

National Exams May 2011

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 model.
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 wheel of a Pelton-wheel (impulse) water turbine, which is depicted in Figure 1, has a diameter of 0.9 m and rotates at a speed of 400 rpm. The wheel's vane angles are 0° at the inlet and 170° at the outlet. The flow rate of the jet impinging on the vanes is $0.21 \text{ m}^3/\text{s}$. The diameter of the jet is 0.075 m. The absolute velocity of the water leaving the vanes is 6.8 m/s. The mechanical efficiency of the turbine is 94%. Determine (i) the power loss due to friction in the vanes and (ii) the brake power produced by the turbine.

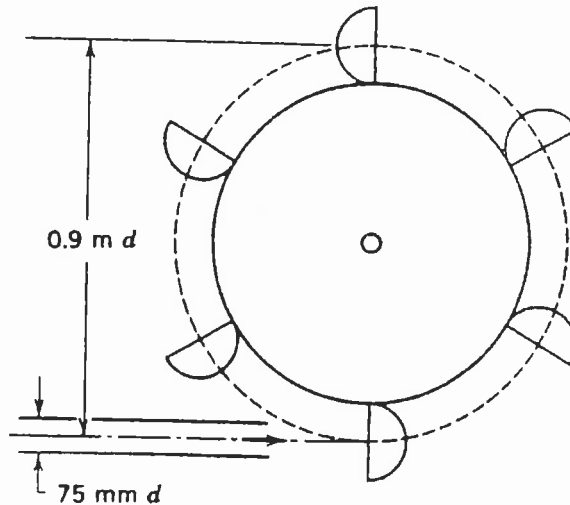


Figure 1

QUESTION #2

An adiabatic centrifugal air compressor with backward-curved blades operates at a speed of 20,600 rpm under best-efficiency-point (BEP) conditions. The brake power supplied to the compressor is 121.5 kW, and the mechanical efficiency of the compressor is 92%. The absolute pressure and temperature of the air are, respectively, 99.25 kPa and 15.2°C at the inlet of the compressor casing, and 285.14 kPa and 144.66°C at the outlet of the casing. The inlet and outlet areas of the casing are, respectively, $7,830 \text{ mm}^2$ and $6,920 \text{ mm}^2$. The inlet and outlet diameters of the impeller of the compressor are, respectively, 12 cm and 25 cm, and the impeller has a constant width of 5 cm. The air has a gas constant (R) of $287 \text{ J/kg}\cdot\text{K}$ and an effectively constant specific heat ratio (k) of 1.4. Determine (i) the mass flow rate through the compressor, and (ii) the inlet and outlet blade angles.

Note:

- Between the inlet and outlet of the compressor casing, the magnitude of the kinetic energy change per unit mass is less than 5% of the magnitude of the specific enthalpy change, but it *cannot* be neglected.
- The thickness of the blades can be neglected.

QUESTION #3

A Francis reaction water turbine equipped with a draft tube operates at a speed of 480 rpm under a gross head of 105 m. The water is conveyed to the turbine by means of a penstock with a length of 600 m, a diameter of 1.5 m, a friction factor of 0.02, and minor head loss coefficients amounting to 2.5. The overall efficiency of the turbine is 0.94, and the dimensionless specific speed of the turbine is 0.12 revolutions. The water temperature is 20°C, and the local atmospheric pressure is 100.5 kPa. Determine (i) the brake power produced by the turbine, and (ii) the maximum permissible elevation of the turbine runner above the surface of the tailwater (to assure against cavitation in the turbine) via Figure 2.

Note:

- It can be assumed that the velocity in the tailrace is negligible.
- A trial and error procedure is required.
- The dimensionless specific speed in revolutions is given by: $N^*_{SP} = [(N/60)(BP/\rho)^{1/2}]/(gH_T)^{5/4}$, where N denotes speed in rpm, BP denotes brake power, ρ denotes density, g denotes gravity and H_T denotes net head.

