HYDRAULIC TURBOMACHINES
Exercises 5 - Axial Turbines

Hydropower plant equipped with Kaplan turbines

The Gezhouba power plant is located in the Hubei province, China (the frequency of the electrical grid is equal to $f_{grid} = 50$ Hz). It is equipped with 2 Kaplan turbines of 176 MW and 5 Kaplan turbines of 129 MW. In this problem, we will investigate the 176 MW units. A cut-view of the Kaplan unit is given in Figure 1.

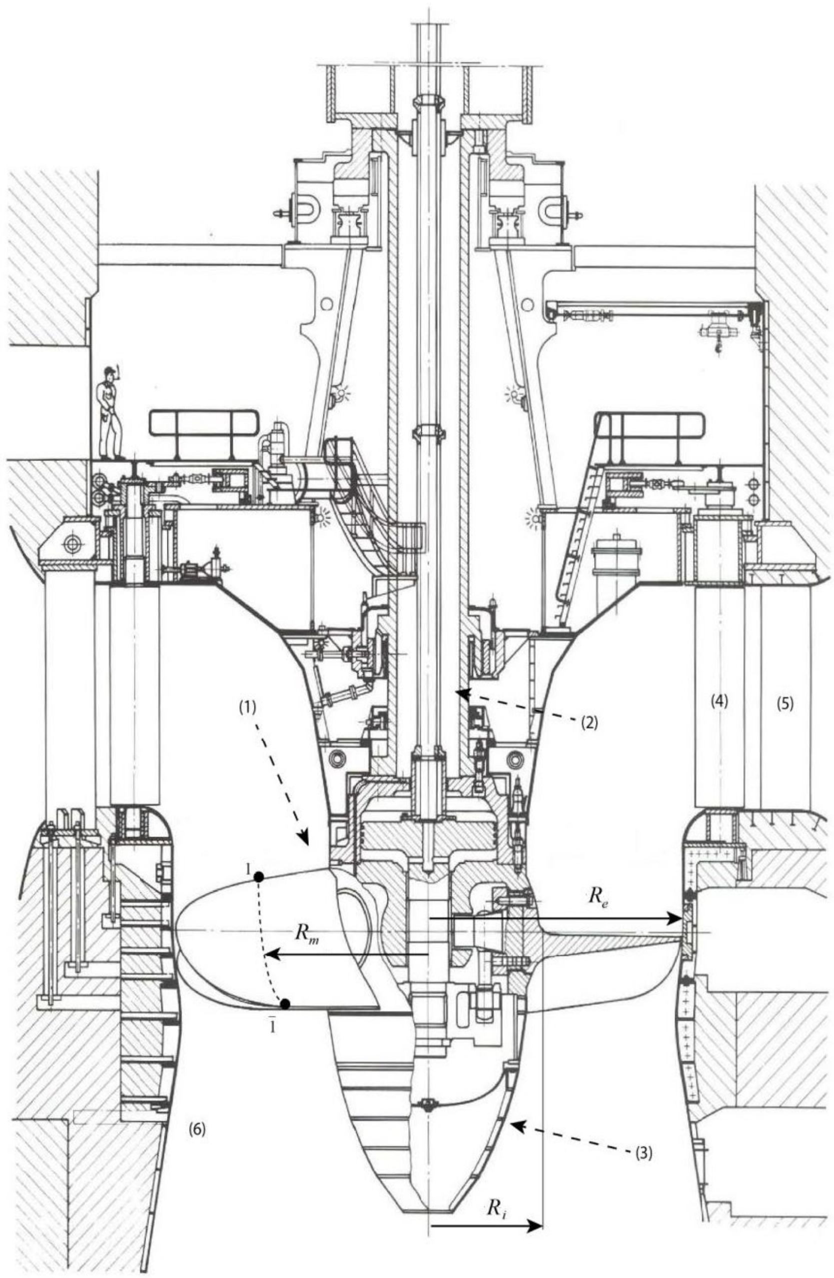

Figure 1 – Kaplan turbine unit - Gezhouba power plant.

1. Name the components in Figure 1:

Number	Name
(1)	*Runner*
(2)	*Shaft*
(3)	*Hub*
(4)	*Guide vanes*
(5)	*Stay vanes*
(6)	*Draft tube*

2. Compute the specific potential energy of the installation for an upstream reservoir level of $Z_B = 45$ m and a downstream reservoir level of $Z_{\bar{B}} = 25$ m. The value of the gravitational constant is $g = 9.794$ m s^{-2}.

$$gH_B - gH_{\bar{B}} = g(Z_B - Z_{\bar{B}}) = 195.88 \text{ Jkg}^{-1}$$

3. For a nominal discharge of $Q = 1130$ m^{3}s^{-1}, the head losses of the installation have been measured and are equal to $\sum gH_r = 13.48$ J kg^{-1}. Compute the available specific energy of the turbine. Deduce the net head H of the turbine.

$$E = gH_B - gH_{\bar{B}} - \sum gH_r = 182.4 \text{ J kg}^{-1}$$

$$H = \frac{E}{g} = 18.6 \text{ m}$$

4. For this turbine, the pole number of the generator is equal to $Z_0 = 110$. Compute the runner frequency n and the specific speed ν of the runner.

