National Exams May 2002

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

(a) A prototype reaction water turbine is required to operate at a speed of 430 rpm under a head of 30 m. In order to predict the power that this turbine would produce, a quarter-scale model turbine is tested under a head of 10.8 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 1.12 m^3/s and a dimensionless specific speed of 0.5. Determine the power developed by the model turbine and its efficiency.

(c) Given that the efficiency of the prototype turbine is 3% higher than that of the model turbine, determine the power that will be obtained from the prototype turbine under operating conditions.

QUESTION #2

Under best-efficiency-point (BEP) operating conditions, the speed of a Francis reaction turbine is 1000 rpm and the net turbine head is 15 m 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, 90% and 85%. Neglecting the thickness of the runner vanes, determine (i) the diameter of the turbine runner, and (ii) the power developed by the turbine.

QUESTION #3

(a) The head-discharge characteristics of a water pump are given by:

$$H_P = 42 - 2025Q^2,$$

where H_P is the pump head in metres and Q is the pump discharge in cubic metres per second. The length, diameter, and friction factor of the pump's suction pipe are, 4 m, 0.12 m, and 0.02, respectively. During a test on the pump, the suction pipe is immersed in a 20°C water reservoir, the pump is located 0.8 m above the reservoir surface, and cavitation is found to be incipient when the gauge pressure at the pump inlet is –71.3 kPa, the atmospheric pressure is 101 kPa, and the pump head is 32.5 m. Determine the head loss associated with the suction pipe and the critical value of the cavitation parameter for the pump.

(b) The pump referred to in (a) is to be installed at a high-altitude location where the atmospheric pressure is 83.4 kPa and used to transport 15°C water from a reservoir at a flow rate of 55 litres per second. Determine the maximum permissible elevation of the pump relative to the reservoir surface, if the length of the pump's suction pipe is increased to 5 m.

QUESTION #4

A centrifugal fan operating under best-efficiency-point (BEP) conditions at a speed of 1,800 rpm supplies air to a ventilation duct at a rate of 4.5 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 0.5 m and its width is 0.18 m. The head loss within the fan is 75% of the absolute velocity head at the outlet of the fan impeller, and the overall efficiency of the fan is 5% lower than its hydraulic efficiency. 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 Pelton-wheel impulse turbine is to be installed at a location where the gross available (or static) head is 250 m. The wheel will have a diameter of 1 m and an outlet bucket angle of 155°. The water to drive the wheel will be transported through a penstock with a diameter of 0.3 m and an effective length of 750 m. The flow in the penstock will be completely turbulent and the associated friction factor will be 0.028. Neglecting the nozzle loss, determine (i) the nozzle diameter and the turbine speed (in rpm) that will result in the maximum possible power output from the turbine, and (ii) this maximum power output.

Note: The power produced by a given Pelton wheel is maximum when (a) the velocity head at the nozzle exit is equal to two thirds the static head (provided that the flow in the penstock transporting the water to drive the wheel is completely turbulent), and (b) the bucket velocity is equal to one half the nozzle velocity.

QUESTION #6

Air is compressed at a rate of 0.8 kg/s by means of a centrifugal compressor operating under best-efficiency-point (BEP) conditions. The power supplied to the compressor is 17.5 kW. The absolute pressure and temperature of the air at the inlet of the compressor casing are, respectively, 101.5 kPa and 25°C. The absolute pressure of the air at the outlet of the casing is 120 kPa. The inlet and outlet areas of the casing are, respectively, 12,000 mm^2 and 7,000 mm^2. The impeller of the compressor has backward-curved vanes, and at the impeller outlet, the radius and width are, respectively, 0.20 m and 0.25 m, and the vane angle is 30°. Determine (i) the overall efficiency of the compressor and (ii) the compressor speed (in rpm).

QUESTION #7

Water ($\nu = 10^{-6}$ m^2/s) is transported from one reservoir to another reservoir by means of a pipeline and two pumps, A and B, connected in series. The difference between the elevations of the water surfaces in the reservoirs is 50 m. The pipeline has a diameter of 0.5 m, a length of 2000 m and an absolute roughness of 0.2 mm. The head-discharge characteristics of the pumps are given by:

$$H_A = 120 - 20Q_A^2, \text{ and, } H_B = 80 - 16Q_B^2,$$

where H is pump head in metres and Q is pump discharge in cubic metres per second. Neglecting minor losses, determine the power supplied to the water by the two pumps.