Vattenkraftens
FoU-dagar

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

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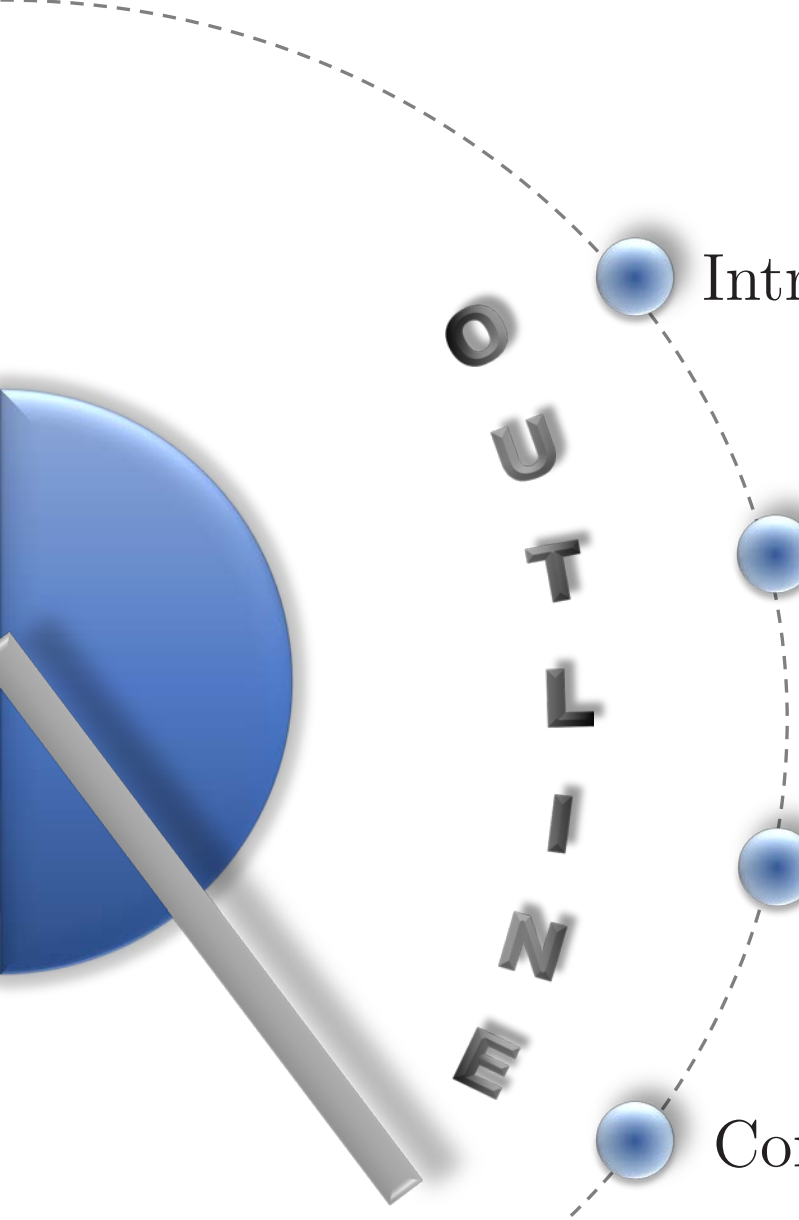
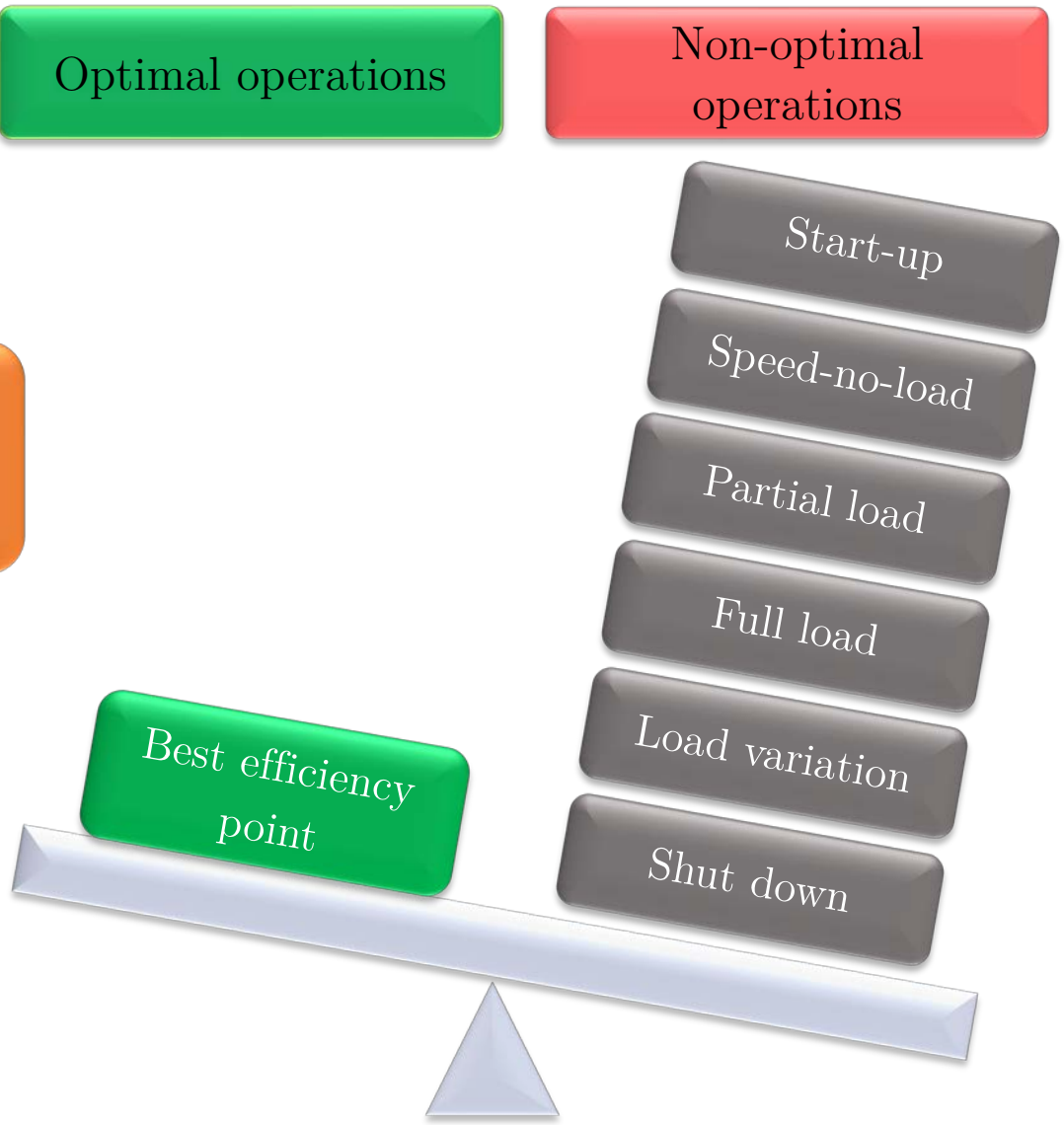


