Comet supports the design of Pelton turbines

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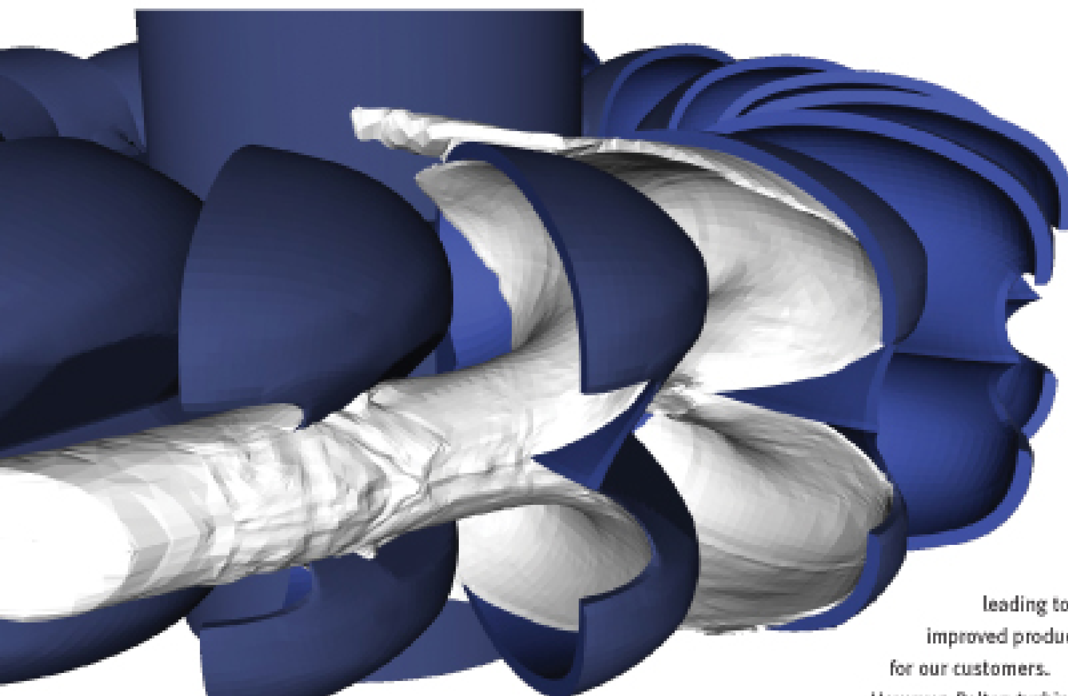

Fig. 2 (above): Predicted water jet deformation as it interacts with three buckets, showing thin water sheets leaving buckets.

Hydropower is - with an installed capacity of approximately 650 000 MW - by far the largest renewable energy source worldwide. 31% of this energy is generated with turbines from Voith Siemens Hydropower Generation and with over 40 000 power units in operation, Voith Siemens Hydropower Generation is one of the leading suppliers of high-end water power solutions.

In the past decade, CFD has become an essential tool for the development of reaction turbines at Voith Siemens Hydropower Generation. Using CFD, the number of development tests for Francis, Kaplan and pump turbines has been reduced significantly. Quality improvements and design innovations are now achievable much more quickly for these turbines. Furthermore, CFD has helped to widen the operating range and to improve cavitation behavior and stability of the turbine performance, leading to improved products for our customers.

However, Pelton turbines, common to small specific speed applications (high head and low flow rate), involve a number of special flow characteristics, which are extremely difficult to simulate. Firstly, the interaction of the free jet with the Pelton runner is fully transient and depends on the moving geometry of the buckets. A reasonable reduction to a quasi steady-state problem, as with reaction turbines, is simply not possible for the Pelton turbine without losing the essential mechanisms of the jet-bucket interaction. Even more challenging is the multiphase system of air and water that governs the formation of the free jet and the flow through the buckets. For years, developing a flow simulation that would allow a realistic analysis of these phenomena seemed to be an insurmountable task.

In the year 2000, we carried out an intensive investigation on different multi-purpose CFD codes with respect to the necessary modeling features. Out of a number of commercial software codes we chose Comet because of its long-standing experience in transient calculation with moving grids and free surface modeling. It has been found, that the combination of these features, which are essential for a realistic modeling of Pelton turbines, is one of the weakest points for most of the commercial codes. In addition, Comet provides a code that shows good performance with respect to parallelization. This is especially valuable as shortening the computation time is important to speed up the development cycle.

