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Numerical investigation of solutions to suppress the inlet vortex of an existing booster pump

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Abstract. The study focuses on a booster pump used to feed the main pump of one unit of the FMHL hydropower plant (Veytaux I). From the beginning of the operation of the power plant, vibrations have been observed on this booster pump with sometimes the presence of cavitation erosion. The visualisations carried out show that a cavitating vortex develops at the suction side of the booster pump runner and causes the measured vibrations. The booster pump is running without any modification since the beginning of the operation of the power plant, however future mechanical failures cannot be excluded, since in these harsh conditions, the permissible mechanical strain shall be exceeded.

Flow numerical investigations have been carried out using OpenFOAM and shown the presence of vortices below the bell of the booster pump. The main vortex observed is assumed to be responsible for the vibrations due to its interaction with the runner blades and to promote the inception of cavitation, which could explain the cavitation erosion observed.

Several modifications of the chamber have been considered by simulation. Two of them provide a solution to suppress or at least to damp the vibrations due to the presence of vortices in the bell inlet.

1. Introduction

The present study focuses on the booster pump that feed the main pump of the Forces Motrices Hongrin-Léman SA (FMHL) Veytaux I hydropower plant. FMHL belongs to the shareholders Romande Energie SA, Alpiq Suisse SA, Groupe E SA and City of Lausanne. Alpiq, as owners' representative, is in charge of the asset management and the operator is Hydro Exploitation SA. FMHL power plant was originally a 240 MW pumped-storage power plant (Veytaux I) in Switzerland, put in operation in 1971 [1] whose installed capacity was extended to 480 MW in 2016 with a maximal output power set to 420 MW including 60 MW as reserve, known as the FMHL+ project [2] and corresponding to the Veytaux II power plant.

After 150 hours of operation, the control of the booster pump of Veytaux I showed the presence of some damages due to cavitation that was not expected [3]. The investigations of the flow condition in the intake channel put in evidence the presence of a free surface vortex entraining air into the pump bell. Some modifications of the intake channel and chamber [3] allowed removing the free surface vortex. However, there is still the presence of a sub-surface vortex that leads to vibrations of the entire booster pump and promotes cavitation, at least for some configurations of the hydropower plant operation (confidential report). These vibrations do not prevent the operation of the power plant. However, since the booster pump has not been designed to tolerate such high mechanical stresses, a solution is currently investigated to damp the vibrations.

In the literature, the various vortices at the suction side of a pump sump have been classified mainly in free surface vortices and sub-surface vortices [4, 5]. In these documents, there are also several recommendation regarding to the design of the pump intake chamber to avoid the presence of vortices. Otherwise, Reynolds-Averaged Navier-Stokes (RANS) computations are now able to capture the mean flow topology close to the pump bell, such as the submerged vortices [6, 7]. However, to capture the unsteadiness of the flow structures and the mechanisms responsible for the appearance of the vortices, Large Eddy Simulation (LES) are required [8, 9, 10].

In the present work, a RANS simulation simulation of the current geometry has been carried out to identify the main vortices located close to the pump bell. Then, several solutions have been considered in order to remove the submerged vortices. First, the test case and the numerical set up are described, followed by the presentation of the main results and a conclusion.

2. Test case

The FMHL Veytaux I hydropower plant is equipped with four ternary units composed of a Pelton turbine, a motor/generator and a pump. Due to the choice of mounting the group horizontally, the pump is located above the level of the downstream reservoir (Leman Lake). By consequence, a booster pump has been set up upstream of the main pump in order to guarantee a sufficient pressure level at the inlet of the main pump. To keep the pressure at the inlet of the main pump constant, the energy of the booster pump is provided by a small Pelton turbine, whose the rotational speed is controlled by a pressure sensor located between the booster pump and the main pump [1].

Films of the flow beneath booster pump bell (group 2) showed the presence of an unsteady cavitating vortex. According to Hydro Exploitation SA investigations, the vortex is responsible for the large vibrations observed all along the shaft of the booster pump. Even if all the groups undergo strong vibration, only the group 2 shows some damages due to cavitation.