- Introduction
- Porjus U9 measurement campaign
- Results
- Conclusion

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



Research Question

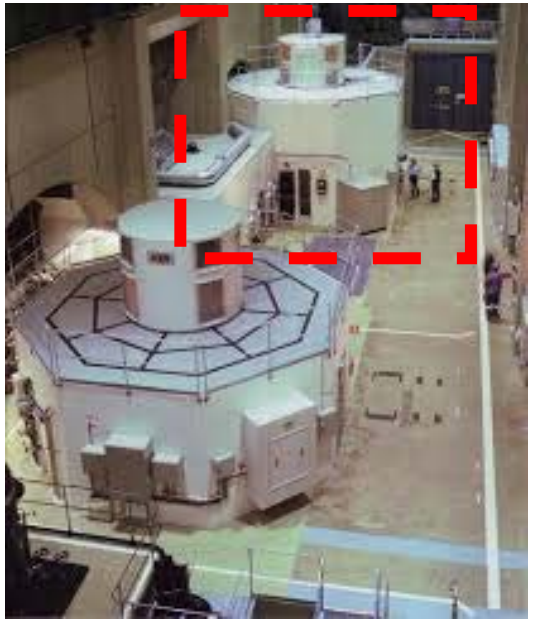
- Proposing a measurement methodology in which the blade loading can be predicted by performing measurements on the shaft.

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.

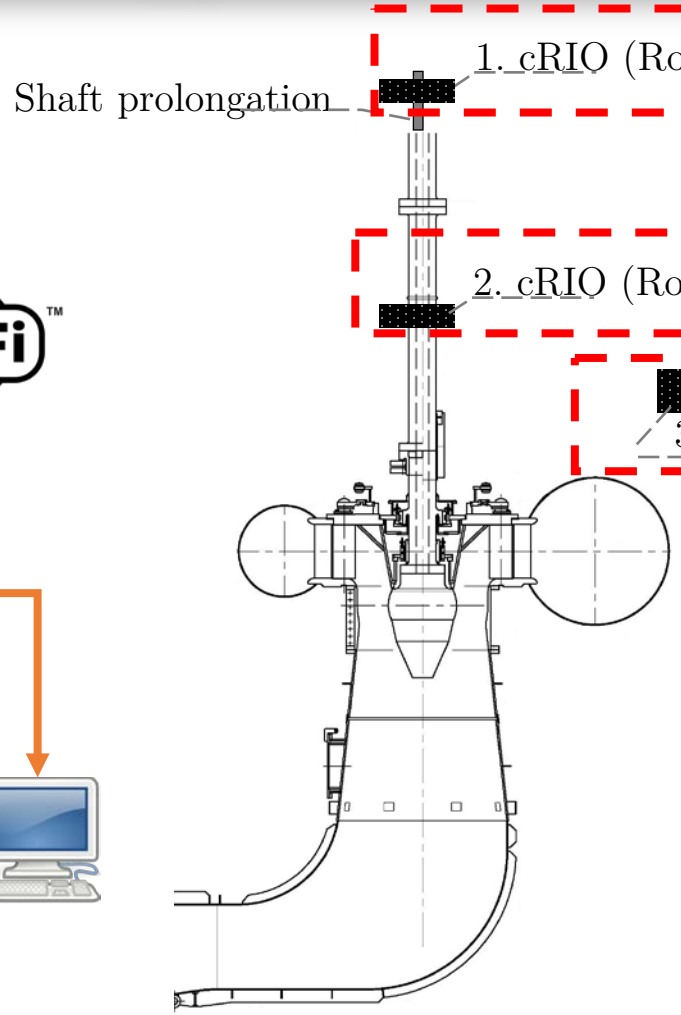


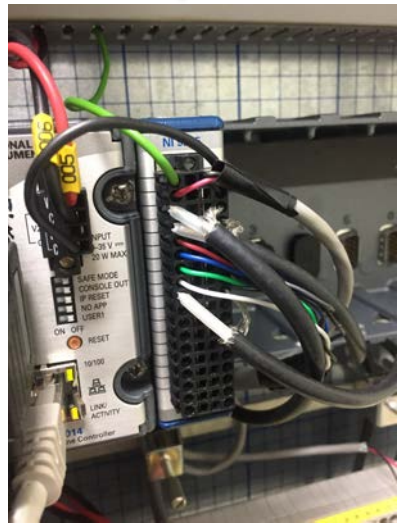
Porjus U9 Kaplan turbine prototype, Porjus powerplant

