HYDRAULIC TURBOMACHINES
Exercises 8 - Pumped Storage Power Stations

Pumped storage power plant – Bajina Basta

The Bajina Basta pumped storage power plant is located on the Drina river, about 150km south-west from Belgrade, near the border between Serbia and Bosnia-Herzegovina. The power plant was originally commissioned in 1966. At that time, the project featured two pump-turbines with a nominal power of 281 MW in pumping mode and of 294 MW in turbine mode. The outline of the power plant and a cut-view of one power unit are given respectively in Figure 1 and 2.

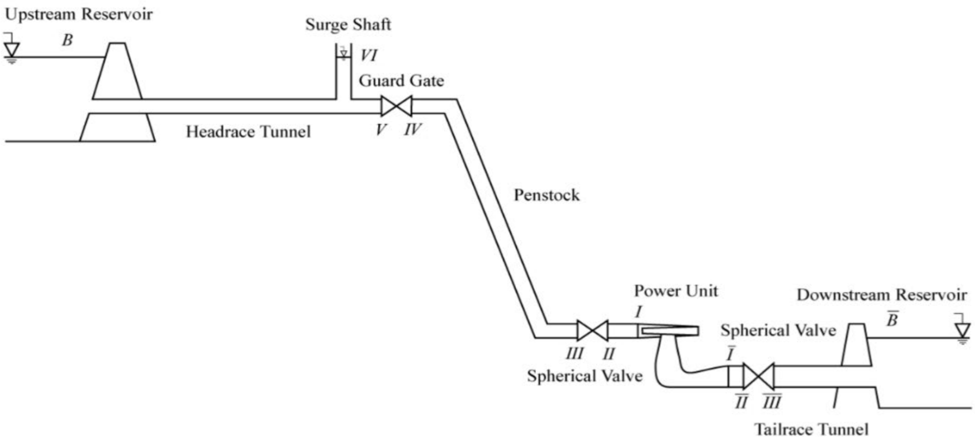

Figure 1 – Outline of the power station

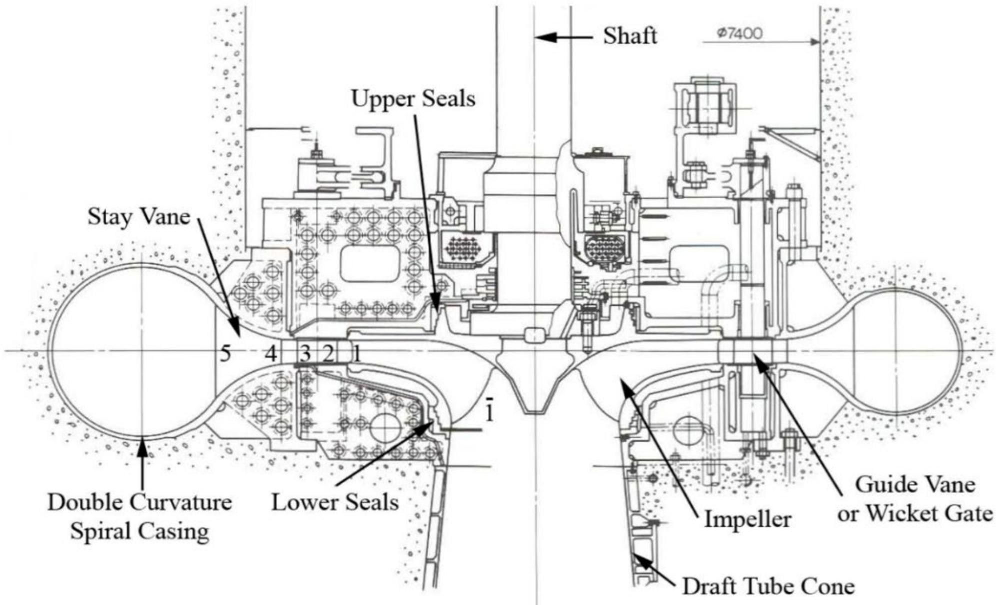

Figure 2 – Outline of the power unit

In Table 1, the main operating parameters of the power units are listed. The power P is the electrical power generated/consumed. To simplify, neglect the electrical losses in the generator/motor, so you can consider P as the output power in turbine mode, respectively the input power in pumping mode.

Table 1 – Operating parameters of the power unit

Pompe	minimum	nominal	maximum
E (J/kg)	5214	5904	6093
H (m)	531,7	602	621,3
Q (m^3/s)	50,8	41,8	36,7
P (MW)		281,0	310,0
N_{QE} (-)	0,069	σ_{min} (-)	0,104
n_q	23	σ_{max} (-)	0,159
ν (-)	0,14		

Turbine	minimum	nominal	maximum
E (J/kg)	4874	5434	5885
H (m)	497,0	554,1	600,1
Q (m^3/s)	57,0	61,8	60,5
P (MW)	243,0	294,0	315,0
N_{QE} (-)	0,089	σ_{min} (-)	0,108
n_q	30	σ_{max} (-)	0,171
ν (-)	0,19		
$D_{\bar{1}e}$ (m)	2,180	f (Hz)	50
D_{1i} (m)	4,728	n (t/s; t/min)	7,14; 428,6
D_o (m)	5,605	z_r (-)	6
B_o (m)	0,312	z_o (-)	20
		z_{avd} (-)	10

Bajina Basta - Turbine mode

1. In Table 1, three different operating conditions are described: the minimum and the maximum power conditions, as well as the nominal condition. Compute the global machine efficiency of the three different operating conditions. Then, consider the condition with the highest efficiency as the best efficiency point (BEP), and use it for the next questions.