3. Numerical set up

The free surface vortex, originating from the free surface, observed at the beginning of the operation of the hydropower plant has been removed by previous modifications [3], consequently only single phase RANS simulations using the OpenFOAM 3.0 toolbox are carried out to investigate the submerge vortex.

Since the submerged vortex is present whatever the number of pumping group in operation, only one booster pump (currently the one of group 2) is considered in the present study including the tailrace channel (corresponding to the intake waterways of the pump), the intake chamber, the splitter, the bell, the pump runner and the outlet pipe of the booster pump (see figure 1).

The computational domain has been divided in several parts and each part has been mesh with tetrahedral elements and prism layers close to the solid walls using the ANSYS ICEM software (see figure 2). The total number of cells varies from 13.5 millions to 31 millions according to the geometry.

The mass flow is imposed at the inlet of the tail race channel, whereas at the outlet of the tail race channel the flow rate is set to zero. At the outlet of the booster pump, the relative pressure is set to zero. The runner speed is set to the nominal rotational speed provided by Hydro Exploitation. All the solid walls are set to no slip wall.

Turbulence is modelled using the Boussinesq's assumption, which requires to calculate an eddy viscosity using the SST $k-\omega$ model in the present case. The system of equations is solved using the SIMPLE algorithm with under-relaxation coefficients. For each computation at least 10'000

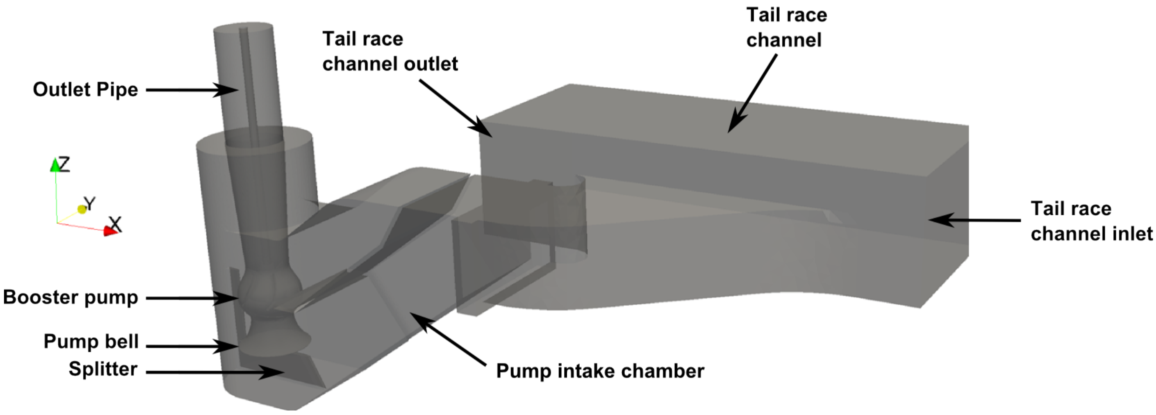

Figure 1. Computation domain.

iterations are achieved. The convective fluxes are discretized with the limitedLinear scheme for the momentum equations (the initialisation of the flow is performed with the upwind scheme) and the upwind scheme for the turbulent transport equations.

4. Results

The results are first shown for the current geometry in order to visualize the flow features in the pump intake chamber. Then, three modifications of the intake chamber are investigated mainly regarding their ability to mitigate the development of submerged vortices close to the pump bell.

4.1. Current geometry

The visualisation of the vortices beneath the pump bell is done using an iso-surface of the Q-criterion (see figure 3). It is noticeable that three vortices are captured by the simulation : one originating from the bottom wall, another one originated from the backside wall and the last one (smaller in size) originated from the right side wall on the picture (left side wall in the flowing direction).
The contours of the magnitude of the transverses flow $\sqrt{u^2+v^2}$ (in comparison to the main flow direction in the pump, *i.e* the z-direction) are displayed in figure 4 for several planes located above the runner from $z/D_p = 0$ to $z/D_p = -1.456$ with a space step of $z/D_p = -0.243$ (with D_p the inlet pump diameter). The contours show an asymmetry close to the bottom wall with a higher magnitude on the left side, where the submerged vortices are observed.