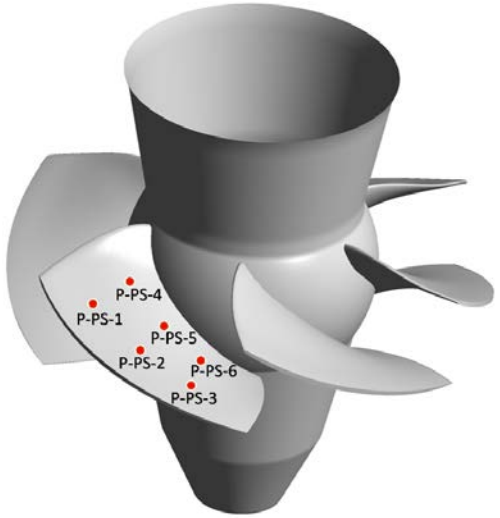
Nominal operating parameters of the Porjus U9 prototype Kaplan turbine

Parameter	Value	Unit
Head (H)	55.5	[m]
Power (P)	10	[MW]
Discharge (Q)	20	[m^3s^{-1}]
Rotational speed (n)	600	[RPM]

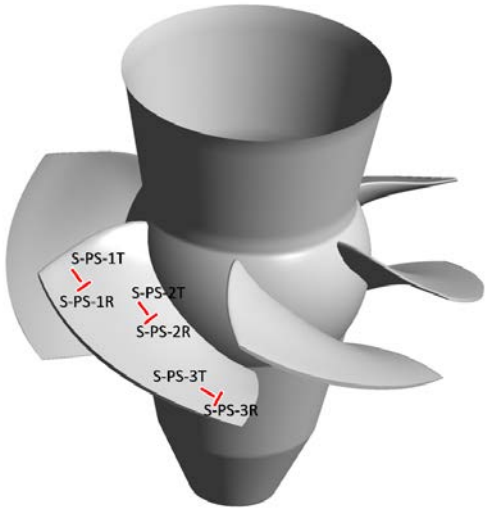
Prototype turbine instrumentation



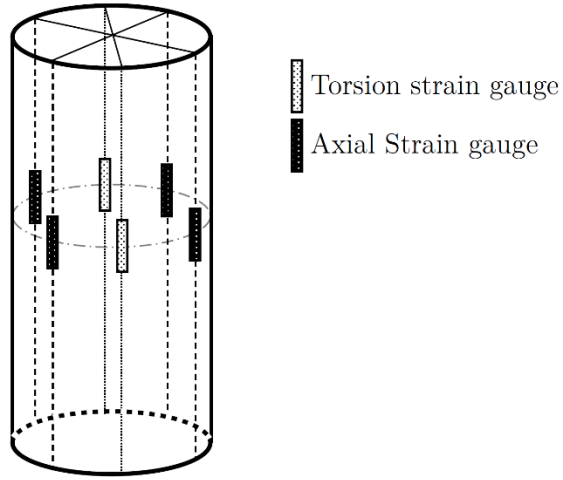




