National Exams May 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.
   Any non-communicating calculator is permitted.

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.

original graph

QUESTION #1

Tests performed on a 500-mm-diameter pump operating at a speed of 1600 rpm yielded the data tabulated below. A homologous 800-mm-diameter pump operating at a speed of 2000 rpm is to be used to pump water through a pipeline system for which the head-discharge characteristics are given by

$$H = 27.3 + 40.8Q^2,$$

where H is head in metres and Q is discharge in cubic metres per second. Determine the power that must be supplied to the homologous pump under steady state operating conditions.

Discharge (m^3/s)	Head (m)	Efficiency (%)
0.10	21.74	56.5
0.15	21.18	75.4
0.20	20.26	83.1
0.25	19.12	76.0
0.30	17.65	50.3

QUESTION #2

Water is transported through a pipeline at a flow rate of 0.045 m^3/s from one reservoir with a free-surface elevation of 5 m to another reservoir with a free-surface elevation of 13 m by means of a centrifugal pump operating under best-efficiency-point (BEP) conditions. The pump's suction and delivery pipes have a diameter of 0.15 m, a combined length of 190 m, a friction factor of 0.024, and total minor loss coefficients of 4.3. The pump impeller has forward-curved vanes with an outlet angle of 145° and an outlet width of 50 mm. The vanes occupy 7% of the circumference of the impeller. The outer diameter of the impeller is 0.2 m. The hydraulic and overall efficiencies of the pump under BEP conditions are 84.2% and 79.5%, respectively. Determine (i) the power supplied to the pump, and (ii) the pump speed (in rpm).

QUESTION #3

The speed of a radial-flow reaction water turbine operating under BEP conditions is 1200 rpm. The diameter of the turbine runner is 0.25 m, the inlet angle and width of the runner vanes are 125° and 70 mm, respectively, and the inlet guide-vane angle is 25°. The hydraulic and overall efficiencies of the turbine are 86.5% and 81%, respectively. Neglecting the thickness of the runner vanes, determine (i) the (net) turbine head, (ii) the turbine discharge, and (iii) the turbine brake power.

QUESTION #4

An initially empty tank with a volume of 638.2 m^3 is filled with water from a reservoir by means of a pump-pipeline system involving several (N) identical pumps connected *in parallel*. The top of the tank is open to the atmosphere and is located 23 m above the surface of the water in the reservoir. With respect to the suction pipe of the system, the pipe length (L), the pipe diameter (D), the pipe friction factor (f) and the total minor head-loss coefficients (ΣK) are, respectively, 39 m, 0.3 m, 0.02 and 1.9. With respect to the discharge pipe of the system, the pipe length, the pipe diameter, the pipe friction factor and the total minor head-loss coefficients are, respectively, 60 m, 0.2 m, 0.018 and 1.5. The downstream end of the discharge pipe is attached to the top of the tank. The head-discharge characteristics of each pump are as follows:

$$H_P = 26 + 87Q_P - 250Q_P^2,$$

where H_P is the pump head in metres and Q_P is the pump discharge in cubic metres per second.

(a) Given that four (4) pumps are used, determine (i) the time (T) taken to fill the tank, and (ii) the power supplied to the water by the four pumps.

(b) Given that the time taken to fill the tank is to be reduced to *approximately* 80% of the time found in part (a), determine (i) the number of pumps required to accomplish this 'filling-time reduction', (ii) the corresponding time taken to fill the tank as a percentage of the time found in part (a), and (iii) the corresponding power supplied to the water.

QUESTION #5

A single-stage axial-flow impulse gas turbine is used in a jet engine. At the engine entrance, the temperature is 640°C and the pressure is 300 kPa. The gas flows through the engine at a rate of 25 kg/s. The (absolute) axial velocity of the gas is 100 m/s, and the (absolute) tangential velocity of the rotor vanes of the turbine is 170 m/s. The angle between the absolute velocity of the gas leaving the stator vanes of the turbine and the tangential velocity of the rotor vanes is 20°. The flow can be assumed to be isentropic, and the gas can be considered to be an ideal gas with a gas constant of 287 J/kg·K and a specific heat ratio of 1.35. Fluid friction in the rotor blade passages can be neglected; consequently, the magnitude of the relative velocity of the gas is the same at the inlet and outlet of the rotor blades; also, the axial flow velocity is the same at these locations. (The rotor blades are shaped so as to ensure this.) Determine (i) the inlet and outlet rotor-vane angles, (ii) the power developed by the turbine, (iii) the temperature at the engine exit, and (iv) the pressure at the engine exit.

QUESTION #6

An axial-flow reaction water turbine equipped with a draft tube, which is depicted in Figure 1, operates at a speed (N) of 124 rpm. The flow rate through the turbine is 118.5 m^3/s, and the overall and hydraulic efficiencies of the turbine are 0.935 and 0.97, respectively. The guide vanes of the turbine have an inner radius of 2.4 m and a height of 1.6 m, and they are set at angle of 38° with respect to the direction of the peripheral velocity of the turbine runner. The turbine runner vanes have a tip radius of 1.2 m and a hub radius of 0.2 m. Determine (i) the net turbine head (H_T), (ii) the brake power (BP) produced by the turbine, (iii) the dimensionless specific speed (N_{SP}) of the turbine in revolutions, and (iv) the inlet runner vane angles at the hub and the tip.

