Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

Fluid-Structure interaction in hydraulic machines: optimizing start-up for longevity

Elena Vagnoni
Mechanical Engineering Department, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland
*elena.vagnoni@epfl.ch

Abstract

The growing demand for increased flexibility in modern power systems poses a significant challenge to the safe operation of the hydropower asset. Extended operating ranges and frequent start-ups and stops, necessary to regulate the power grid, lead to performance degradation and reduce the lifespan of the hydraulic machines. In particular, start-up sequences of hydraulic turbines play a critical role in their structural integrity and long-term performance.

This talk presents a framework based on experimental investigation, deep learning and optimization techniques to minimize damage during start-up procedures for improved longevity of hydraulic machines. Through high-frequency measurements of dynamic loads and stresses in reduced-scale models of Francis and Pelton turbines, we characterize the transient mechanical stresses experienced during start-up and assess their impact on fatigue-induced damage. To predict fatigue life, we develop physics-based models using both stress-life methods and elastic-fracture mechanics, incorporating crack growth analysis. These models are further leveraged through polynomial expansion techniques and deep learning algorithms, enabling accurate damage estimation under varying operational conditions. Finally, we apply constrained optimization—both convex and nonlinear—to refine start-up protocols, minimizing fatigue-induced damage.

Results demonstrate a substantial reduction in fatigue damage, with optimized start-up sequences lowering damage by up to a factor of 15. These findings underscore the potential of physics-informed machine learning and advanced optimization techniques in extending the service life of hydraulic turbines, offering a pathway toward more resilient hydropower operations.