.

QUESTION #5

A 4-nozzle Pelton wheel impulse turbine is to be connected to a reservoir supplying a gross head of 300 m by means of a penstock with a length of 3 km, a friction factor of 0.025 and minor-loss coefficients amounting to 7.5. The nozzle velocity coefficient will be 0.98; the operating speed of the turbine will be 600 rpm; and, under operating conditions, the available head (i.e., the turbine head) should be 94% of the gross head, the turbine should produce 9.5 MW, the overall turbine efficiency should be 0.85, and the speed (or peripheral-velocity) factor should be 0.45. Determine (i) the diameter of each nozzle, (ii) the diameter of the Pelton wheel, and (iii) the diameter of the penstock.

QUESTION #6

A Francis reaction water turbine equipped with a draft tube operates at 1,600 rpm under BEP conditions. The gross head supplied to the turbine (i.e., the vertical distance between the surfaces of the headwater and the tailwater) is 72 m, and the velocity at the exit of the draft tube, whose lower portion is submerged in the tailwater, is negligible. The pipeline used to convey the water to the turbine has a length of 250 m, a diameter of 0.55 m, and a friction factor of 0.021. The associated minor loss coefficients amount to 3.1. The specific speed of the turbine (N_{sp}) is 199, and its overall efficiency is 93.7%. The critical value of the cavitation parameter for the turbine is 0.14. The temperature of the water is 15°C, and the atmospheric pressure is 102 kPa. (i) Establish that the power produced by the turbine is 500 kW, and (ii) determine the maximum permissible elevation of the turbine relative to the surface of the tailwater.
Note: $N_{sp} = NP^{1/2}/H^{5/4}$, where N is in rpm, P is in kW and H is in m.

QUESTION #7

The head-discharge equation for a 0.4-m-diameter water pump, pump "A", operating at a speed of 1,000 rpm is given by:

$$H_A = 18.24 - 237.5Q_A^2,$$

where H_A is the pump head in metres and Q_A is the pump discharge in cubic metres per second. A homologous 0.6-m-diameter pump, pump "B", is used to transport water through a pipeline from one reservoir with a water-surface elevation of 5 m to another reservoir with a water-surface elevation of 27.8 m.

(a) Determine the head-discharge equations for pump "B" when it is operating at speeds of 1,200 rpm and 1,600 rpm.

(b) When pump B is operating at a speed of 1,200 rpm, the pump discharge is 0.504 m^3/s. Determine the corresponding pump head.

(c) When pump B is operating at a speed of 1,600 rpm, the friction factor of the pipeline is (effectively) unchanged. Determine the pump discharge and the pump head.