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Numerical study of solutions to mitigate a cavitating vortex rope at the inlet of a booster pump at FMHL

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Description

The present study focuses on the FMHL pumped-storage hydropower plant located in Switzerland and belonging to the shareholders Romande Energie SA, Alpiq Suisse SA, Groupe E SA and City of Lausanne and put in operation in 1971 [1]. Alpiq, as owner's representative, is in charge of the asset management and the operator is Hydro Exploitation SA. The power plant was originally built with 4x60 MW ternary groups connecting the Leman Lake and the Hongrin dam. The project FMHL+ extended this power to 480 MW, with a maximal operating power of 420 MW, in 2016 [2]. The FMHL hydropower plant is equipped with four horizontally ternary units composed of a Pelton turbine, a motor/generator and a pump. The pump being located above the level of the downstream reservoir (Leman Lake), 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. The focus of this study is set on this booster pump.

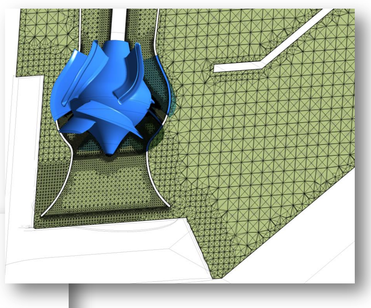
General overview of the Hongrin-Leman hydropower plant, in Switzerland.

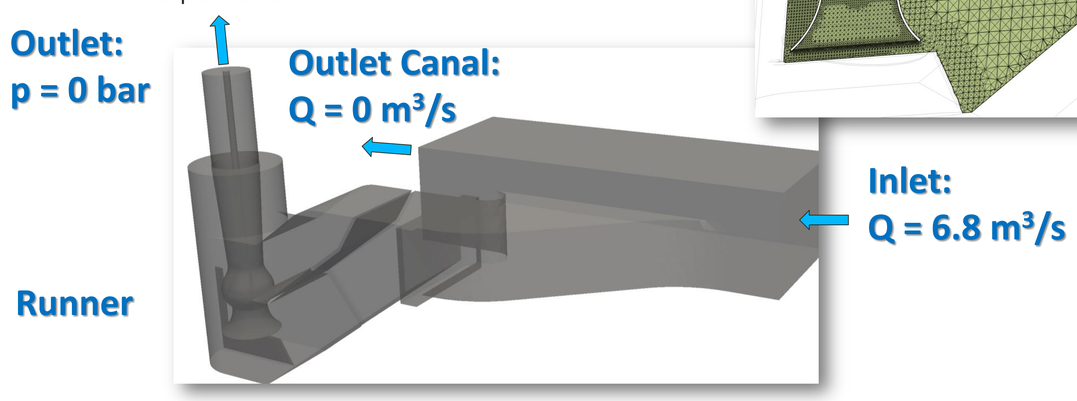
Methodology

For some operating conditions of the booster pump, a cavitating vortex rope appears on the suction side of the runner and generate wear and vibrations. The measured vibrations have a frequency of 32 Hz, resulting of the split of the vortex by the 4 blades of the runner, rotating at 8 Hz. These vibrations do not prevent the operation of the group but the mechanical parts have not been designed to support this level of constraints. Numerical simulations, performed with the open source OpenFOAM 3.0 software [3], have been carried out to reproduce the flow for the actual geometry and to predict the effect of different solutions to mitigate the development of the vortex. The computational domain is composed by the tailrace channel, the intake chamber, the splitter, the pump bell and the booster pump. The mesh contains 13.5 millions of unstructured elements. Near the wall, the mesh is constituted of prismatic elements and in the middle of the domain of tetrahedron. The OpenFOAM software solves the RANS equations which are closed with the k-ω SST turbulence model. The steady-state solution is calculated with the SIMPLE algorithm for 10'000 iterations.

The boundary conditions are:

+ Inlet: Flow rate, flow direction & the turbulent intensity
+ Outlet canal: Flow rate & the flow direction
+ Outlet pump: Pressure
+ Runner: Rotational speed
+ Wall: No slip conditions

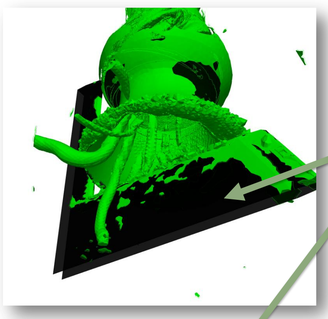




Results of the simulations for the current geometry

The simulation for the existing geometry show indeed the development of several vortex ropes including one axial also observed in 2013 by an immerged camera installed by Hydro Exploitation.