Note: The dimensionless specific speed is given by: $N_{SP} = (N/60)(BP/\rho)^{1/2}/(gH_T)^{5/4}$, where ρ denotes density and g denotes gravity.

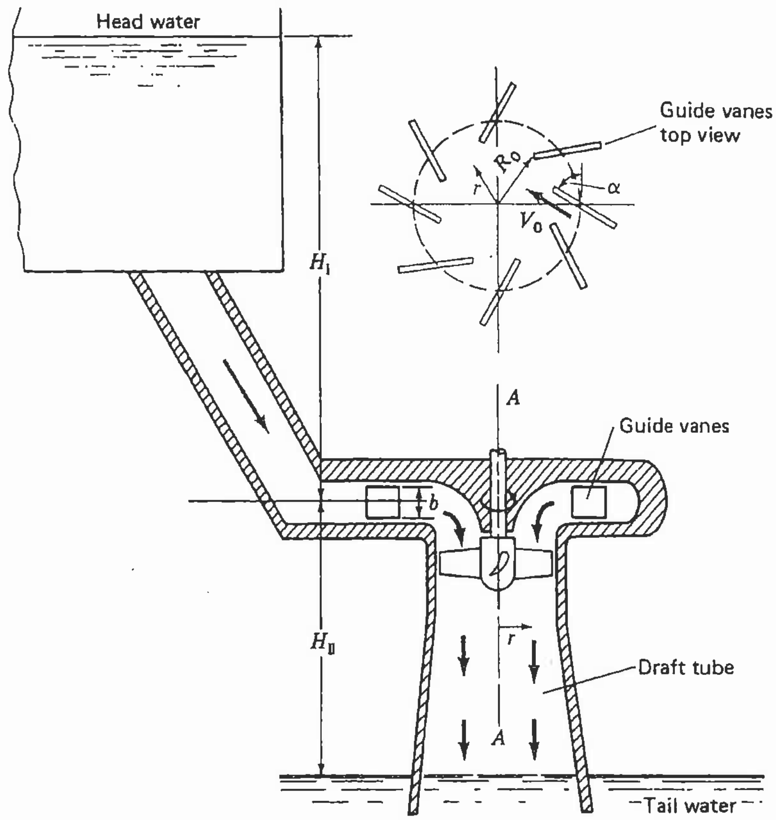

Figure 1. Axial-flow reaction turbine.

QUESTION #7
Under BEP conditions, a Francis reaction water turbine equipped with a draft tube operates at a speed of 400 rpm. The overall and hydraulic efficiencies of the turbine are 0.93 and 0.96, respectively; the flow rate through the turbine is 12.6 m^3/s; the diameter of the turbine runner is 1.3 m, the inlet runner-vane angle is 115°, the inlet guide-vane angle is 20°; the water temperature is 15°C, and the local atmospheric pressure is 102 kPa. Determine (i) the (net) turbine head, (ii) the brake power produced by the turbine, (iii) the dimensionless specific speed of the turbine in revolutions, (iv) the critical cavitation parameter for the turbine, via Figure 2, and (v) the maximum permissible elevation of the turbine runner above the surface of the tailwater (to assure against cavitation in the turbine). Note: With respect to the dimensionless specific speed, refer to QUESTION #6.

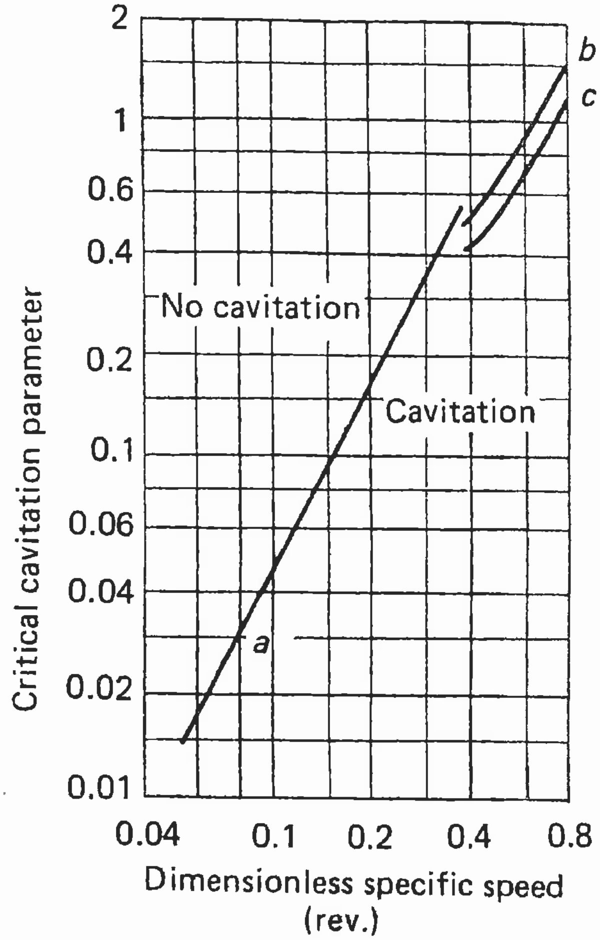

Figure 2. Cavitation limits for reaction turbines: (a) Francis, (b) fixed-blade propeller, (c) Kaplan.