4.2. Alternative geometries

In order to remove the development of the submerged vortices observed beneath the pump bell, three solutions have been considered (see figure 5). A first solution, inspired from [11, 5], consists in a structural engineering modification of the bottom and side walls of the intake chamber by adding a cone align with the pump rotational axis and by limiting the place in the backside in order to force the flow to go inside the pump bell. A second solution consists in replacing the current intake chamber by a draft tube. Finally, based on the simulations of Yamada [9, 10], who shows the role of the boundary layer at the bottom wall in the development of the submerged vortices, and examples proposed in [5], a grid is set beneath the bell.

The iso-contours of the Q-criterion for each solution is shown on figure 6. It is obvious that the engineering solution is not able to remove the development of the vortices in the intake chamber. On the contrary, the draft tube solution allows removing all of the vortices. The

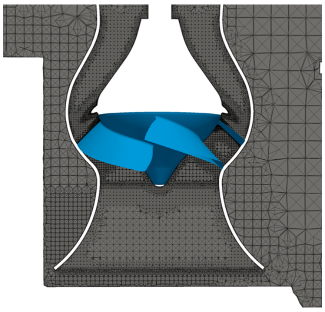

Figure 2. Mesh inside the bell and the runner. Side view. Current geometry.

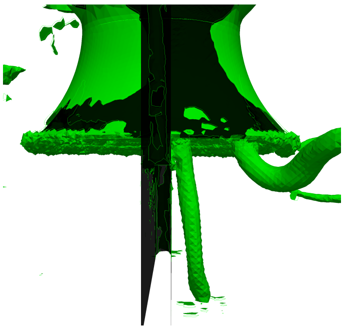

Figure 3. Iso-surface of the Q-criterion. Backside view. Current geometry.

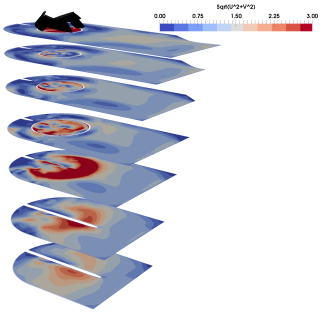

Figure 4. Contours of $\sqrt{u^2+v^2}$ in various transverse planes. Current geometry.

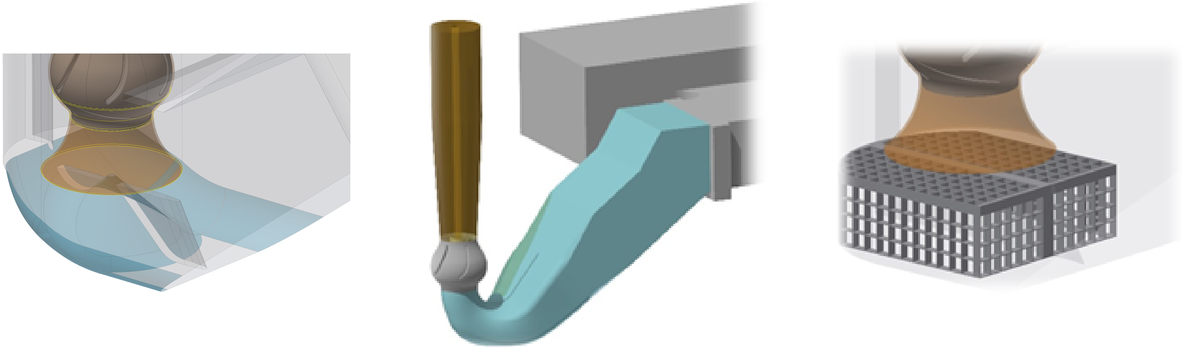

Figure 5. Modifications of the pump intake: structural engineering solution (left in blue), draft tube solution (center in blue) and grid solution (right).

