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STUDY OF FLOW PATTERNS IN HYDRAULIC TURBINES WITH SPH-ALE

BY JEAN-CHRISTOPHE MARONGIU, MARTIN RENTSCHLER AND ETIENNE PARKINSON

Hydropower is the most developed and stable source of renewable energy. It relies on efficient and reliable mechanical equipment, and primarily on hydraulic turbines whose size can vary from micro power plants (several kilowatts) to large projects (several hundred megawatts). Performance of hydraulic turbines is primarily defined in term of efficiency, which is the ability to convert the mechanical energy of water into mechanical energy for the electro generator.

Global performance also includes stability and safety of operation, cavitation margin, sensitivity to hydro-abrasive erosion, vibration and noise levels and design robustness. Head and flow discharge at site define the amount of energy that can be produced; they also define the type of turbine that can be used and the contours of hydraulic components must be perfectly adapted to these local conditions. Each new project consequently requires an important phase of hydraulic engineering in order to optimize global performance. Computational Fluid Dynamics has naturally acquired an important role in the design process, enabling much faster developments and supporting the continuous improvement of hydraulic performance.

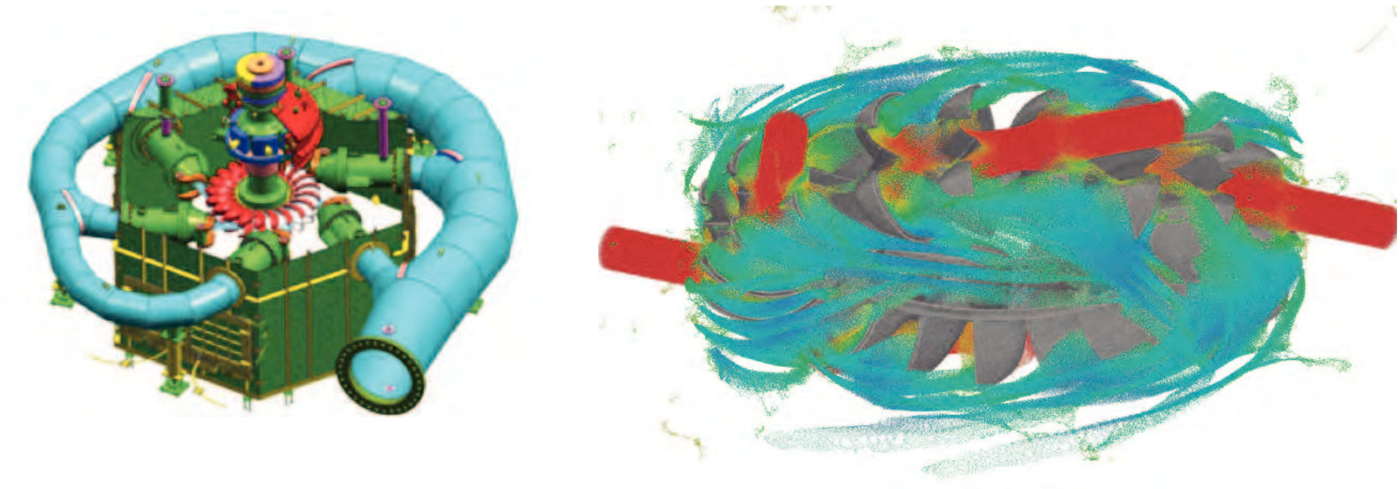
Traditional CFD (Computational Fluid Dynamics) approaches are however limited when treating the free surface flows in Pelton turbines. Mesh-based methods make use of a rotating mesh domain around the runner and steady mesh domain(s) in the casing. The flow coming from the water jet enters the rotating domain, interacts with the rotating buckets, and leaves the rotating domain to enter the casing (1). It crosses the so-called rotor-stator mesh interface twice, which leads to an unacceptable diffusion of the free surface and the impossibility to predict the flow characteristics in the casing, far from the runner.

A mesh-less method like SPH presents obviously some interesting properties for this type of application, thanks to its lagrangian nature. Starting in 2004, ANDRITZ Hydro has developed an internal tool named ASPHODEL which is based on a variant of the SPH method called SPH-ALE (Arbitrary Lagrangian-Eulerian) (2). Compared to the traditional SPH method, this approach allows the use of an arbitrary particle motion which can be Lagrangian (computational particles follow the fluid motion), Eulerian (computational particles are steady) or resulting from more complex models.

ASPHODEL has been tightly integrated into the design process of Pelton hydraulic components. Engineers are relieved from the burden of mesh generation and can concentrate on flow analysis and on hydraulic design. SPH also offers great savings regarding the time to result for Pelton applications. On top of the simplified pre-processing, ASPHODEL simulations outperform the computational time required by mesh-based approaches by a factor of 5, thanks to the possibility of having computational particles only in the liquid phase. For Pelton applications this allows for much reduced case sizes.

