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Measured flow at the inlet of a Francis turbine at various no-load and one deep part-load operating conditions

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ABSTRACT

The prolonged operation of hydraulic turbines under off-design conditions, such as no-load and deep part-load, accelerates turbine damage and may ultimately lead to premature runner failure. As the integration of other renewable energy sources leads to increased reliance on these off-design operations, manufacturers and energy producers are prioritizing the study of their effects. This knowledge can drive the development of mitigation strategies to reduce energy production costs.

However, most experimental studies in this field are limited mainly to pressure and strain measurements on the runner or fixed turbine parts, with relatively few investigations measuring the velocity field. Additionally, the existing numerical simulations lack robust validation due to the limited availability of experimental data. This study employs an endoscopic stereoscopic particle image velocimetry technique to measure flow velocity at the inlet of a Francis turbine with a high acquisition rate. The turbine under investigation is a scaled-down homologous model of a medium-head Francis turbine installed in the Jean-Lesage generating station. This model turbine is mounted on the closed-loop test bench of Heki at Université Laval. Velocity fields are measured and analyzed under multiple no-load operating conditions and one deep part-load condition. Both average and instantaneous flow fields are studied and compared to identify the most energetic dynamic flow phenomena. No-load and deep part-load operating conditions are characterized by significant backflow within the turbine. Measurements show that this backflow moves upstream along the suction side of the blades. In some cases, it is strong enough to extend into the vaneless space, while in others, it remains confined within the runner. A companion numerical simulation of the turbine at speed no-load indicates the existence of large pressure fluctuations at the leading edge of the runner blades. At speed no-load and at operating conditions with a guide vane opening larger than that of speed no-load, three average flow circulation zones are identified near the leading edge. One circulation zone is located on the suction side of the blades, while two are on the pressure side. The intensity and configuration of all these flow structures, backflow and circulation zones, vary with the guide vane angle and the torque extracted from the flow. These phenomena are intermittent and cause velocity fluctuations in the region near the maximum pressure fluctuations estimated by the turbine's numerical simulation.