FLUID MECHANICS D209 Q10 1996

(a) (i) Distinguish between impulse and reaction water turbines.

(ii) Describe three different types of reaction turbine and specify appropriate conditions under which each type of machine would be used.

(b) A turbine is required to work under a total head of water of 28 m and to operate at 7.14 rev/s. A one-quarter scale model of the proposed turbine is to be tested under a total head of water of 10.8 m.

(i) Determine the speed at which the model should be operated in order to predict the performance of the full scale turbine.

(ii) At the speed described in (i), the model develops 100 kW of power at a discharge of 1.085 m^3/s.
Calculate the corresponding power developed by the full-scale turbine.

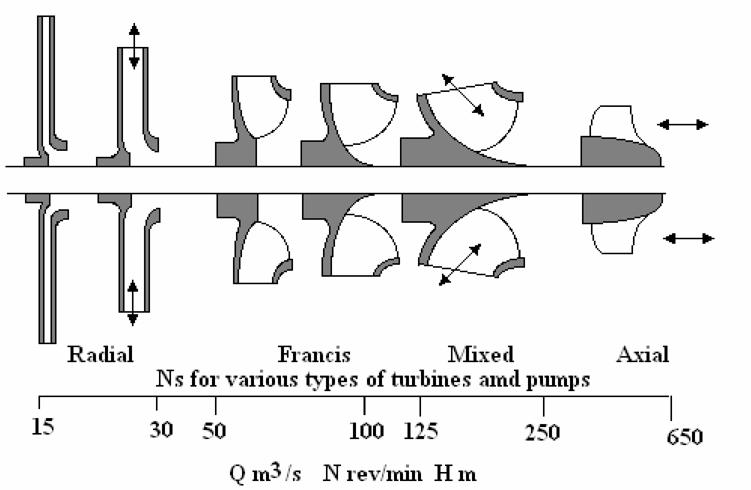
(iii) Calculate the specific speed, stating the units used, of the full-scale turbine and specify the type of machine.

IMPULSE – All the pressure is converted into Kinetic Energy in the nozzles and the KE is converted into mechanical power by the rotor.

REACTION – All the pressure is used in the rotor to accelerate the fluid over the vanes and the reaction force to this produces a torque and mechanical power.

In practice turbines like the Francis Wheel are partly impulse and partly reaction.

(b) The diagram illustrates the different types of turbines. On the left we have high pressure and on the right low pressure. The optimal efficiency for each occurs at a particular specific speed as indicated.



The Francis Wheel used Ns ≈ 75 and is used with fairly high heads and flow rates.

The mixed design uses lower heads and larger flow rates with Ns ≈ 200

The Axial flow (Kaplan) turbine uses the lowest head and is almost a free wheel propeller driven by the stream. Ns ≈ 600

The units for Head are m, speed is rev/min and flow is m^3/s

(b) H1 = 28 m N_1 = 7.14 rev/s

Model ¼ scale H_2 = 10.8 m

The dimensionless equation for turbines is $\frac{P}{\rho N^3 D^5} = \varphi\left(\frac{Q}{ND^3}\right)\left(\frac{g\,\Delta H}{N^2D^2}\right)$

The head coefficient must be the same for both.

$$\left(\frac{g\,\Delta H}{N^2D^2}\right)_1 = \left(\frac{g\,\Delta H}{N^2D^2}\right)_2 \qquad \left(\frac{\Delta H}{N^2D^2}\right)_1 = \left(\frac{\Delta H}{N^2D^2}\right)_2$$

$$\left(\frac{28}{7.14^2 D_1^2}\right) = \left(\frac{10.8}{N^2(D_1/4)^2}\right) \quad \left(\frac{28}{7.14^2}\right) = \left(\frac{10.8 \times 16}{N^2}\right)$$ hence N = 17.73 rev/s for the model.

The flow coefficients must also be the same

$$\left(\frac{Q}{ND^3}\right)_1 = \left(\frac{Q}{ND^3}\right)_2$$

$$Q_1 = Q_2 \frac{N_1 D_1^3}{N_2 D_2^3} = \frac{1.085 \text{ x } 7.184 \text{ x } 4^3}{17.73} = 27.82 \text{ m}^3/2$$

The Power Coefficients must be the same.

$$\left(\frac{P}{\rho N^3 D^5}\right)_1 = \left(\frac{P}{\rho N^3 D^5}\right)_2 \qquad P_1 = P_2 \frac{\rho N_1^3 D_1^5}{\rho N_2^3 D_2^5} = 100 \text{ x } \frac{7.14^3 \text{ x } 4^5}{17.73^3} = 6687.5 \text{ kW}$$

$$Ns = \left(\frac{N_1 Q_1^{1/2}}{H^{3/4}}\right) = \frac{7.14 \text{ x } 60 \text{ x } 27.82^{1/2}}{28^{3/4}} = 185.6$$

This would indicate the a mixed flow turbine (The official examiners answer is a Kaplan)