An indirect measurement methodology to identify load fluctuations on axial turbine runner blades

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The flexibility of hydropower plants due to the rapidly increasing share of intermittent renewable energy sources
Research Question

- Proposing a measurement methodology in which the blade loading can be predicted by performing measurements on the shaft.

Goals

- Analyses of measurement results performed on the Porjus U9 Kaplan turbine prototype during steady operations on the runner and shaft:
  - Strain on the blade
  - Pressure on the blade
  - Torsion, bending and axial strain on the shaft
  - Proximity probes installed closed to the turbine bearing

- Relate the measurements on the blade to the one on the shaft during steady-state operations.
Porjus U9 Kaplan prototype turbine

- This turbine was designed by Kvaerner Turbine AB, Sweden, in the late 1990s.
- This unit is located along the Lule river in Sweden. It is part of the Porjus Hydropower Center and is primarily used for research and educational purposes.
- The turbine is composed of six runner blades, 20 equally spaced guide vanes, and 18 unequally distributed stay vanes with a runner diameter of 1.55 m.

Nominal operating parameters of the Porjus U9 prototype Kaplan turbine

| Parameter            | Value | Unit |
|----------------------|-------|------|
| Head (H)             | 55.5  | [m]  |
| Power (P)            | 10    | [MW] |
| Discharge (Q)        | 20    | [m³s⁻¹] |
| Rotational speed (n) | 600   | [RPM] |

Porjus U9 Kaplan turbine prototype, Porjus powerplant
Prototype turbine instrumentation

1. cRIO (Rotating DAQ system)
2. cRIO (Rotating DAQ system)
3. cRIO (Stationary DAQ system)

Shaft prolongation
The strain gauges on the turbine shaft

Position of the distance probes

Position of the pressure transducers

Position of the strain gauges
The guide vane opening and runner blade pitch angle variation for different operating points; ‘OP’ denotes operating point.
Results

Time-averaged parameters on the blade

Normalized average pressure of four pressure transducers on the runner blade.

Time-averaged strain obtained on the runner blade.
Time-averaged parameters on the shaft

- Time-averaged axial strain
- Time-averaged torsion strain
- Time-averaged bending strain

Operating point:
- OP0
- OP1
- OP2
- OP3
- OP4
- OP5
- OP6
- OP7
- OP8
- OP9
- OP10

Graphs showing:
- Propeller curve-1, $\beta = -14.3^\circ$
- Propeller curve-2, $\beta = -3.5^\circ$
- Propeller curve-3, $\beta = +4.2^\circ$
Peak-to-peak normalized pressure amplitude of four pressure transducers.
Peak-to-peak amplitude of parameters on the shaft

- Peak-to-peak amplitude of parameters on the shaft
- Peak-to-peak amplitude of torsion strain
- Peak-to-peak amplitude of axial strain
- Peak-to-peak amplitude of bending strain

Graphs showing peak-to-peak amplitudes for different operating points and parameters.
A non-dimensional number \((SR)\) is defined as:

\[
SR = \frac{S_{\text{blade}}}{S_{\text{torsion}}}
\]

where \(S\) is the peak-to-peak strain amplitude.
Obtained by Sweco.

Inverse of peak-to-peak torsion strain amplitude obtained on the shaft as a function of turbine output power. The red line is a hypothetical cam-curve.
Spectral analysis of parameters on the shaft

The amplitudes are normalized.

Rotating vortex rope in the draft tube of a Francis turbine*

*Iliescu, M.S., Ciocan, G.D. and Avellan, F., 2008. Analysis of the cavitating draft tube vortex in a Francis turbine using particle image velocimetry measurements in two-phase flow. Journal of Fluids Engineering, 130(2).
A summary of the spectral analysis results regarding hydraulic phenomena detection with transducers installed in the rotating and stationary frame of reference; ✓, - , and × denote ‘detected’, ‘not detected’, and ‘the transducer is not applicable’, respectively.

| Phenomenon                  | P-PS-2 | S-SS-5R | S-SS-5T | Axial strain | Torsion strain | Bending strain | Proximity probes |
|-----------------------------|--------|---------|---------|--------------|----------------|----------------|------------------|
| RVR - Synchronous mode     | ✓      | ✓       | -       | ✓            | ✓              | -              | ×                |
| RVR-Synchronous mode*2     | ✓      | ✓       | -       | ✓            | ✓              | -              | ×                |
| RVR-Asynchronous mode      | ✓      | ✓       | ✓       | ✓            | ✓              | ✓              | ✓                |
| $f_n = 1$                   | ✓      | ✓       | ✓       | ✓            | ✓              | ✓              | ✓                |
| $f_n = 2$                   | ✓      | ✓       | ✓       | ✓            | ✓              | -              | ✓                |
| $f_n = 20$                  | ✓      | ✓       | ✓       | ✓            | -              | -              | -                |
• A successful measurement campaign was performed on the Porjus U9 Kaplan prototype turbine covering several operating conditions.

• For any propeller curve of a Kaplan turbine, the guide vane opening corresponding to the minimum pressure and strain fluctuation on the runner blade can be obtained by the axial, torsion, and bending measurement on the shaft.

• Torsion measurement on the shaft could be an indication for the index test in Kaplan turbines.

• A signature of every phenomena observed in the data obtained on the runner is found in the data on the shaft.
