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Fatigue analyses of the prototype Francis runners based on site measurements and simulations

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Abstract

With the increasing development of solar power and wind power which give an unstable output to the electrical grid, hydropower is required to give a rapid and flexible compensation, and the hydraulic turbines have to operate at off-design conditions frequently. Prototype Francis runners suffer from strong vibrations induced by high pressure pulsations at part load, low part load, speed-no-load and during start-stops and load rejections. Fatigue and damage may be caused by the alternating stress on the runner blades. Therefore, it becomes increasingly important to carry out fatigue analysis and life time assessment of the prototype Francis runners, especially at off-design conditions. This paper presents the fatigue analyses of the prototype Francis runners based on the strain gauge site measurements and numerical simulations. In the case of low part load, speed-no-load and transient events, since the Francis runners are subjected to complex hydraulic loading, which shows a stochastic characteristic, the rainflow counting method is used to obtain the number of cycles for various dynamic amplitude ranges. From middle load to full load, pressure pulsations caused by Rotor-stator-Interaction become the dominant hydraulic excitation of the runners. Forced response analysis is performed to calculate the maximum dynamic stress. The agreement between numerical and experimental stresses is evaluated using linear regression method. Taking into account the effect of the static stress on the S-N curve, the Miner's rule, a linear cumulative fatigue damage theory, is employed to calculate the damage factors of the prototype Francis runners at various operating conditions. The relative damage factors of the runners at different operating points are compared and discussed in detail.