Cavitation Simulations of a Low Head Contra-rotating Pump-turbine

CAVITATION SIMULATIONS OF A LOW HEAD CONTRA-ROTATING PUMP-TURBINE

JONATHAN FAHLBECK*, HÅKAN NILSSON, SAEED SALEHI
and MOHAMMAD HOSSEIN ARABNEJAD
Department of Mechanics and Maritime Sciences, Chalmers University of Technology,
*SE-412 96 Gothenburg, Sweden, *fahlbeck@chalmers.se*

Keywords: *Cavitation, Schnerr-Sauer, SAS, headLossPressure, Energy storage, Pumped hydro storage, Low-head*

To meet the demands of a larger share of the electrical energy produced by intermittent renewable energy sources, an increasing amount of plannable energy sources is needed. One solution to handle this is to increase the amount of energy storage in the electrical grids. The most widespread energy storage technology today is by far pumped hydro storage (PHS) [1]. In an attempt to enable PHS at low-head sites, the ALPHEUS (augmenting grid stability through low head pumped hydro energy utilization and storage) [2, 3] EU Horizon 2020 research project was formed. In ALPHEUS, new axial flow, low-head, contra-rotating pump-turbine (CRPT) designs are investigated. A CRPT has two individual runners rotating in opposite directions.

CRPTs developed within the ALPHEUS project have already been thoroughly analysed at stationary and transient operating conditions by the authors [4, 5, 6, 7]. However, the effects on the CPRT's performance due to potential cavitation on the runner blade surfaces have previously not been investigated. For that reason, the current study focuses on running cavitation simulations on a model scale CRPT using the OpenFOAM computational fluid dynamics (CFD) software. In the CFD simulations, cavitation is modelled as a two-phase liquid-vapour mixture using the `interPhaseChangeDyMFoam` solver. The two runner domains have a prescribed solid body rotation. Condensation and evaporation processes are handled with the Schnerr-Sauer model [8]. Turbulence is managed with the $k - \omega$ shear stress transport–scale adaptive simulation (`kOmegaSSTSAS`) model. Flow-driving pressure differences over the computational domain are achieved with the `headLossPressure` boundary condition [9] to emulate a larger experimental test facility of which the CRPT is part.

Figure 1 shows a snapshot in time of an iso-surface (light blue) of cavitating cloud with $\alpha_{\text{liquid}} = 0.9$ in turbine mode. At this operating point, a small amount of cavitating flow is found by the suction side of the leading edges of the left runner, which is facing a lower reservoir. In Figure 2, the same type of iso-surface is shown, however now in pump mode. It is seen that the pump mode operating condition is much worse than the turbine mode. The cavitating cloud covers most of the suction side of the left runner, additionally, the tip-clearance region is also exposed to cavitation. Furthermore, traces of cavitation are found on the leading edges of the right runner as well as on the left small-support struts. It is thus important to, at least, analyse the pump mode to determine if and how much cavitation affects the CRPS's operating performance.

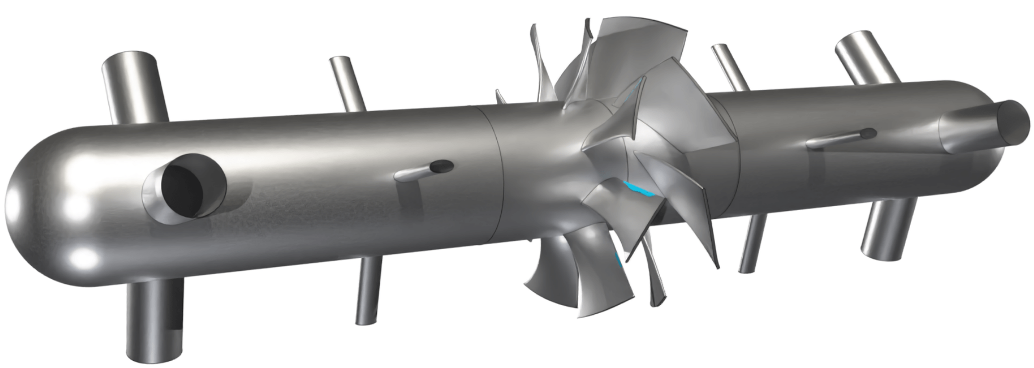

Figure 1: Iso surface of liquid volume fraction ($\alpha_{\text{liquid}} = 0.9$) in turbine mode, flow from right to left