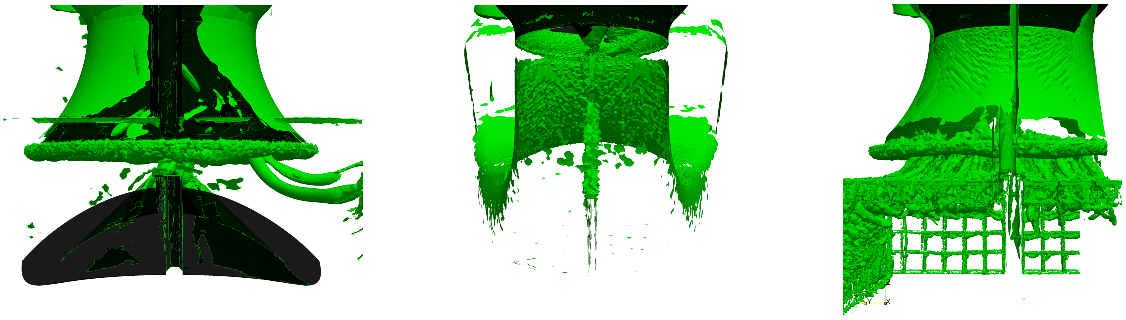

Figure 6. Iso-surface of the Q-criterion. Backside view. Structural engineering solution (left), draft tube solution (center) and grid solution partially cropped (right).

grid solution removes the large and strong vortices observed in the current geometry. This last solution leads to the development of several small vortices downstream the upper grid, which are expected to be less harmful for the pump due their lower intensity and stability.

The contours of the magnitude of $\sqrt{u^2+v^2}$ are displayed on figure 7. Compared to the

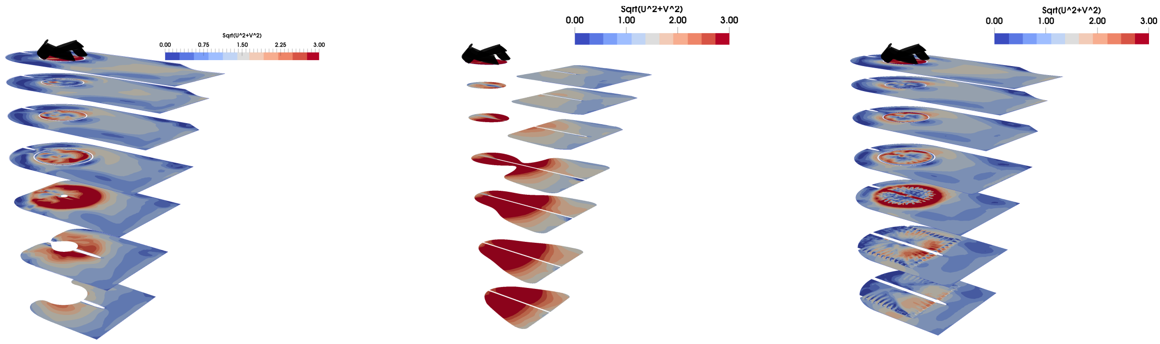

Figure 7. Contours of $\sqrt{u^2+v^2}$ in various transverse planes. Structural engineering solution (left), draft tube solution (center) and grid solution (right).

current geometry, the structural engineering solution is not able to remove the asymmetry and to reduce the intensity of $\sqrt{u^2+v^2}$ in the intake chamber. Regarding the draft tube solution, the contribution of u et v in the magnitude of $\sqrt{u^2+v^2}$ are not equal (not shown here) since due to design of the draft tube the u component is responsible for the major part. Therefore the draft tube solution allows the damping of the transverse components u and v, which prevents the development of vortices. The grid solution provides a damping of the transverse flow and a better mixing of the flow mainly close to the bottom wall of the intake chamber. Considering the description of the submerged vortex provided in [10], it could be assumed that this mixing prevents the vertical stretching of the vortices align with the side walls that are at the origin of the submerged vortex.