Position of the pressure transducers



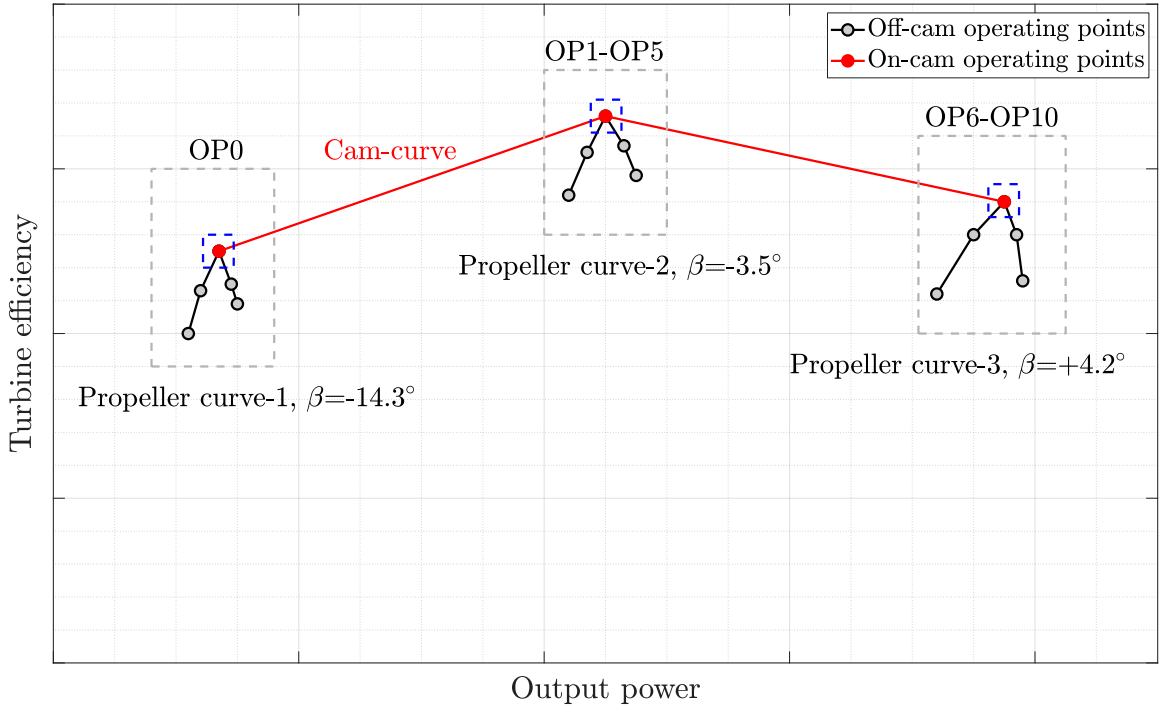
Position of the strain gauges



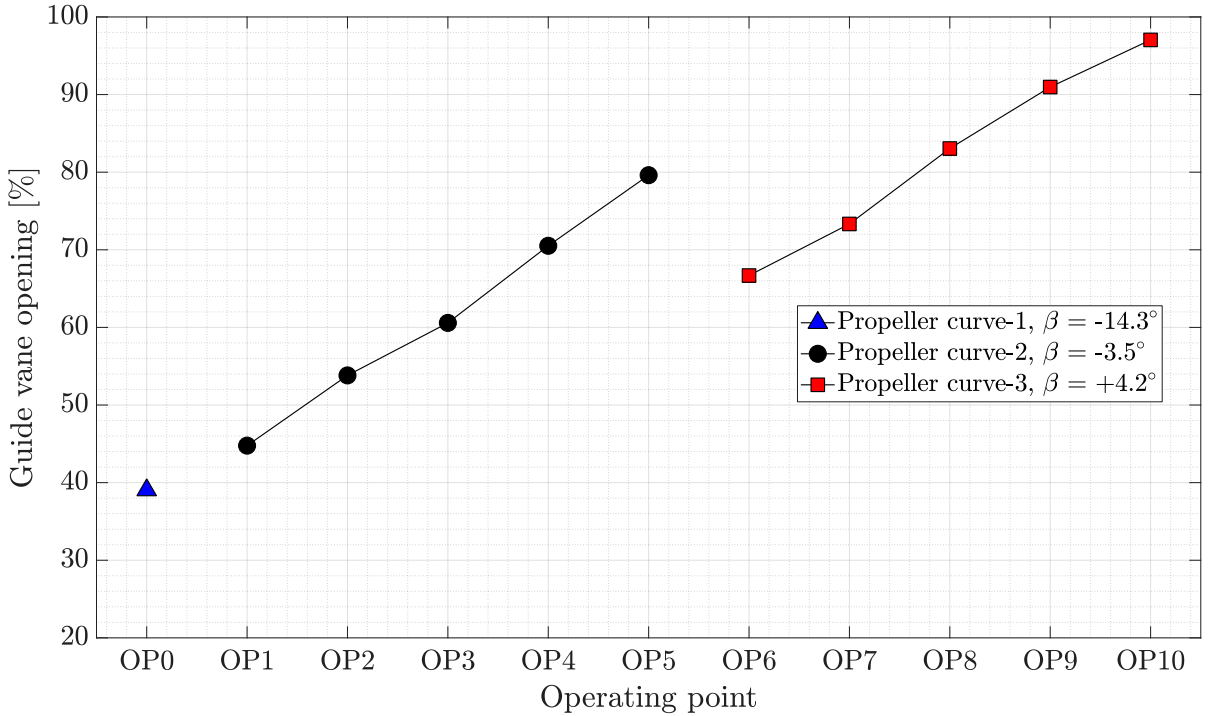
The strain gauges on the turbine shaft

Position of the distance probes

Measurement program



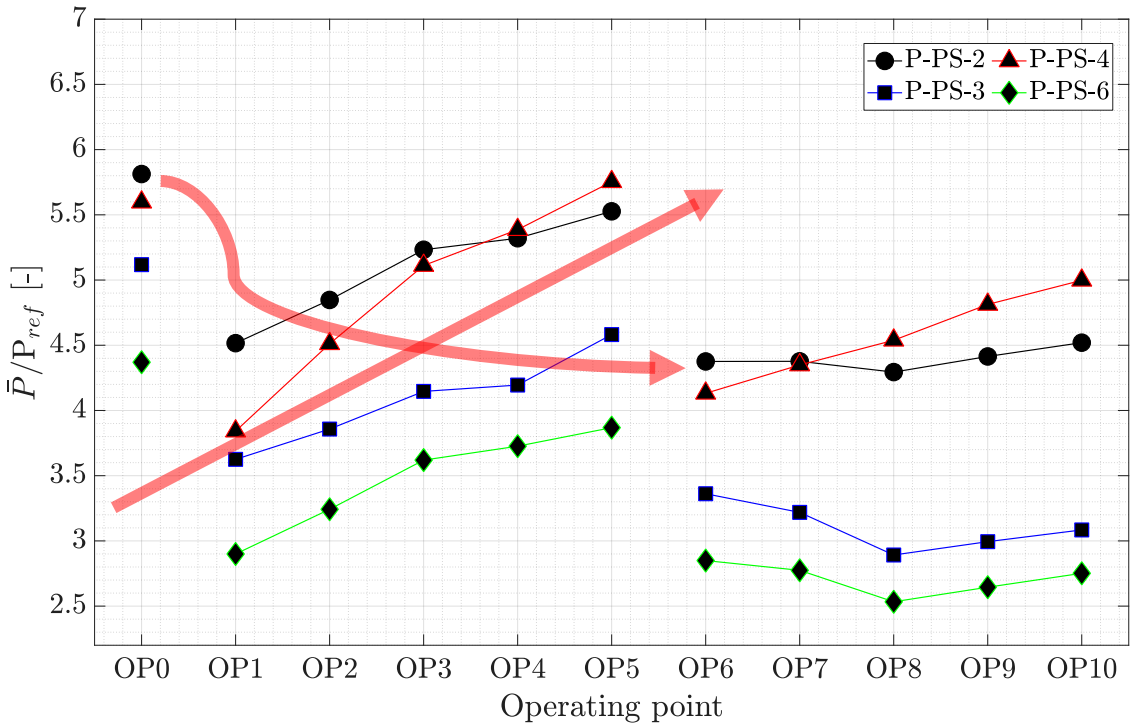
Schematic of the investigated operating conditions



