Through-flow analysis of hydraulic turbines

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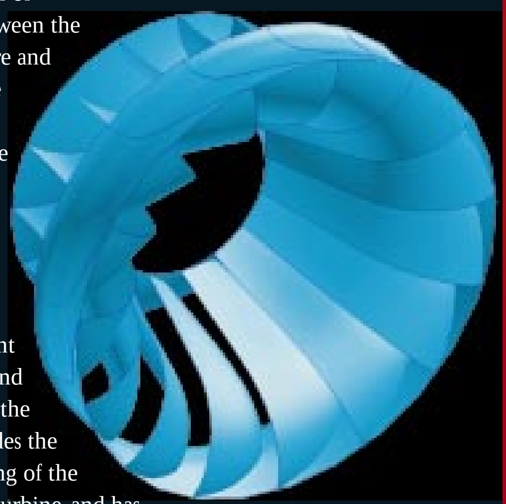
Contemporary hydraulic turbine design is the result of over a century of development. Until recently, this was done mostly by trial and error in hydraulic laboratories, despite which, quite impressive efficiencies of around 90% were achieved at the best operating point. During the last decade however, most turbine manufacturers have adopted CFD software such as CFX-TASCflow as standard tools in the design process, and this has led to further improvements in runner efficiency.

Simulations of the complete turbine system to error levels of 1% or better can still be prohibitively expensive however. Since the optimization of interactions between the waterways before and after the turbine necessitates simulation of the complete turbine system, we have developed an approximate model to account for the runner and its influence on the flow. This provides the required coupling of the flow across the turbine, and has many features in common with the so-called through-flow methods used in gas turbine design. A strict mathematical averaging procedure produces a modified set of momentum equations for the runner region of the flow domain, with extra terms resulting from blade blockage, and lift and drag on the runner blades. These terms have been implemented in CFX through user Fortran. A typical result is shown in Figure 1, with a velocity slice through the axis of the runner and the centreline of the draft tube, and pressure variations on the walls of the plant.



The model can also be used to design the camber surface of the runner blades, using the surface normal vectors that are obtained by optimizing the extra terms in the averaged equations. An example of optimized camber surfaces generated by the model is shown in Figure 2.

Figure 1 (Top): Pressure level at the surface of a complete hydraulic turbine. The figure also shows a slice through the centreline of the draft tube representing the velocity magnitude.

Figure 2 (Middle): Francis runner created in CFX-Build. Note the complicated 3-dimensional shape of the runner blade camber surfaces.

CENTRIFUGAL COMPRESSOR DESIGN

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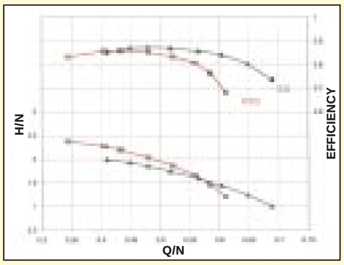
Solar Turbines, Inc. has standardized on CFX-TASCflow for the design and analysis of its line of centrifugal gas compressors. These machines are used in a variety of applications involving the compression of light hydrocarbon gases. With CFX-TASCflow being used throughout the design process, new levels of performance are being obtained, and several new machines have been introduced with unsurpassed efficiency, range and reliability. Early use of CFX-TASCflow assists in establishing critical design assumptions in inlet velocity profiles and impeller work levels, while detailed design optimization relies heavily on CFX-TASCflow to direct geometric modifications.

During the recent design of two different two-stage compressors, CFX-TASCflow was used extensively. Both first-stage impellers were analyzed and the pitchwise-averaged exit profiles were used as inlet boundary conditions to the diffuser, crossover and return vane system. While one- and two-dimensional analysis showed the impellers to be very similar, CFX-TASCflow indicated that the impeller exit profiles were very different. This meant that different hub-to-shroud twist of the return vanes would be required for the optimum performance of the two machines.



Closed loop test data validates excellent range and efficiency for both configurations.

Each return vane was designed and manufactured based on the profiles calculated from CFX-TASCflow. Closed-loop testing of these two machines showed excellent performance with state-of-the-art efficiency levels being obtained over a wide operating range. To obtain this level of performance, each element must be properly matched to the upstream component, something which is only possible with sophisticated CFD tools.

CFX-TASCflow has not replaced our 1-D or 2-D tools at Solar Turbines, Inc., but has become an integral part of our design system, allowing us to optimize our designs and maximize their potential.