Hydropower Plants: Generating and Pumping Units
Mock exam – part 2

Duration : 2 hours;

Documentation: personal hand written notes, bilingual dictionary, and available lectures and exercises on the Moodle are authorized; you can use your laptop in offline mode (no internet connection).

Exam evaluation: The weight of each question is indicated. General presentation and clarity of answers will be taken into account for the evaluation.

Maximum total score: 30 points

1 SPECIFIC ENERGY LOSS CALCULATION

The schematic of a hydropower plant is shown in Figure 1. The reservoir level changes throughout the year due to seasonal effect. The maximum and minimum annual headwater levels are Z_B^{max} and Z_B^{min}, respectively. Similarly, the tailwater level ranges between $Z_{\overline{B}}^{max}$ and $Z_{\overline{B}}^{min}$. The headwater and tailwater levels are maximum during summer and minimum in winter. <u>The power plant has 4 turbines</u>. Answer to the questions based on the values provided in Table 1.
The gravity acceleration, the water density and the water kinematic viscosity are:

$$g = 9.81 \text{ m s}^{-2},\ \rho = 998 \text{kg} \cdot \text{m}^{-3} \text{ and } \nu_{water} = 10^{-6} \text{ m}^2 \text{ s}^{-1}$$

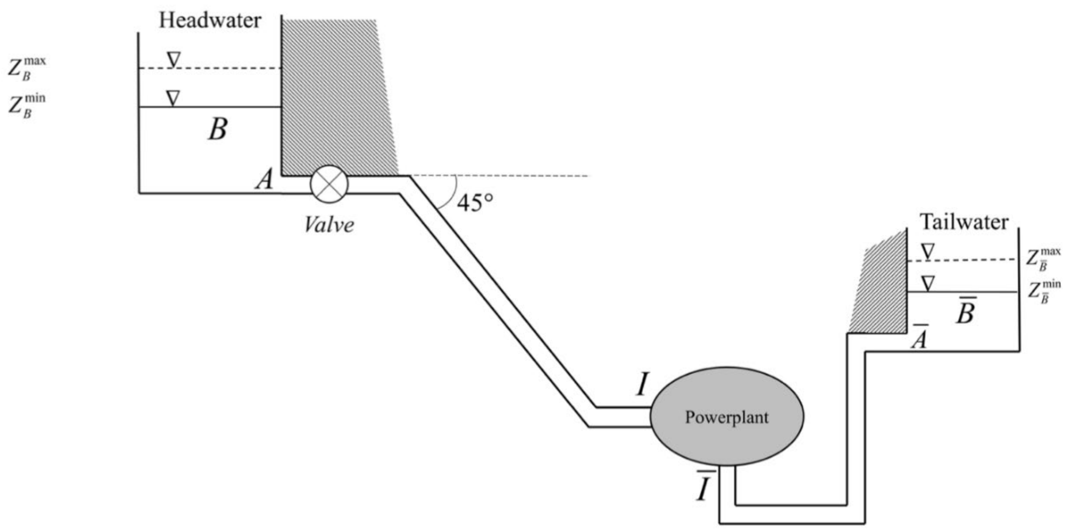

Figure 1: Simplified layout of the power plant.

Data	*Symbol*	*Value*	*Unit*
Max headwater reservoir level	$Z_B^{\max}$	780	m
Min headwater reservoir level	$Z_B^{\min}$	769	m
Max tailwater reservoir level	$Z_{\bar{B}}^{\max}$	575	m
Min tailwater reservoir level	$Z_{\bar{B}}^{\min}$	572	m
Number of turbines in the power plant	$z_{turbines}$	4	-
Rated discharge <u>per turbine</u>	Q	55	m^3s^{-1}
Penstock diameter	D_{pen}	5	m
Penstock length	L_{pen}	180	m
Pipeline roughness	k_s	5×10^{-5}	m
Elbow loss coefficient	k_{elbow}	0.15	-
Intake loss coefficient	k_{intake}	1.00	-
Valve loss coefficient	k_{valve}	0.10	-
Energetic efficiency	η_e	0.92	-
Volumetric efficiency	η_q	0.99	-
Global machine efficiency	η	0.90	-
Number of pole <u>pairs</u>	$z_{p,pairs}$	8	-
Frequency of the grid	f_{grid}	50	Hz
Turbine inlet section diameter	D_{1e}	3.50	m
Turbine inlet section height	B	0.60	m
Turbine outlet section diameter	$D_{\bar{1}e}$	2.80	m

Table 1: Technical data of the power plant.

Do not consider, for now, the season at which the power plant is operating.

