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EXPERIMENTAL ASSESSMENT OF THE IMPACT OF TERNARY UNITS START-UP STRATEGIES ON MULTISTAGE PUMP LIFETIME USING A FRACTURE MECHANICS APPROACH

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ABSTRACT

As the energy transition progresses, hydropower plants (HPPs) are increasingly relied upon to enhance the power system flexibility, with pumped-storage plants (PSPPs) being among the most efficient and widely deployed solutions. The growing penetration of non-dispatchable renewables introduces operational challenges, requiring more frequent start-stop cycles and off-design operation to address unpredictable variations of the power generation from day-ahead schedules. This increased variability is acknowledged to induce structural-related problematics on different mechanical components, particularly due to fatigue damage.

Fatigue-related damage assessments in solid mechanics typically rely on empirical models linking stress amplitude to failures. While these models are widely adopted in industry, they rely on statistically derived failure forecasts and they do not account for the chronological impact of cyclic loads, leading to reduced accuracy in lifetime assessments. Concerning fatigue evaluation on hydraulic machines, computational fluid dynamics (CFD) simulations can estimate mechanical stresses based on specific operating conditions, yet they inherently include modeling-related uncertainties. On-site experimental measurements, while more direct, require plant shutdowns and present relevant instrumentation challenges.

In view of the above, the aim of this research is to develop a framework to assess the fatigue-related damage in multistage pumps used in ternary units of PSPPs by a linear elastic fracture mechanics approach. A reduced-scale model of a three-stage pump is instrumented with strain gauges at the blade-crown intersection, and an extensive experimental campaign is conducted on a dedicated test rig under transient conditions. The start-up sequences of interest are computed by assuming the pump as being carried in back-to-back mode by the turbine-side. The tested start-up trajectories are optimized with respect to the turbine-side operation of the ternary unit and then implemented on the test rig to evaluate the mechanical stress-related impact on the pump-side. By means of similarity laws, the progression of a hypothetical crack in the real-scale impeller can be modeled and assessed.

The proposed approach enhances the understanding of structural damage mechanisms in multistage pumps and establishes a direct link between the generating side optimization and fatigue mitigation on the pumping side. The study highlights how different start-up strategies influence the growth of pre-existing cracks - expected due to machining, maintenance, and long-term operation - providing insights into extending pump lifetime while maintaining operational flexibility.