$$n = \frac{2 f_{grid}}{Z_0} = 0.91 \text{ Hz}$$

$$\omega = 2\pi n = 5.712 \text{ rad s}^{-1}$$

$$\nu = \frac{\omega \sqrt{Q}}{\sqrt{\pi}\,(2E)^{\frac{3}{4}}} = 1.298$$

5. Compute P_h, the hydraulic power. The value of water density ρ is 998 kg m^{-3}.

$$P_h = \rho\, Q\, E = 205.7 \text{ MW}$$

6. We assume an energy efficiency for this turbine of $\eta_e = 92$ %. Compute the transformed (or supplied) specific energy E_t.

$$E_t = \eta_e E = 167.8 \text{ J kg}^{-1}$$

7. Compute the torque experienced by the runner shaft T_t.

We neglect the leakage flow loss, i.e. the volumetric efficiency $\eta_q = 1.0$ *and* $Q_t = Q$.

$$P_t = \omega T_t = \rho\, Q\, E_t = 189.2 \text{ MW}$$

$$T_t = \frac{P_t}{\omega} = 33.1 \cdot 10^6 \text{ Nm}$$

8. Compute the mechanical efficiency (defined by $\eta_{me} = \eta_{rm} \cdot \eta_m$), and global machine efficiency. Neglect the generator losses.

$$\eta_{me} = \frac{P}{P_t} = 0.93$$

$$\eta = \frac{P}{P_h} = 0.856$$

9. The streamline $1 - \bar{1}$ is assumed to be on a cylinder with a mean radius R_m. The internal and external diameters are equal to $D_i = 4.520$ m and $D_e = 11.3$ m. Compute the peripheral runner speed U_1 and $U_{\bar{1}}$.

$$U_1 = \omega R_m = 2\pi n R_m = 2\pi n \frac{D_e + D_i}{4} = 22.61 \text{ ms}^{-1}$$

$$U_{\bar{1}} = \omega R_m = 2\pi n R_m = 2\pi n \frac{D_e + D_i}{4} = 22.61 \text{ ms}^{-1}$$

10. By considering that the flow at the runner outlet is purely axial, compute Cu_1 the peripheral component of the absolute velocity at the runner inlet.

By solving the Euler equation and considering a purely axial flow ($Cu_{\bar{1}} = 0 \text{ ms}^{-1}$):

$$Cu_1 = \frac{E_t}{U_1} = 7.42 \text{ ms}^{-1}$$

11. Compute the meridional components of the absolute velocity Cm_1 and $Cm_{\bar{1}}$.

$$A_1 = A_{\bar{1}} = \frac{\pi(D_e^2 - D_i^2)}{4} = 84.24 \, \text{m}^2$$

$$Cm_1 = \frac{Q}{A_1} = 13.41 \text{ ms}^{-1}$$

$$Cm_{\bar{1}} = \frac{Q}{A_{\bar{1}}} = 13.41 \text{ ms}^{-1}$$

12. From the previous results, compute the angles α_1 and β_1 at the runner inlet, and $\alpha_{\bar{1}}$ and $\beta_{\bar{1}}$ at the runner outlet.

$$\alpha_1 = \tan^{-1}\left(\frac{Cm_1}{Cu_1}\right) = 61.04^\circ$$

$$\beta_1 = \tan^{-1}\left(\frac{Cm_1}{U_1 - Cu_1}\right) = 41.44^\circ$$

$$\alpha_{\bar{1}} = 90^\circ$$

$$\beta_{\bar{1}} = \tan^{-1}\left(\frac{Cm_{\bar{1}}}{U_{\bar{1}} - \cancel{Cu_{\bar{1}}}}\right) = 30.67^\circ$$

13. Finally, sketch the corresponding velocity triangles at the runner inlet and outlet.

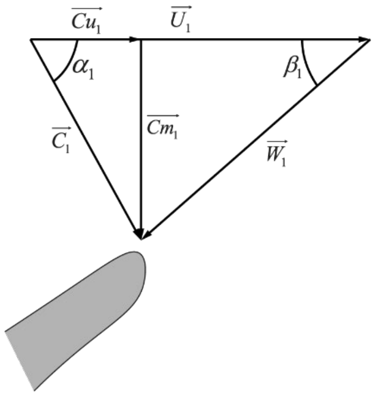

Figure 2 – Velocity triangle - Runner Inlet.

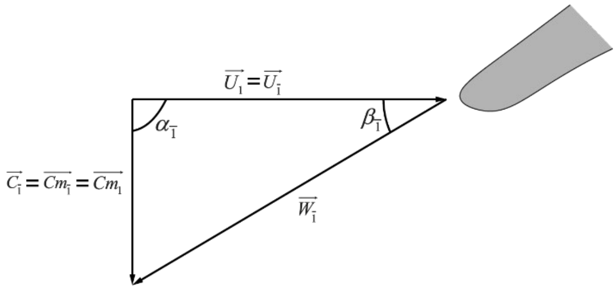

Figure 3 – Velocity triangle - Runner Outlet.