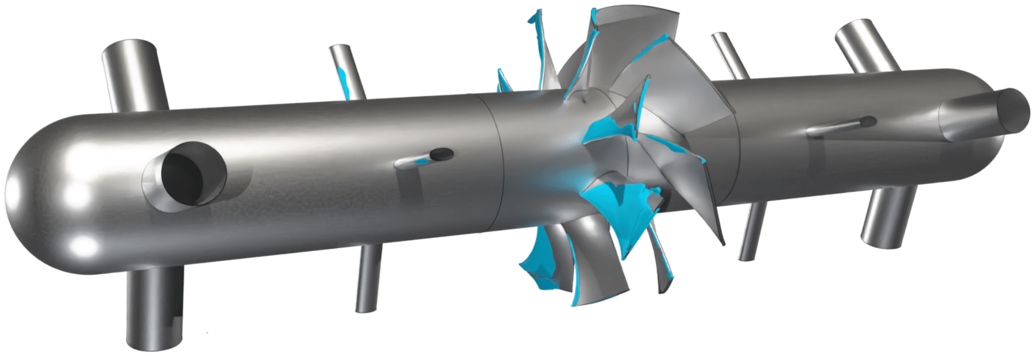

Figure 2: Iso surface of liquid volume fraction ($\alpha_{\text{liquid}} = 0.9$) in pump mode, flow from left to right

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 883553. The computations were enabled by resources provided by the National Academic Infrastructure for Supercomputing in Sweden (NAISS) at NSC and C3SE, partially funded by the Swedish Research Council through grant agreement No. 2022-06725. Mohammad was funded by Chalmers Energy Area of Advance and the "Swedish Hydropower Centre - SVC". SVC is established by the Swedish Energy Agency, EnergiForsk and Svenska Kraftnät together with Luleå University of Technology, The Royal Institute of Technology, Chalmers University of Technology and Uppsala University, www.svc.nu.

References

[1] H. E. Murdock *et al.*, *Renewables 2021 - Global status report*. REN21, 2021.

[2] "ALPHEUS H2020," 2023, URL https://alpheus-h2020.eu/, accessed on 22 February 2023.

[3] M. Qudaih *et al.*, "The Contribution of Low-Head Pumped Hydro Storage to a successful Energy Transition," in *Proceedings of the Virtual 19th Wind Integration Workshop*, 2020.

[4] J. Fahlbeck *et al.*, "Numerical analysis of an initial design of a counter-rotating pump-turbine," *IOP Conference Series: Earth and Environmental Science*, vol. 774, no. 1, p. 012066, 2021.

[5] J. Fahlbeck, H. Nilsson, and S. Salehi, "Flow Characteristics of Preliminary Shutdown and Startup Sequences for a Model Counter-Rotating Pump-Turbine," *Energies*, vol. 14, no. 12, p. 3593, 2021.

[6] ——, "Evaluation of startup time for a model contra-rotating pump-turbine in pump-mode," *IOP Conference Series: Earth and Environmental Science*, vol. 1079, p. 012034, 2022.

[7] ——, "Surrogate based optimisation of a pump mode startup sequence for a contra-rotating pump-turbine using a genetic algorithm and computational fluid dynamics," *Journal of Energy Storage*, vol. 62, p. 106902, 2023.

[8] J. Sauer and G. H. Schnerr, "Unsteady cavitating flow-a new cavitation model based on a modified front capturing method and bubble dynamics," in *Proceedings of 2000 ASME fluid engineering summer conference*, vol. 251, 2000, pp. 1073–1079.

[9] J. Fahlbeck, H. Nilsson, and S. Salehi, "A Head Loss Pressure Boundary Condition for Hydraulic Systems," *OpenFOAM Journal*, vol. 2, pp. 1–12, 2022.