Method for Fatigue Analysis of Hydraulic Turbines by means of Monitoring Systems

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Motivation

Within the last decade the rising amount of volatile sources of energy, such as solar and wind power, led to a falling price on the energy spot market. As a result , there are higher requirements in terms of grid stabilization efforts. Therefore operators of hydropower plants are using their machines to provide balancing energy to the electrical grid. However, this leads to significant worse operating conditions in off-design points as well as to a higher number of start-ups and shut-downs. Thereby, flow phenomena and mechanical structure resonance determine the runner lifetime. Based on the results of the previous project PSP-LowLoad, a further development of the fatigue analysis including prototype site measurements and numerical simulations was aspired. Furthermore, the detection of critical operating points by means of the monitoring systems was investigated. The results of the project have/will been published in several papers and presented at scientific conferences (see [1] [2] [3]).

Prototype Site Measurements

In order to evaluate the behavior of the considered prototype Francis turbine at off-design points and transient operations, site measurements were performed. Especially, start-up low-load and shut-down were of particular interest of the concerned research project. Therefore, numerous pressure transducers and vibrations sensors were installed (see Figure 1). Steady static measurements are done at the the end of the Drafttube (p_{DT}), near the runner ($p_{cone.2}$), in the vaneless space (p_{RN}) and in the spiral casing (p_{SC}) as well as before the throttle valve (p_{TV}). For the purposes of discover draft tube flow phenomena two piezoresistive unsteady static pressure transducers ($p_{cone.1}$, $p_{cone.3}$) were installed in the cone near the runner.
Furthermore, vibration sensors were mounted on the upper ($v_{UGBx,y,z}$) and lower generator bearing ($v_{LGBx,y,z}$) and the turbine bearing ($s_{THBx,y}$) as well as in the hollow hub of the runner (a_{HUB}). Shaft torque (T) and runner speed (n) measurements based on twist angle were done by two optical fork sensors. The total discharge (Q) was determined by the Winter-Kennedy method. In order to evaluate the leakage flow rate (q') a dynamical pressure probe was taken at the only accessible point of the collector pipeline. Moreover, to determine static and dynamic stress, several strain gauges have been attached to the trailing edge of the runner. The obtained stresses were further used to access the runner lifetime. More information about the instrumentation and the measurement can be found in [1].