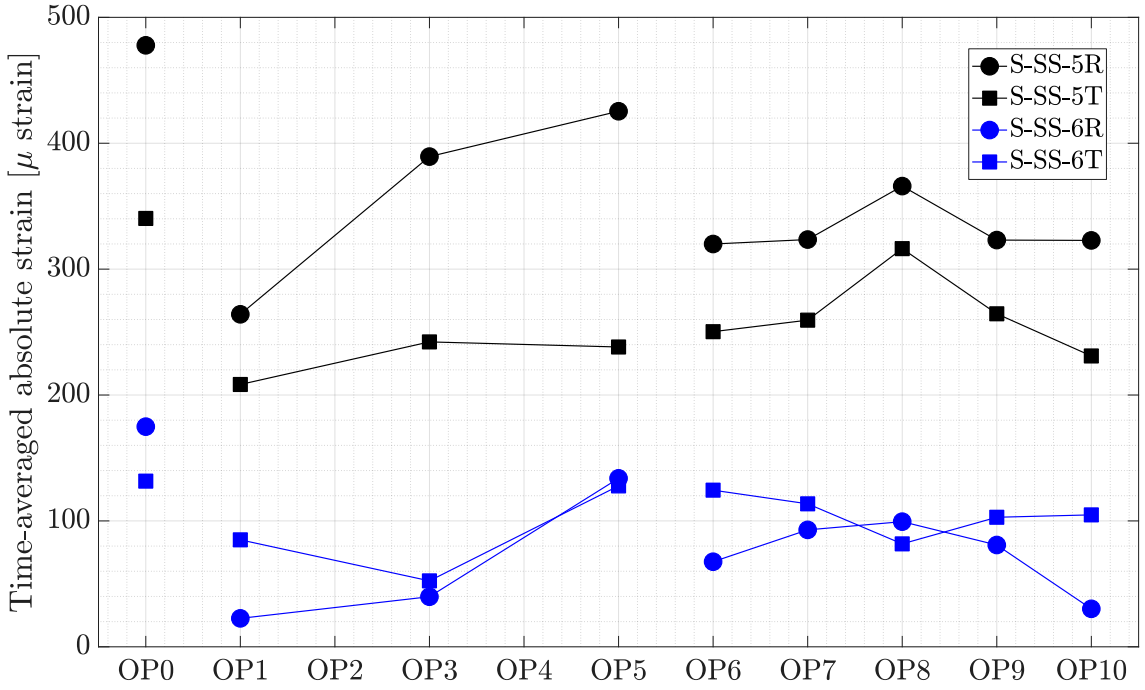
The guide vane opening and runner blade pitch angle variation for different operating points; 'OP' denotes operating point.

Results

Time-averaged parameters on the blade

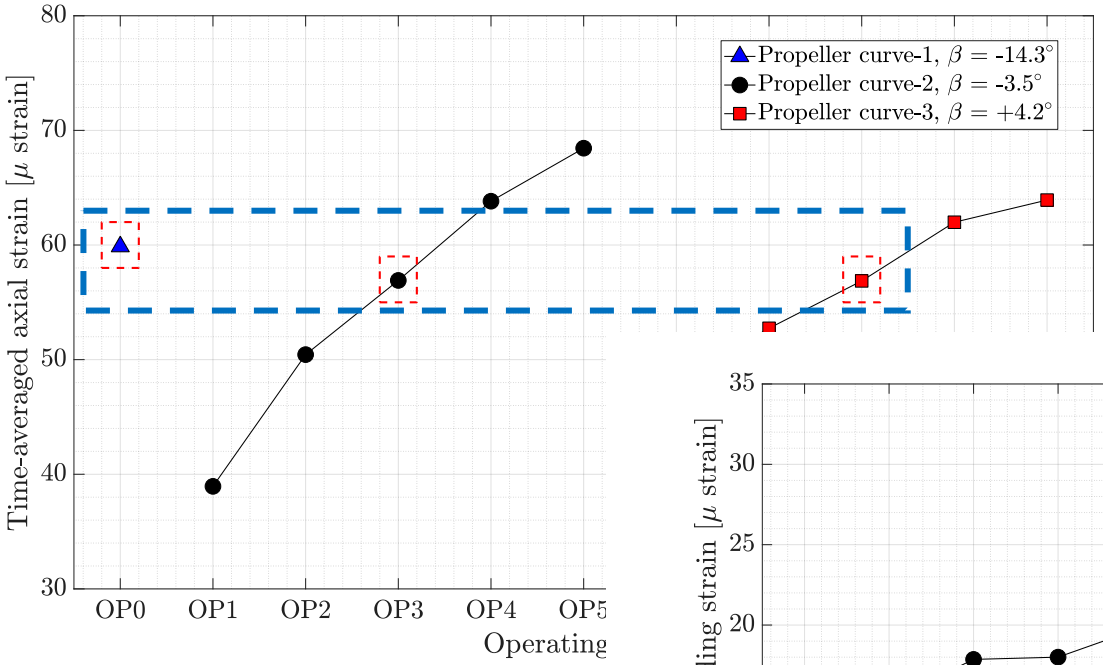


Normalized average pressure of four pressure transducers on the runner blade.

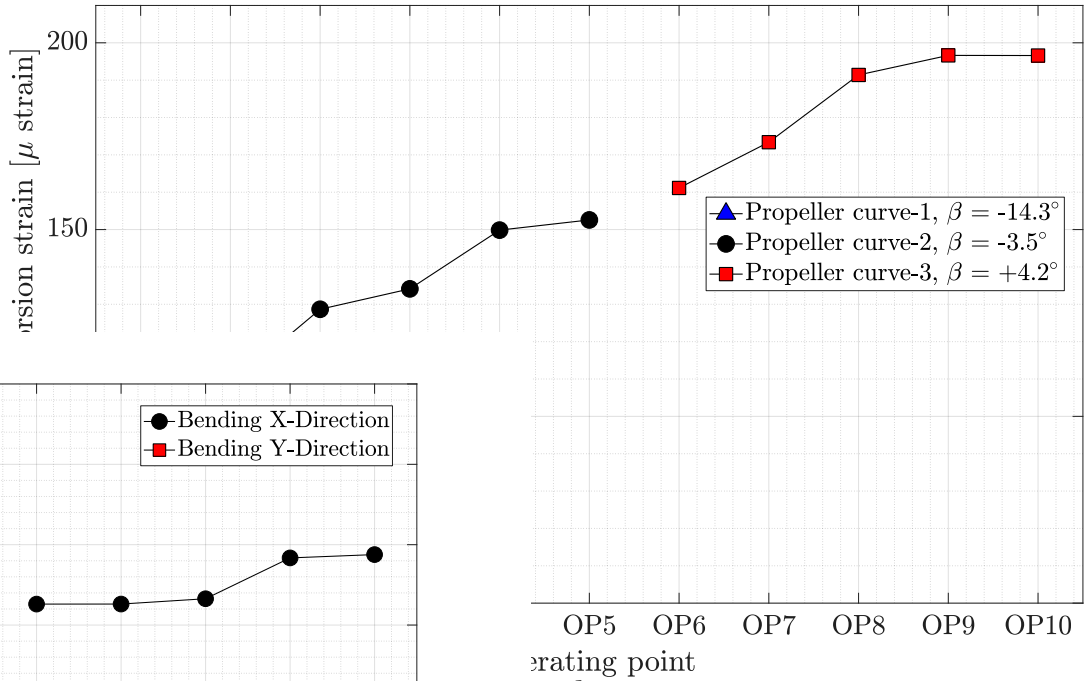


Time-averaged strain obtained on the runner blade.