2. Consider the velocity triangle at the <u>turbine outlet</u>.
    a. Compute the meridional component of the absolute velocity and the rotating velocity. Neglect volumetric losses.

    b. Explain the impact that the hypothesis of neglecting volumetric losses has on the meridional component. Also, what can be said of the tangential component of the absolute velocity at this operating condition?
    c. Draw the velocity triangle.

3. Let's now look at the velocity triangle at the <u>turbine inlet</u>.
    a. Compute the meridional component of the absolute velocity and the rotating velocity. Assume $D_{1e} = D_{1i}$ and $B_1 = B_0$.

b. Consider now the Euler equation, $E_t = k_{Cu_{1e}} U_{1e} Cu_{1e} - k_{Cu_{\bar{1}e}} U_{\bar{1}e} Cu_{\bar{1}e}$. Assume uniform flow at the inlet, and 2% of bearings and disk friction losses. Compute the absolute and the relative flow angles, α_1 and β_1, and draw the inlet velocity triangle.

Bajina Basta - Pump mode

4. Compute the different IEC Factors for speed, discharge, torque and power at nominal operating condition, considering 1% of bearing power losses.

5. Compute the energy and discharge coefficients for the nominal operating condition. Then, compute the specific speed and compare it with the value provided in Table 1.

Pumped storage power plant – FMHL+

Let's now consider the Veytaux II powerhouse of the FMHL pumped storage power plant, already studied last week in the framework of the exercise series focused on industrial pumps. A cut-view of one of two ternary units, each one featuring two hydraulic machines (a Pelton turbine and a centrifugal multistage pump) and an electrical machine on the same shaft, is given in Figure 3.

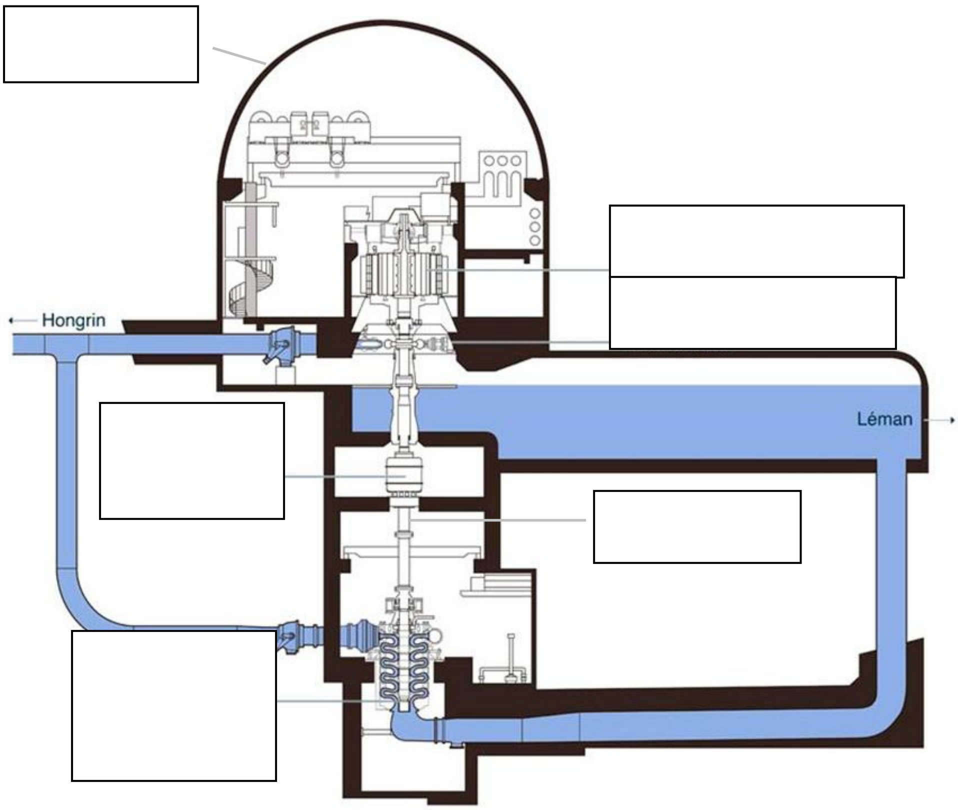

Figure 3 – Veytaux II ternary unit cut view. Retrieved from www.alpiq.com

6. Complete the nomenclature in Figure 3 and specify what type of hydraulic machines are used in this ternary unit.

7. In pumping mode, are the turbine and the multistage storage pump coupled by mean of the mechanical coupling? Why?

8. Which locations of the hydraulic circuit inside the pump are particularly concerned by the risk of cavitation phenomena inception? Does each stage feature the same risk of experiencing cavitation?

Suppose now that we are facing a situation of power excess in the grid. The power plant is therefore required to consume power from the grid, and for this reason we need the multistage pump to be in operation. However, the pump is designed for a rated power of 120 MW, whereas the excess power in the grid is way lower. Since the pump is an ON/OFF machine, its operating condition can't be adjusted, and the ternary unit is operating as hydraulic bypass.
$\rho = 998$ kg m^{-3}
$g = 9.81$ m s^{-2}

9. The pump is working at Q = -11.5 m^{3}s^{-1}, $E = 9000$ J kg^{-1} with a global machine efficiency of $\eta^P = 0.89$. Calculate the input power required by the pump.
10. Assuming an electrical efficiency of $\eta_{el} = 0.99$ for the motor/generator, and that the excess power from the grid is $P_{grid} = -80$ MW, calculate the output power provided by the Pelton turbine.
11. The Pelton turbine is working at a specific energy $E^T = 8927$ J kg^{-1} with a global machine efficiency of $\eta^T = 0.91$. Compute the discharge Q pumped in the headwater reservoir. Neglect volumetric losses.