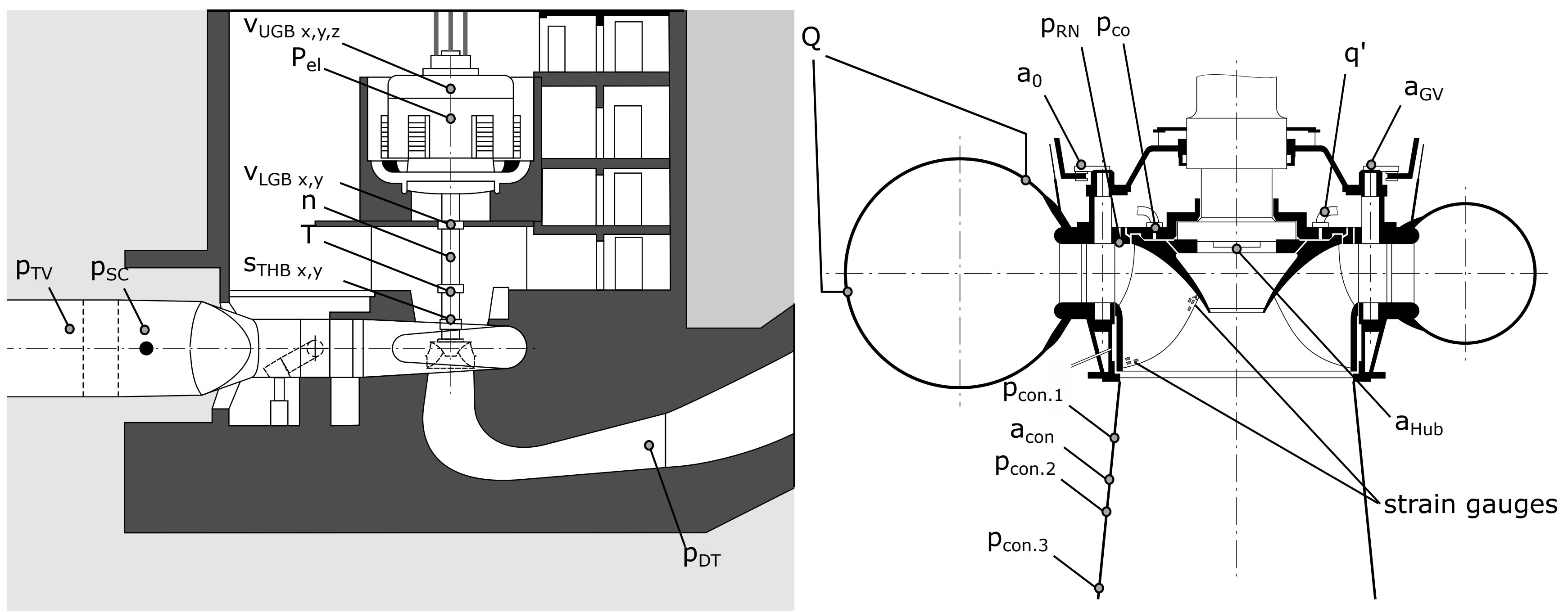

Figure 1: Sensor position and measurement signal plan [1]

Funding and Project Partners

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Fatigue assessment

Based on the measurement data a fatigue analysis of the runner was performed. Thereby, results of the strain gauge measurements were compared to the S-N-Curve. To access fatigue damage, the cumulative fatigue damage theory according to Palmgren-Miner was applied. Figure 2 shows the damage factors for all stationary operating points as well as transient load cases.
Especially, at 44% of the rated power-output the runner suffers under high dynamical stresses (see Figure 2) leading to increased vibrations of the whole machine set. Furthermore, one can see that especially transient events like start-up (STU) condenser-mode-operation (CMO) and load rejection (LR) are contributing a lot to overall runner fatigue damage.