In order to analysed the impact of the proposed solutions on the current booster pump, the static pressure difference between the inlet and the outlet of the computational domain has been computed for each case. Compared to the current geometry, each solution leads to an increase in the pressure difference between 0.3% for the structural engineering solution to 2.2% for the draft tube solution. In addition, the dimensionless torque T/T_{ref} (with T_{ref} the mean torque of the current geometry) variation over the last 5'000 iterations is plotted on figure 8. The draft tube and the grid solutions required a slightly higher torque around 2% compared to the current geometry and the structural engineering solution. Furthermore, all the solutions proposed allow damping the fluctuations of the torque.

5. Conclusion

The booster pump of the FMHL hydropower plant has been investigated by RANS simulations in order to understand the flow topology in the intake chamber and proposed some solutions to remove the presence of a submerged vortex observed experimentally and responsible for strong vibrations of the entire pump.

The numerical simulation was able to capture the observed submerged vortex as well as some others vortices attached to the side and backside walls of the intake chamber. Inspiring from a literature review, three modifications of the current intake chamber have been considered : a structural engineering solution, a draft tube solution and a grid solution. The engineering solution does not remove the vortices. The draft tube solution allows removing the vortices beneath the pump. This solution leads to an increase of approximately 2% in the torque required by the pump and in the static pressure difference between the inlet and outlet of the computational domain. However, such a solution is costly, not easy to set and cannot be removed easily in case of problem. The grid solution, which can be easily set up and remove, provides a strong damping of the submerged vortices. This solution required also a higher torque

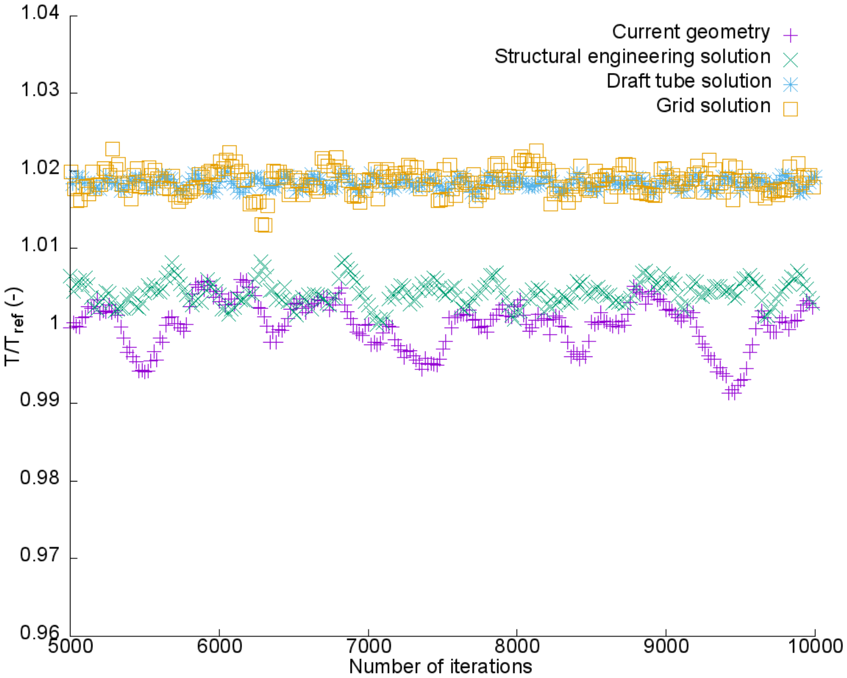

Figure 8. Dimensionless torque variation over the last 5'000 iterations.

close to 2% compared to the current geometry.
Even if the grid seems to be an acceptable solution, some additional simplifications will be considered in a future work in order to reduce the cost of the installation.

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