St. Lawrence-FDR power project propeller-type runner

Runners Experience **Longer Life**

Fracture mechanics helps ensure longevity of propeller-type runners in hydropower plants.

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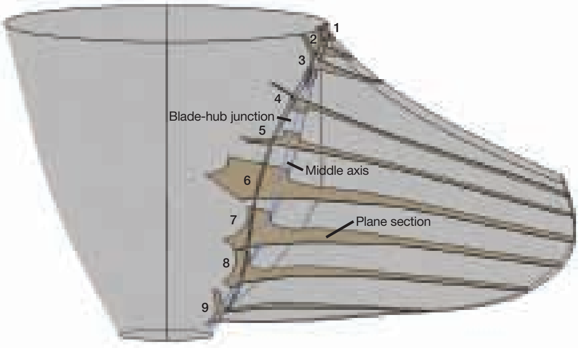
Meeting predicted life estimates and avoiding component failure are essential for hydropower generation projects. The New York Power Authority is involved in the rehabilitation of large hydropower units, such as those at the St. Lawrence-FDR Power Project. Recent progress in numerical simulation software allows these units to reach a high level of performance in order to improve productivity and reliability. For phase 2 of the rehabilitation project, eight new replacement propeller runners are to be supplied by Alstom Hydro — a company that develops power generation products and systems — for the original Allis-Chalmers turbines.

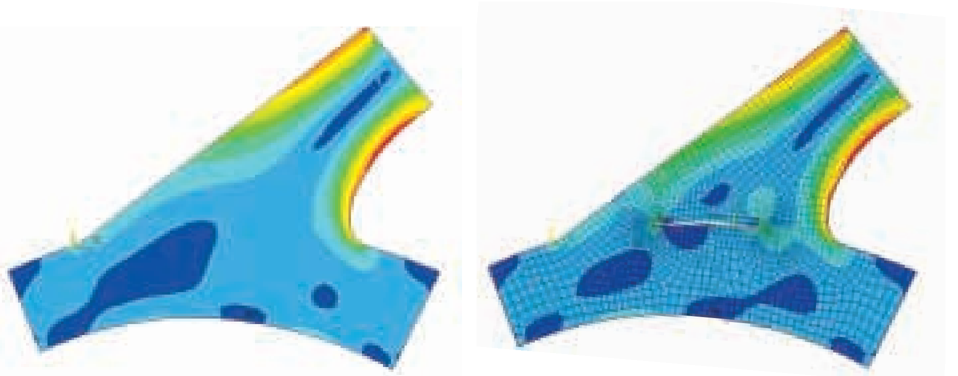
These runners are 6.096 meters in diameter, have an expected lifespan of 70 years and are capable of producing 64.9 MW under 24.7 meters net head. The hub and blades of the runner are castings of stainless steel machined to final shape. Dynamic loads that occur during the life of hydraulic turbine runners can cause failure and, therefore, present a significant risk with regard to the reliability of the turbine as well as the economic viability of the project.

Because of this, technical specifications now require dynamic load analyses of turbine runners. A fracture mechanics analysis is used to evaluate crack growth rates for flaws and to predict the mechanical failure of the component over a given lifespan. To help ensure longevity, engineers at Alstom Hydro of Quebec, Canada, use ANSYS Mechanical software to compute the stress intensity factor as a function of the crack length for complex shapes like those found in propeller-type hydraulic turbine runners.

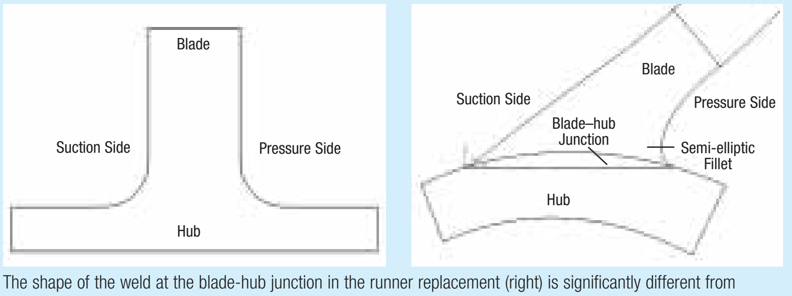
The goal of fracture mechanics analysis is to determine the critical dimensions of an initial defect at a given location for the expected lifetime of the component. Engineers evaluate crack propagation and brittle failure of the runner by computing stress intensity factors and then applying a loading pattern representative of the anticipated operating conditions. The fracture mechanics approach is, therefore, particularly suitable for the analysis of the partial-penetration welds between runner hubs and blades.



