HYDRAULIC TURBOMACHINES
Exercises 3 - Cavitation

Settling level of a Francis turbine

In Figure 1, the installation of the turbine and setting level are shown.
Consider the following input data:

$C_{\bar{I}} = 0.86 \ \mathrm{m \cdot s^{-1}}$
$Z_{\bar{B}} = 175.6 \ \mathrm{m}$
$p_{atm} = 1.0 \ \mathrm{bar}$
$p_v = 2343 \ \mathrm{Pa}$

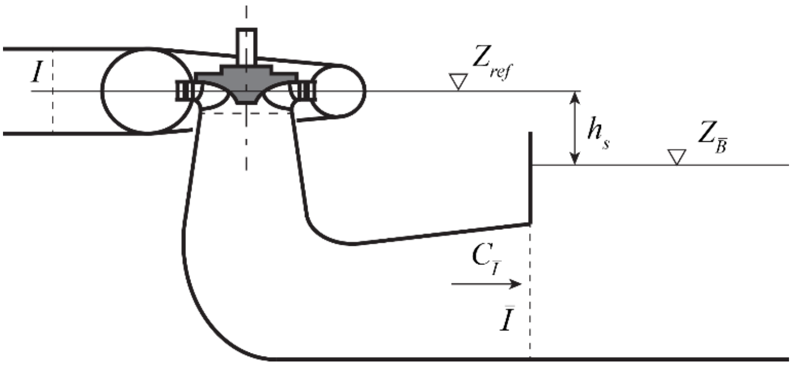

Figure 1. Machine setting level

1) Express the Net Positive Suction Specific Energy (*NPSE*) by ρ, $gH_{\bar{I}}$, Z_{ref}, and a saturated pressure p_v.

$$NPSE = gH_{\bar{I}} - \frac{p_v}{\rho} - gZ_{ref}$$

2) Express Thoma number σ defined by $\frac{NPSE}{E}$, using the setting level $h_s = Z_{ref} - Z_{\bar{B}}$, the flow velocity $C_{\bar{I}}$, the saturated pressure p_v and the atmosphere pressure p_a. Assume that the draft tube outlet is considered as a water outflow ($K_v = 1$).

Using the specific energy balance, as detailed in lecture 4, slide 10:

$$\sigma = \frac{NPSE}{E} = \frac{\frac{p_{atm} - p_v}{\rho} - gh_s + \frac{C_{\bar{I}}^2}{2}}{E}$$

3) Compute Z_{ref}, the setting elevation of the turbine units, to achieve a Net Positive Suction Head (NPSH) of 13.4 m.

The following condition needs to be verified:

$$NPSH = \frac{NPSE}{g} = H_{\bar{I}} - \frac{p_v}{g\rho} - Z_{ref} = 13.4\text{m}$$

The specific energy at the outlet section of the machine is:

$$gH_{\bar{I}} = gZ_{\bar{I}} + \frac{p_{\bar{I}}}{\rho} + \frac{C_{\bar{I}}^2}{2}$$

As $Z_{\bar{I}}$ and $p_{\bar{I}}$ are unknown, we use the following relationship:

$$\frac{p_{\bar{I}}}{g\rho} = \frac{p_{atm}}{g\rho} + Z_{\bar{B}} - Z_{\bar{I}} \text{ (column of water in } \bar{\text{I}})$$

$$\Rightarrow gH_{\bar{I}} = gZ_{\bar{B}} + \frac{p_{atm}}{\rho} + \frac{C_{\bar{I}}^2}{2}$$

Note that the kinetic energy corresponds to the specific energy losses due to the water outflow ($K_v = 1$) at the draft tube outlet.

Using the relationship found in 1):

$$\begin{aligned} Z_{ref} &= H_{\bar{I}} - \frac{p_v}{\rho g} - \frac{NPSE}{g} \\ &= Z_{\bar{B}} + \frac{p_{atm}}{\rho g} + \frac{C_{\bar{I}}^2}{2g} - \frac{p_v}{\rho g} - \frac{NPSE}{g} \\ &= Z_{\bar{B}} + \frac{p_{atm} - p_v}{\rho g} + \frac{C_{\bar{I}}^2}{2g} - NPSH = 172.2\ m \end{aligned}$$