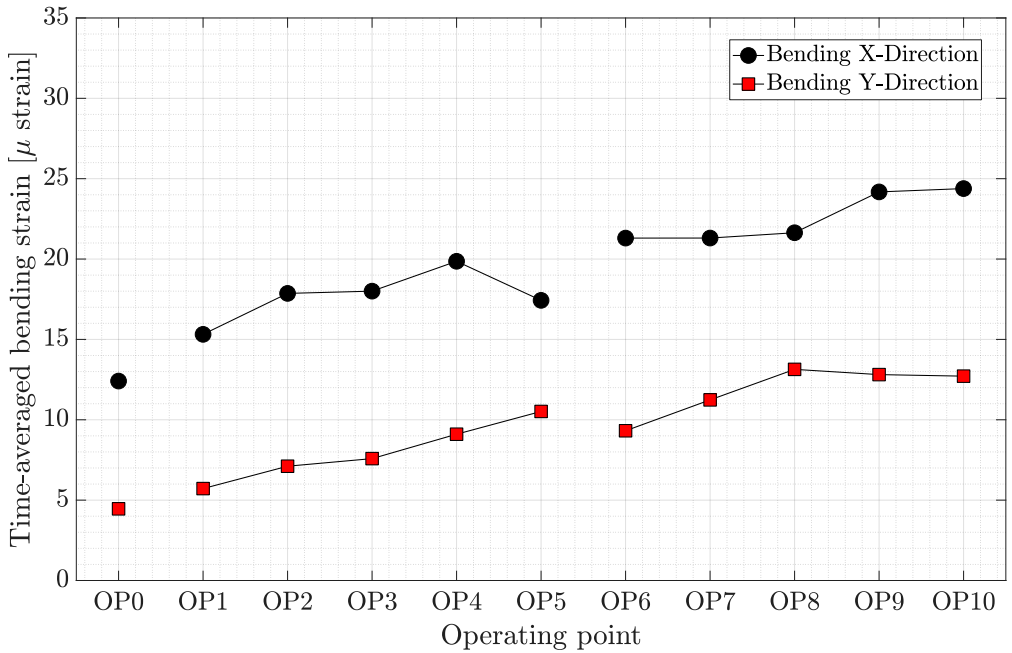
Time-averaged parameters on the shaft



Time-averaged axial

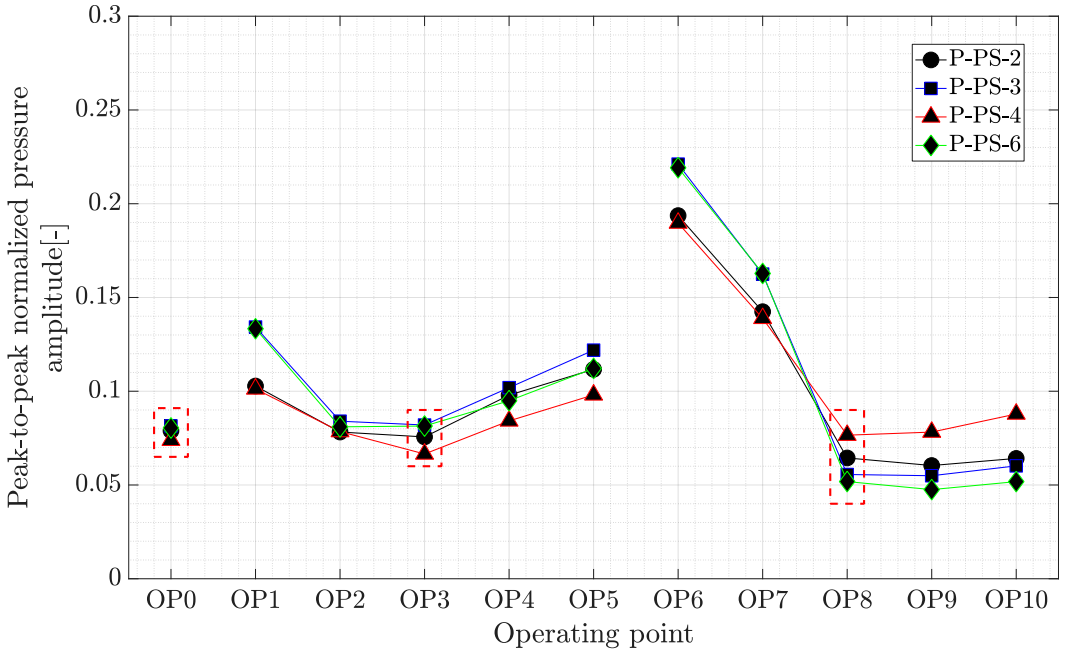


ged torsion strain

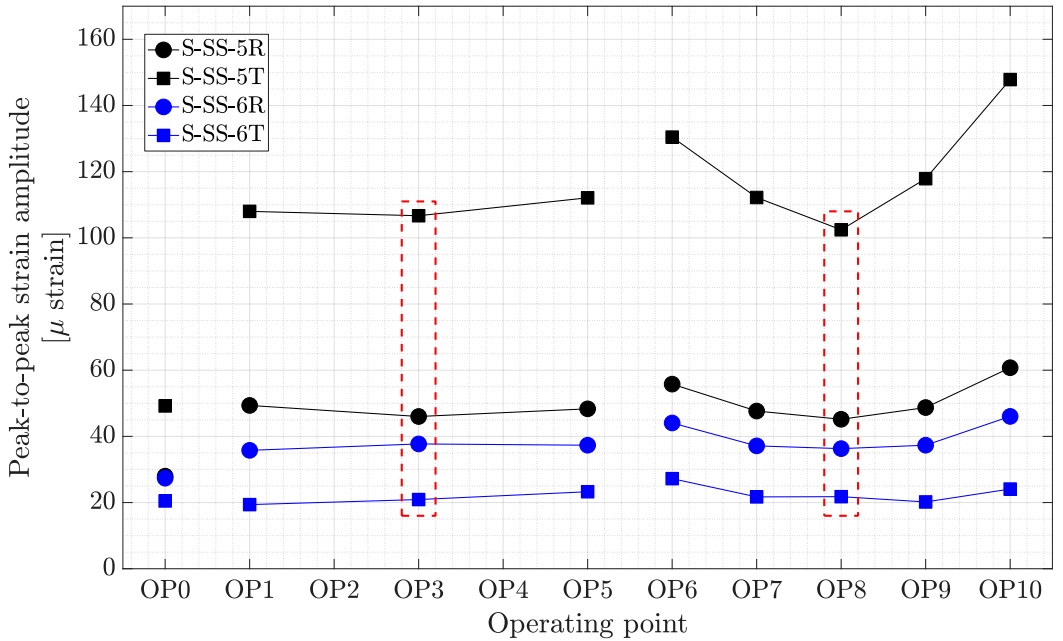


Time-averaged bending strain