Definition of planes for fracture mechanics analysis. Intersection of the FMA with hubs and blades is shown.



Comparison of stress intensity for the blade design used in the St. Lawrence runner with no defects (left) and with a partial penetration weld (right)



The shape of the weld at the blade-hub junction in the runner replacement (right) is significantly different from that specified in the *British Standard* (left).

A standard approach to evaluating the stress intensity factors of a defect is to use the British Standard *BS 7910:2005: Guidance to methods for assessing the acceptability of flaws in metallic structures*. This standard considers the blade–hub junction as a simplified geometry, such as a cruciform joint. In the case of the blade design used in the St. Lawrence runner, as well as some other modern runner designs, however, the shape of the welded joint is far from being cruciform. These partial-penetration welded joints include an unfused area, such that the weld metal does not penetrate the entire cross section of the joint. Engineers at Alstom developed an improved methodology to design a safe weld configuration for these new runners. In parallel, the engineers validated stress intensity factors by comparing results from ANSYS Mechanical software to published solutions for a standard cruciform joint from the British Standard. The results were satisfactory.

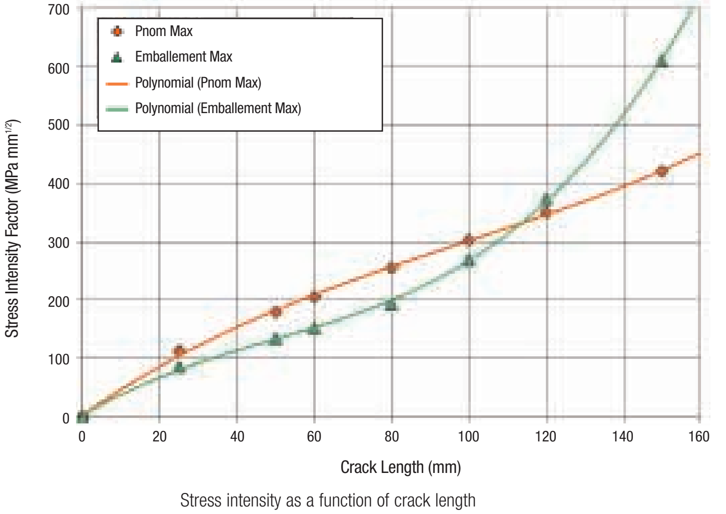
The team first performed a static 3-D finite element analysis (FEA) to evaluate displacement and stress distribution for all normal operating and emergency conditions for a theoretical runner that is free of any defects and uses full-penetration welded joints. The engineers increased the complexity of the load pattern to represent as closely as possible the real dynamic operation of the turbine.

From the 3-D FEA results, the engineers extracted 2-D degrees of freedom in planes used to perform fracture mechanics analysis; the 2-D FEA models showed a stress level very similar to the 3-D analysis, confirming the validity of this approach. For these planes, the team modeled the unfused section of the weld between the blades and the hub as a crack using skewed elements at the crack tip. They computed the mixed-mode stress intensity factors using a displacement extrapolation method. They evaluated stress intensity factors for a wide range of crack lengths and positions. Next, the engineers developed a relationship to describe stress intensity factor as a function of the crack length for each plane. They were then able to use this information to design runners with partial welded joints that would be better suited to withstand dynamic loads occurring over the lifetime of the runner.

This resulted in a reduced volume of welding, thus leading to less welding distortion and a very accurate final geometry. Because of Alstom's use of FEA in the design process, the efficiency of the runner can be maintained at a high level, cavitation erosion can be avoided and overall global behavior can be improved. The first runner is now operating smoothly, and it is estimated that it will produce green energy for at least the next 70 years. The remaining units will be delivered and commissioned in years to come. ■

References

Sabourin, M.; Bouffard, D-A.; Paquet, F., "Life Prediction of Hydraulic Runners Using Fracture Mechanics Analysis," Alstom Hydro, © ALSTOM 2007.



Stress intensity as a function of crack length