Before simulating the jet bucket interaction, Comet had to prove its usability on a series of test cases, each combining

Fig. 3: A stroboscopic photograph of water distribution in a Pelton wheel, showing water sheets leaving buckets.

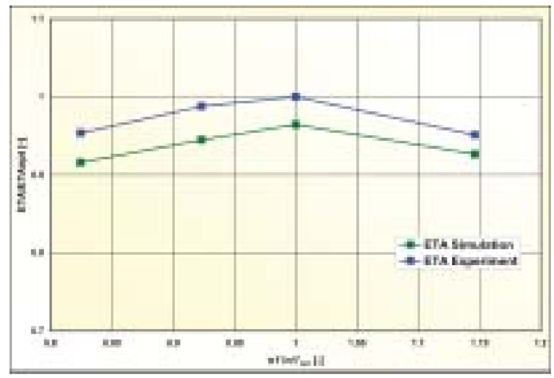

Fig. 4: Efficiency of a Pelton turbine: comparison of simulation and experiment.

the essential flow code features: Volume of Fluid, transient flow, and moving grid. Within the test series the level of complexity of the cases increased, starting from a 2D water wheel, and then extending to 3D, until finally the interaction of three rotating buckets with the free jet was simulated.

A mirrored and rotated image of the surface grid around the buckets is shown in Fig 1. Since each bucket in the runner experiences the same conditions at different times, the problem can be reduced to only three rotation buckets interacting with the stationary jet. The front and backside of the middle bucket (Bucket 2) are the representative surfaces, which will be analyzed and used to predict the performance for the entire runner.

At the start of the transient simulation the complete computational space is filled with air. At each stage, the water jet moves forward over the sliding interface into the rotating part of the grid and the buckets turn in the direction of the jet.

Fig 2 shows a computed “snapshot” taken during the interaction of the jet with the first two buckets. In this illustration an iso-surface of the water concentration is used to visualize the interface between water and air. One can clearly see how the jet is flowing from the entrance at the cutout into the lower radius part of the bucket. This is where the water sheet is leaving the bucket first. Gradually, this outlet region is moving along the inner bucket edge back into the direction of the bucket mouth. Snapshots taken in the test stand with stroboscopic light (Fig 3) show that the numerically predicted flow pattern is similar to the typical observations made in real Pelton turbines.

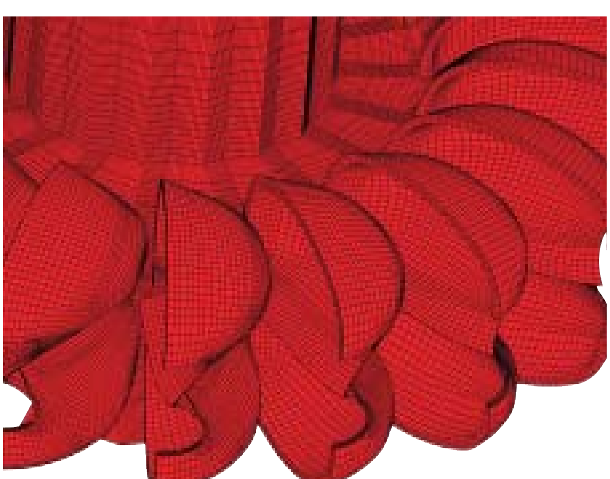

Fig. 1: A view of the grid on the surface of buckets of a Pelton turbine.

In order to quantify the results of the simulation, the angular momentum generated by the pressure acting on the bucket walls of Bucket 2 has been derived. This time-dependent trend on a single bucket is used to project the momentum of the entire runner. Using these results the efficiency of the bucket profile can be calculated. Fig. 4 shows a normalized comparison of the efficiency derived from the simulation with the results of the experiment for a typical head range. It is obvious that the predicted efficiency follows the trend found in the experiment very closely. An offset of about 2 to 3 % between simulation and model test can be recognized.

These results are certainly a breakthrough for the hydraulic development of future Pelton turbines. The CFD code Comet allows us to get a deeper insight into the mechanisms of the bucket flow by detailed qualitative and quantitative analysis. Furthermore, the pressure load is used directly to investigate the structural integrity of the bucket. Whereas in the past assumptions had to be made, there are now detailed and time dependent pressure distributions available for a more realistic structural analysis using FEM.

In summary, one can say that by using the analysis ability of Comet, the designer gains the necessary knowledge for designing improved bucket profiles and developing better products for our customers.