Peak-to-peak amplitude of parameters on the blade

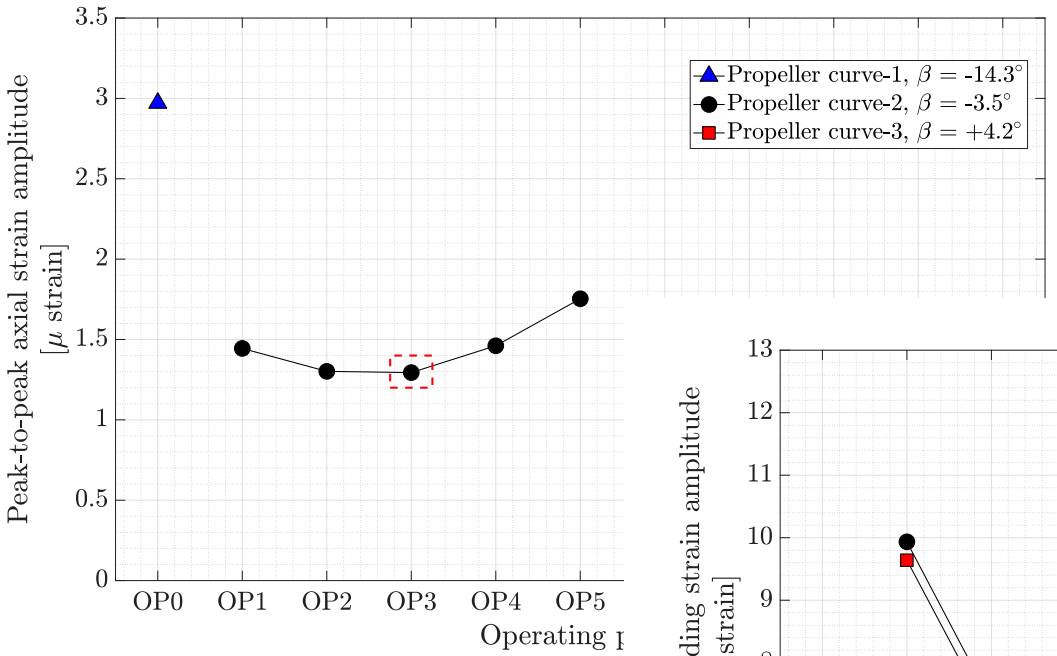


Peak-to-peak normalized pressure amplitude of four pressure transducers.

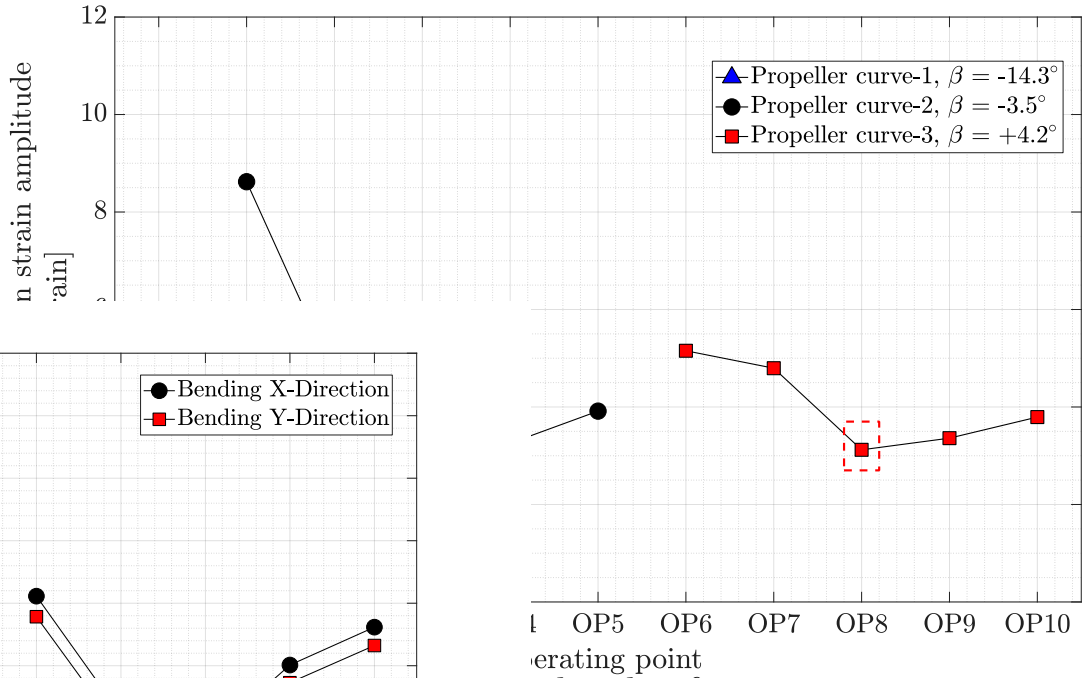


Peak-to-peak strain amplitude.