ASPHODEL is routinely used in ANDRITZ Hydro for the shape optimization of Pelton buckets and the evaluation of mechanical stresses in Pelton runners. This task is critical for Pelton

Figure 1 - Left: global view of a Pelton unit. Right: flow simulation in a 6-jets Pelton runner with ASPHODEL. Computational particles colored by their velocity in the absolute frame of reference. Blue means low and red means high velocity magnitude values



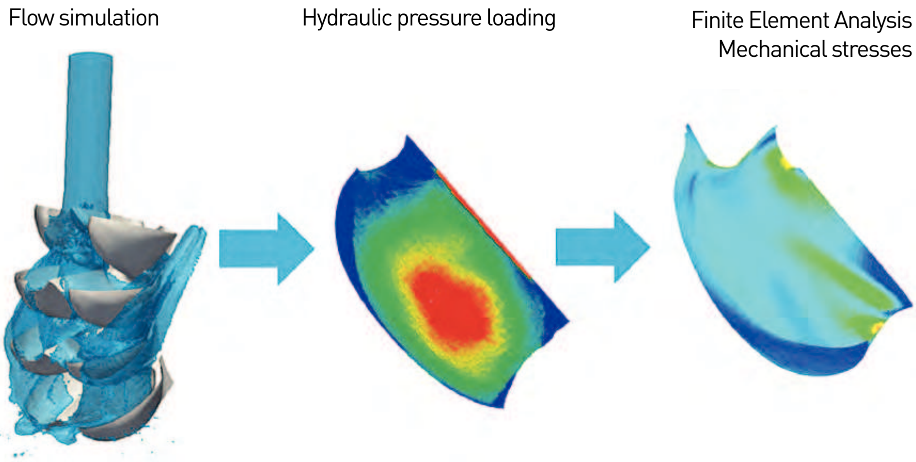


Figure 2 - Coupled Fluid-Structure studies for the mechanical assessment of Pelton buckets. SPH-ALE flow simulation produces an unsteady pressure field transferred to a FE tool for computation of mechanical stresses. Center: blue means low and red means high pressure values. Right: blue means low and red means high Von Mises stress values

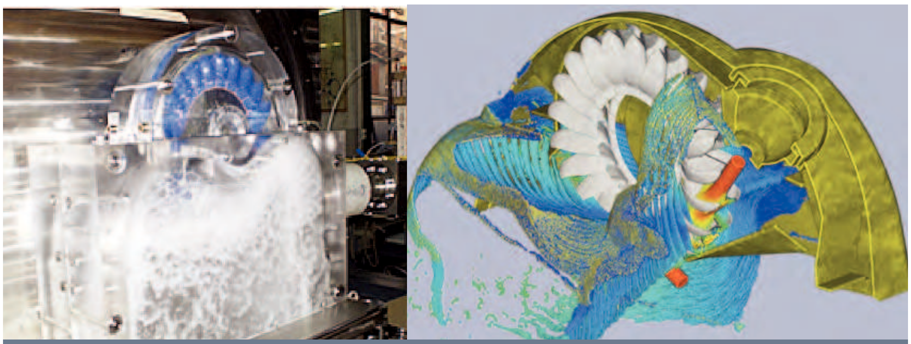
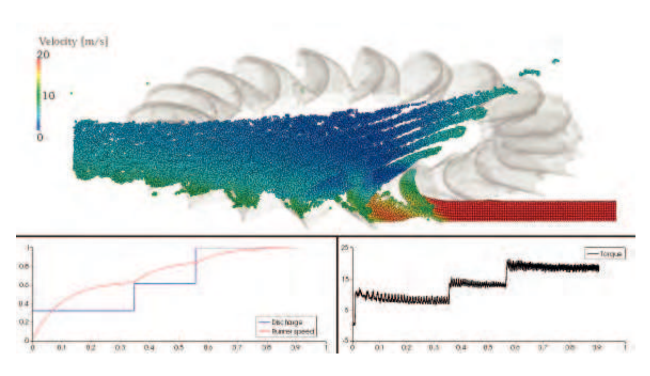


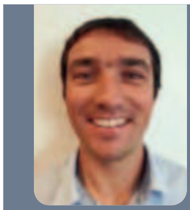
Figure 3 - Study of free surface flows in Pelton casing. Left: model testing of a 2-jets horizontal shaft turbine in hydraulic laboratory. Right: corresponding SPH-ALE flow simulation. Computational particles colored by their velocity in the absolute frame of reference. Blue means low and red means high velocity magnitude values

Figure 4 - Start-up of a Pelton turbine. Top: view of the flow. Bottom-left: time evolution of the flow discharge (blue) and the runner rotation speed (red). Bottom-right: hydraulic torque on the runner. The start-up sequence is composed of three levels of discharge obtained with three different jet diameters. The runner rotation speed results from the hydraulic torque and an externally applied resistive torque



turbines owing to the high amplitudes in the hydraulic loading of rotating buckets, being periodically impacted by water jets. In these studies, ASPHODEL provides an unsteady pressure field on the bucket surface that is then transferred as an external load in a Finite Element Analysis for the evaluation of the mechanical stresses. Thanks to the cost reduction permitted by SPH, these assessments have become systematic, resulting in more optimized designs.