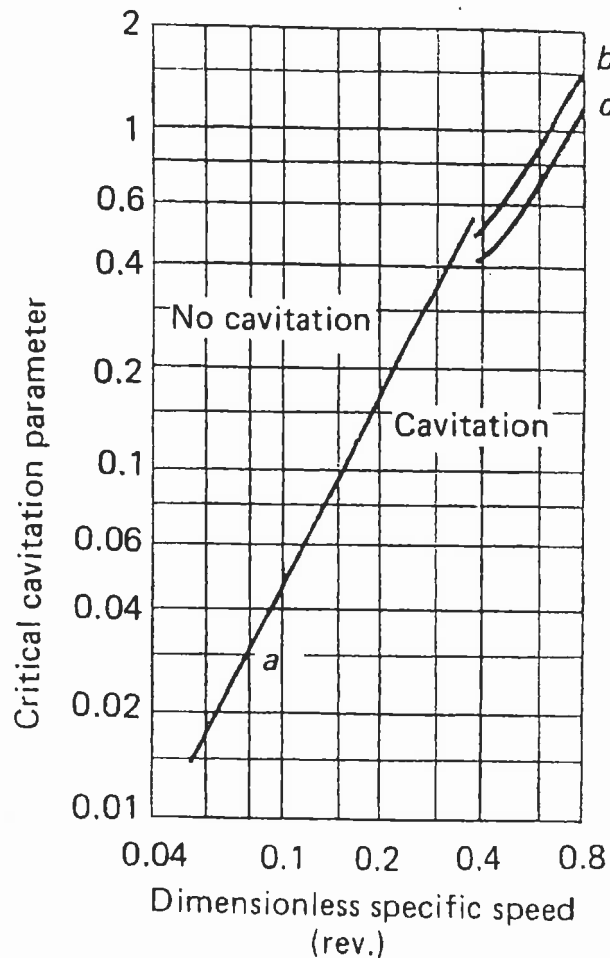


Figure 2. Cavitation limits for reaction turbines: (a) Francis, (b) fixed-blade propeller, (c) Kaplan.

QUESTION #4

A Francis reaction (water) turbine operates under best-efficiency-point (BEP) conditions at a speed of 240 rpm and with a discharge of $17.85 \text{ m}^3/\text{s}$. The diameter of the turbine runner is 1.54 m and its inlet width is 0.36 m. The inlet guide-vane angle is 27° . The volumetric, mechanical and overall efficiencies of the turbine are, respectively, 98%, 95% and 84%. Neglecting the thickness of the runner vanes, determine (i) the hydraulic efficiency of the turbine, (ii) the net turbine head, (iii) the inlet runner-vane angle, (iv) the brake power produced by the turbine and (v) the dimensionless specific speed of the turbine in revolutions.

QUESTION #5

Under steady-state operating conditions, a centrifugal pump is supplied with a brake power of 5.8 kW. The impeller of the pump has an inner diameter of 20 cm and an outer diameter of 36 cm. The inner and outer widths of the impeller are 6 cm and 4 cm, respectively. The inlet and outlet impeller-vane angles are 35° and 50° , respectively. The vanes occupy 10% of the circumference of the impeller at the inlet and outlet. The hydraulic efficiency and the overall efficiency of the pump are 87% and 83%, respectively. Determine the pump speed (in rpm) required for a pump discharge of 95 litres per second.

QUESTION #6

Water is transported from a reservoir through a 20-cm-diameter pipe with a friction factor of 0.013 to a point 16 m above the surface of the water in the reservoir by means of a pump whose head-discharge characteristics are given by:

$$H = 72 - 2,165Q^2,$$

where H is head in metres and Q is discharge in cubic metres per second. The length of pipe downstream from the pump is 146 m, and the associated minor loss coefficients amount to 2; the length of pipe upstream from the pump is 10 m, and the associated minor loss coefficients amount to 3.5; the critical value of the cavitation parameter for the pump is 0.105; the temperature of the water in the reservoir is 20°C ; the barometric pressure corresponds to 765 mm Hg. Determine (i) the pump discharge and the pump head under steady state operating conditions, and (ii) the critical location of the pump with respect to the surface of the water in the reservoir.