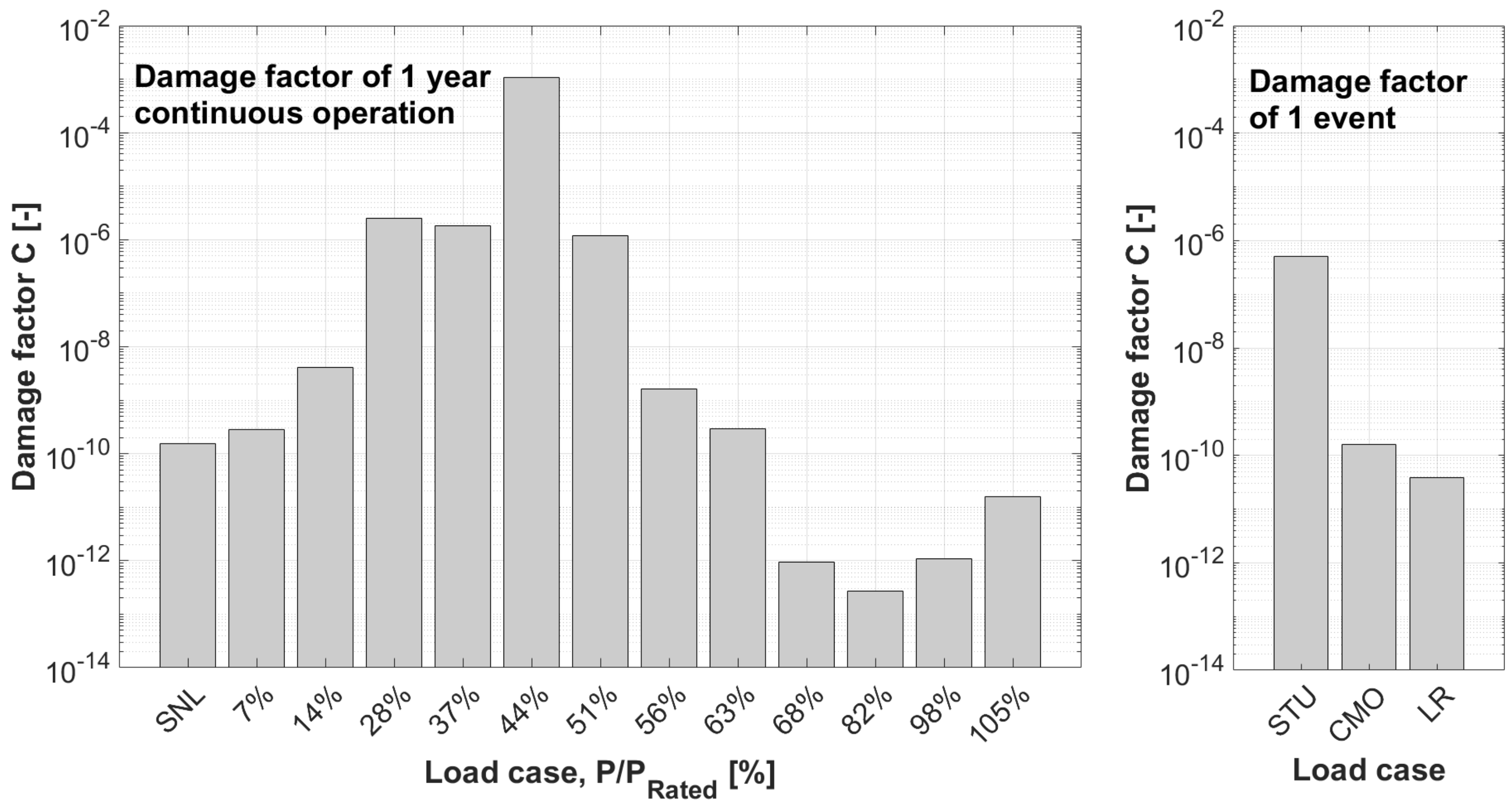

Figure 2: Damage factors based on the strain gauge measurement [2]

In order to investigate the reason for high pressure pulsations and dynamical stresses unsteady CFD-simulations are performed. Therefore the commercial code ANSYS CFX 18 and the open source software OpenFOAM 6 was used. The left side of Figure 3 shows the results for the critical unsteady load point. One can clearly identify a draft tube vortex highlighted by iso-pressure-surfaces. The results of the CFD simulations are used for transient finte-elemente calculations to evaluate the stress in the runner (see Figure 3 right, example at one load step). Moreover, feasibility study concerned with the extension of implementing the CFD simulation of transient events in the numerical process will be done in the future. More information about the numerical setup can be found in [3].

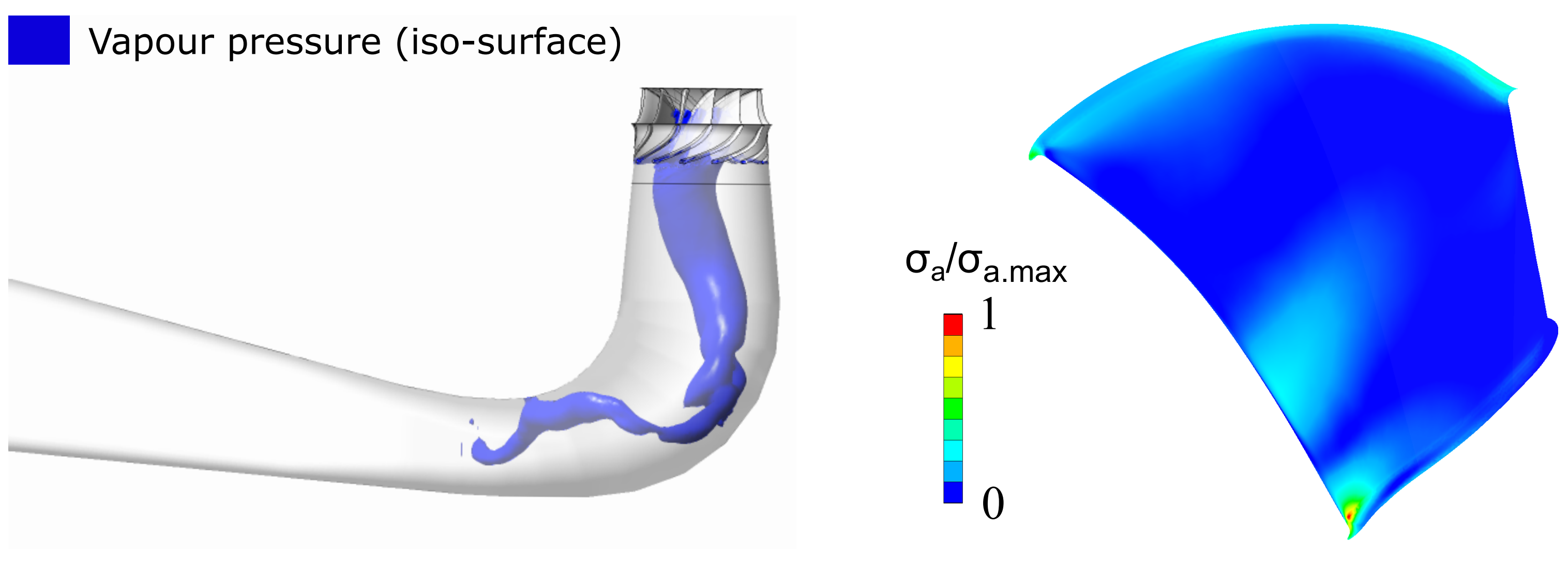

Figure 3: CFD results (left) Mises stress at the Francis runner (right)[3]

References

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