The particle method offers the possibility to precisely capture the water sheets evacuated from rotating buckets until their impact on casing walls. This opens a new era where simulation can help improving the whole hydraulic setting. This is of importance in rehabilitation and modernization projects that combine existing components (casing) and new furniture (runner). Thanks to the numerical prediction of water sheets trajectories, it is possible to detect and correct unfavorable flow phenomena occurring in the casing that could



Jean-Christophe Marongiu graduated in Fluid Mechanics and Turbomachinery at Ecole Centrale de Lyon, France. After a PhD on free surface flow simulations with the SPH-ALE method in Ecole Centrale de Lyon, he joined Andritz Hydro in Switzerland in 2007, where he led numerical activities for Pelton turbines. Since 2012, he leads the R&D team located in Lyon, France, responsible for the development of the in-house SPH-ALE software and its application to business areas of the Andritz group.

Etienne Parkinson graduated in Fluid Engineering at the Hydraulic and Mechanical Engineering school of Grenoble, France. Following a PhD on fluid modelling at Ecole Centrale de Lyon, France, he worked as a research assistant in hydraulic machinery at the Swiss Federal Institute of Technology in Lausanne, Switzerland, until 1995. Moving to ANDRITZ Hydro, he worked actively on numerous R&D issues, especially numerical simulation and model tests for Pelton turbines and Pump-turbines. He is now responsible of Technology Management for Pelton Turbines.

Martin Rentschler graduated in Mathematics at the University of Bonn, Germany. After a PhD in mechanics at the Swiss Federal Institute of Technology in Lausanne, Switzerland, he worked as consultant for several projects before joining ANDRITZ Hydro in 2011 as Simulation Engineer. Currently team leader, he is mostly involved in numerical simulations applied to Pelton turbines.

otherwise lead to a drop in hydraulic efficiency or to vibrations, and which are hardly observable on model tests.

The dynamic nature of SPH-ALE offers unique possibilities to study highly transient operations like the start-up of a Pelton unit. It becomes possible to predict the global acceleration of the runner and the mechanical stresses in the buckets during this very demanding phase. The topic of dynamic operation is of growing importance because of recent evolutions in the electricity market that require more frequent starts and stops of peak-energy hydropower plants, and SPH-ALE is the right tool to answer these issues.

The flexibility of SPH-ALE opens new perspectives in the study of transient internal flows in other types of turbines. Indeed the mesh-less approach presents valuable benefits for moving components and deformable computational domains. ASPHODEL has been used to simulate the start-up of a Francis turbine. The initial configuration involves a ring of guide vanes in fully closed position, isolating the high pressure (spiral casing) and low pressure (runner) parts. Guide vanes are progressively opened, allowing the flow to establish through the runner in the direction of the draft tube. Similarly to the case of the start-up of a Pelton unit, it is then possible to predict numerically the runner acceleration and the mechanical stresses acting on the runner blades.

References

MARONGIU J.C., LEBOEUF F., CARO J., PARKINSON E., “Free surface flows simulations in Pelton turbines using an hybrid SPH-ALE method”, Journal of Hydraulic Research 48, 2010. (2)

PERRIG, A., AVELLAN, F., KUENY, J.L., FAHRAT, M. and PARKINSON, E., "Flow in a Pelton turbine bucket: numerical and experimental investigations". Journal of Fluids Engineering, 128:350-358, 2006. (1)

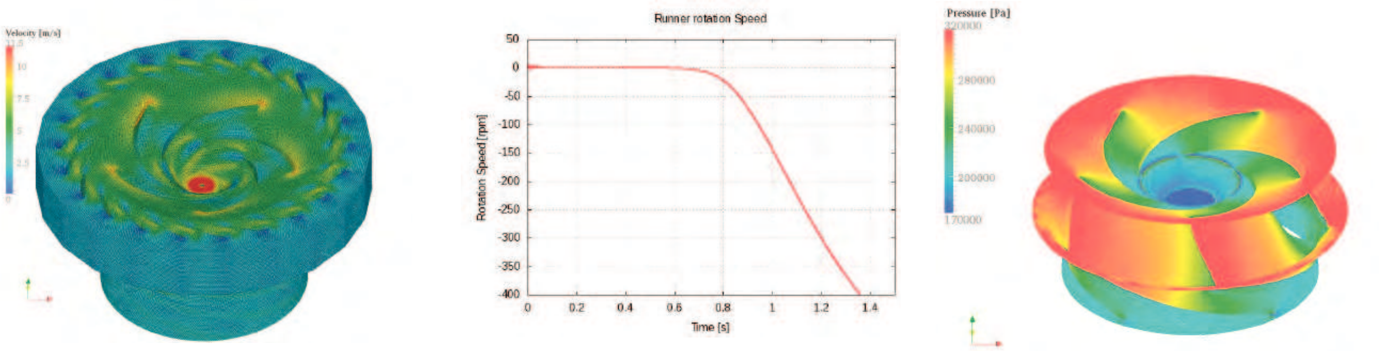


Figure 5 - Start-up of a Francis turbine. Left: flow velocity. Center: runner acceleration. Right: pressure field on runner blades. The start-up scenario is fictitious and consists in gradually opening the circle of guide vanes