Note: The end of the pipe downstream from the pump is open to the atmosphere.

QUESTION #7

Water is conveyed from one reservoir with a water-surface elevation of 5.7 m to another reservoir with a water-surface elevation of 15.9 m by means of a pump-pipe system. The diameter, length, and friction factor of the pipe and the associated total minor loss coefficients are, respectively, 0.8 m, 500 m, 0.017 and 4.5. The pump's dimensionless performance curves are presented in Figure 3, where $C_Q = Q/(\omega D^3)$, $C_H = gH/(\omega^2 D^2)$, and e_p is the overall efficiency. Given that the pump operates at its maximum efficiency and that the pump impeller diameter is 1.2 m, determine (i) the pump speed in rpm, and (ii) the brake power supplied to the pump.

Note:

- Q denotes discharge; H denotes head; D denotes impeller diameter; and $\omega = 2\pi N/60$, where N denotes speed in rpm.
- With respect to Figure 2, if $C_Q \times 100 = 1.0$, then $C_Q = 1.0/100 = 0.01$, and if $C_H \times 10 = 1.0$, then $C_H = 1.0/10 = 0.1$.

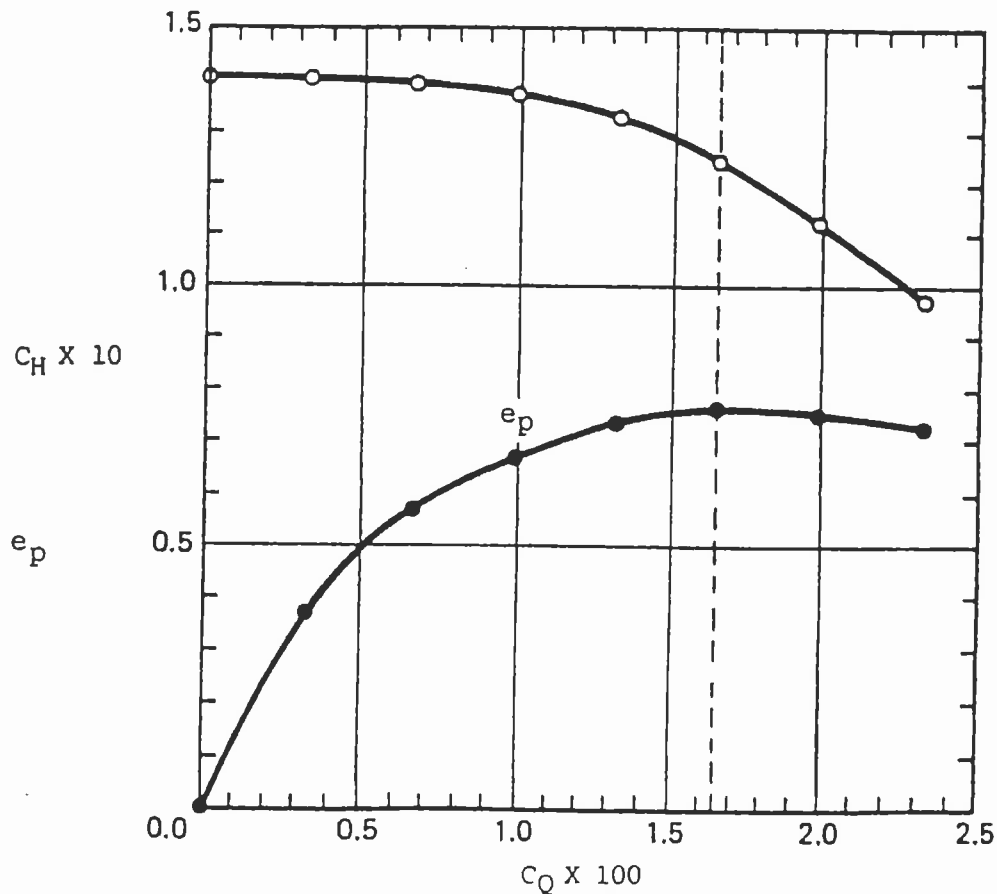


Figure 3