1) Express the potential specific energy of the installation by Z_B, $Z_{\bar{B}}$, and *g*. [1 points]

2) Taking into account the specific energy losses $gH_{rB\div I}$ and $gH_{r\bar{I}\div\bar{B}}$, express the available specific energy *E* by *g*, Z_B, $Z_{\bar{B}}$, $gH_{rB\div I}$ and $gH_{r\bar{I}\div\bar{B}}$. [1 points]

Calculate the water velocity in the penstock. [1.5 points]

4) Calculate the Reynolds number in the penstock. [1 points]
5) Calculate the sum of the singular and distributed energy losses along the penstock, $gH_{rB\div I}$, for the power plant discharge. [3 points]

For the following questions, consider that the power plant operates during a day in the summer season.

6) Calculate the available specific energy and the hydraulic power of one turbine. The specific energy losses in the tailrace channel $gH_{r_{\bar{I}\div\bar{B}}}$ is assumed to be 0.1% of the potential specific energy. [2 points]
7) Calculate the transferred power and the output power of the turbine. [2 points]

POWER TRANSFER IN THE HYDRAULIC MACHINE

The power plant studied so far features four generating units, each one equipped with a Francis turbine. Let's now have a closer look to one of those turbines, whose meridional view is shown in Figure 2.

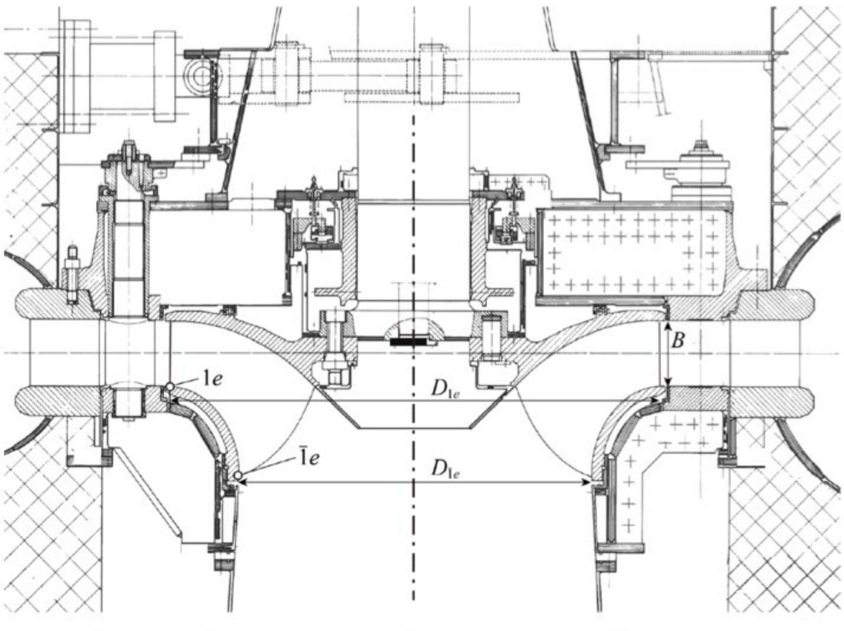

Figure 2: Meridional view of the Francis turbine.

8) Express and compute the external runner rotating velocity at the runner inlet and outlet, respectively U_{1e} and $U_{\bar{1}e}$. [2 points]

9) Express and compute the inlet and outlet surface sections of the turbine A_{1e} and $A_{\bar{1}e}$. [2 points]

10) Express the meridional component of the absolute flow velocity at the runner inlet and outlet, respectively Cm_{1e} and $Cm_{\bar{1}e}$ as a function of the discharge Q, the volumetric efficiency η_q and the sections A_{1e} and $A_{\bar{1}e}$. [2 points]

11) Express the tangential component of the absolute flow velocity at the runner inlet and outlet, respectively Cu_{1e} and $Cu_{\bar{1}e}$, as a function of the absolute velocity angles α_{1e} and $\alpha_{\bar{1}e}$, and of the meridional components Cm_{1e} and $Cm_{\bar{1}e}$ from the previous question. [2 points]

Consider now the operating condition studied in questions 6) and 7), i.e. a summer day with the rated discharge value for each turbine, and assume that this condition is the turbine BEP.

12) Compute the meridional component of the inlet and outlet absolute velocities. [2 points]

13) Compute the inlet absolute and relative flow angle α_{1e} and β_{1e}. [2.5 points]
14) Compute the outlet absolute and relative flow angle $\alpha_{\bar{1}e}$ and $\beta_{\bar{1}e}$. [2 points]
15) Compute the norm of the inlet and outlet relative flow velocities $\left|\vec{W}_{1e}\right|$ and $\left|\vec{W}_{\bar{1}e}\right|$. [2 points]
16) Sketch qualitatively the inlet and outlet velocity triangles for this operating condition. [2 points]