Bottom view



Iso-surface of the Q-criterion
Value : Q = 200 s^{-2}

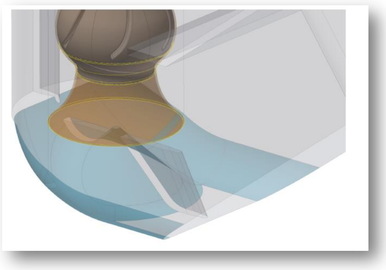
Backside view

Image of the immerged camera.

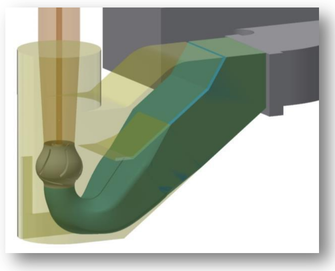
Investigation of solutions

Three solutions have been developed to channel the flow close to the bell and mitigate the development of cavitating vortex rope:

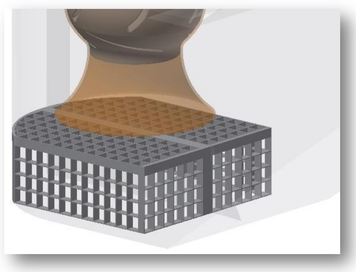
+ Structural modifications of the intake chamber : to guide the flow into the bell
+ Draft tube : to ensure an smooth flow acceleration and guide the flow into the bell.
+ Metallic gate : to break any vortex larger than the grid size.



Structural engineering solution



Draft tube



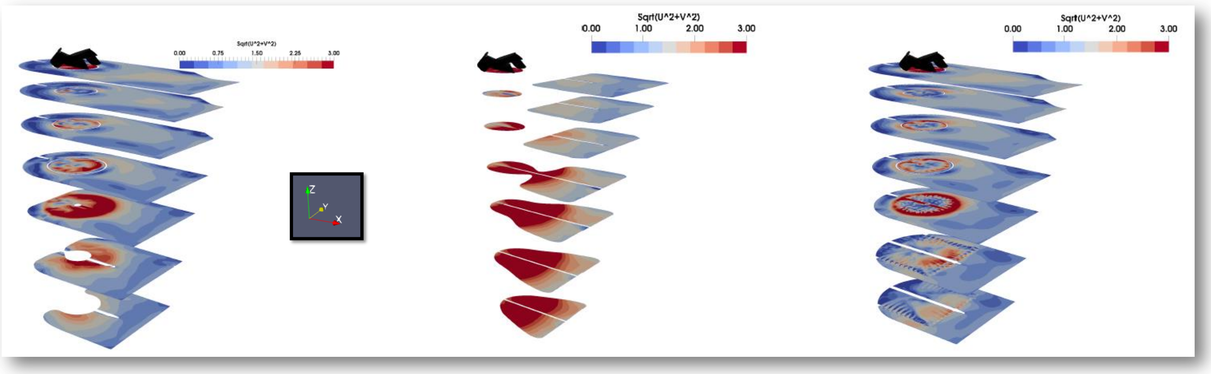
Metallic Gate

Numerical results of the different geometries show that the structural modification of the bottom decreases the intensity of the vortices whereas the draft tube and the metallic gate allow to suppress them.

Structural engineering solution *Draft tube* *Metallic Gate*

The figure below show the secondary flow calculated as the norm of the horizontal velocity vector. Component.

$$C_h = \sqrt{{C_x}^2 + {C_y}^2}$$



Structural engineering solution *Draft tube* *Grid*

The non uniformity of the flow at the pump intake is partly responsible for the vortex apparition. This problem can be solved with a draft tube or a metallic gate whereas the structural approach only decreases their intensity.

Conclusion

Numerical simulations allow to reproduce the observed vortex developing at the booster pump inlet of FMHL hydropower plant. The results highlight an approximately identical position and geometry of the vortex generating vibrations and thus fatigue of the machine. Three solutions have been investigated to mitigate the vortex by preventing the winding of the streamlines. The metallic gate is the cheaper option and can also be easily installed and removed, if necessary, which makes this solution the best choice.

Acknowledgment

FMHL ALPIQ HYDRO EXPLOITATION Hes·so VALAIS WALLIS SCCER – FURIES

References

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[3] https://www.openfoam.org
[4] Decaix J, Gaspoz A, Fischer D, Münch Alligné C, IAHR 2019