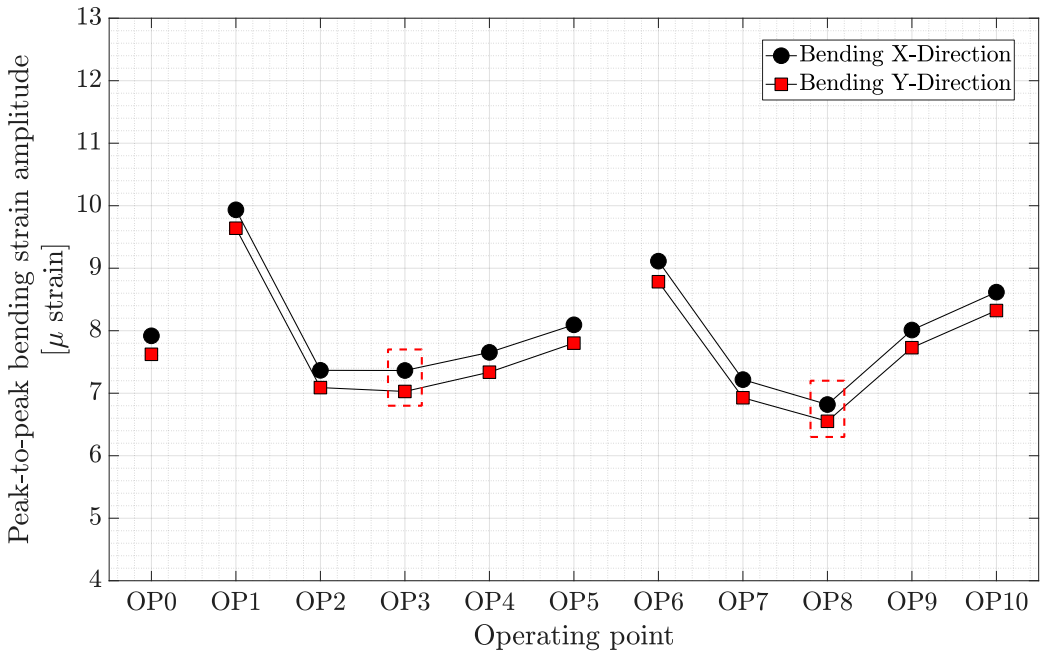
Peak-to-peak amplitude of parameters on the shaft



Peak-to-peak amplitud



plitude of torsion strain



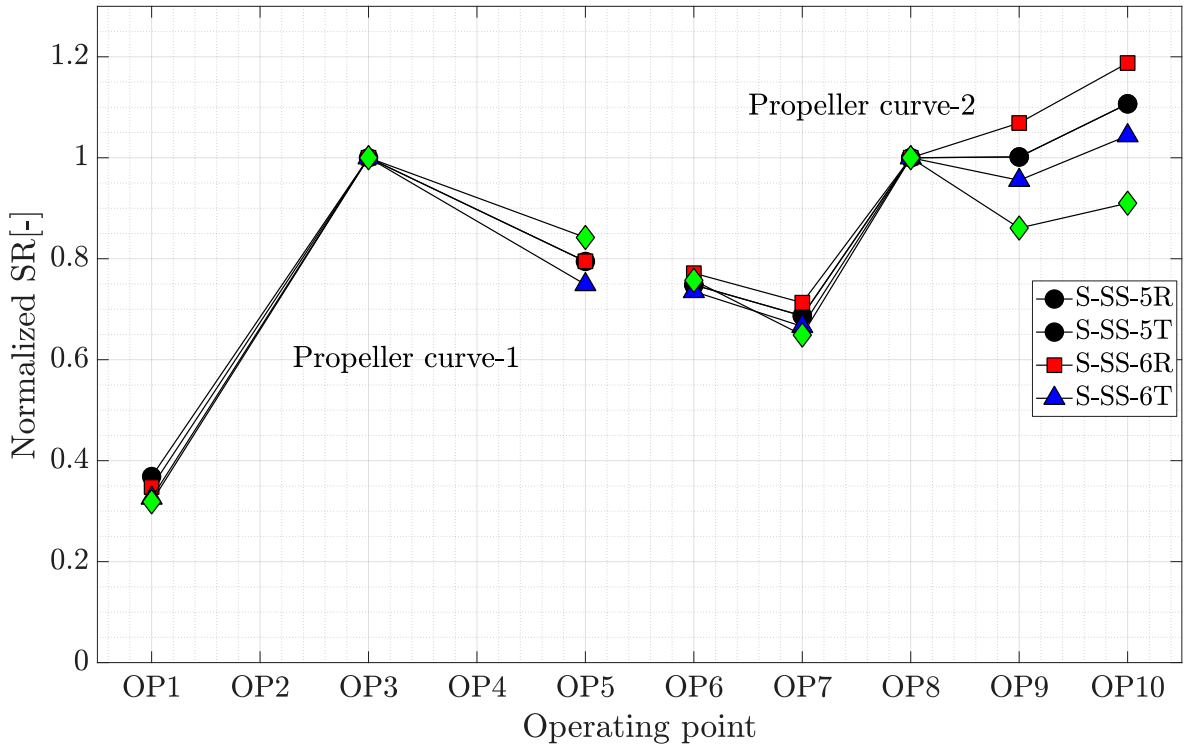
Peak-to-peak amplitude of bending strain

Ratio of peak-to-peak strain amplitude obtained on the runner blade and on the shaft

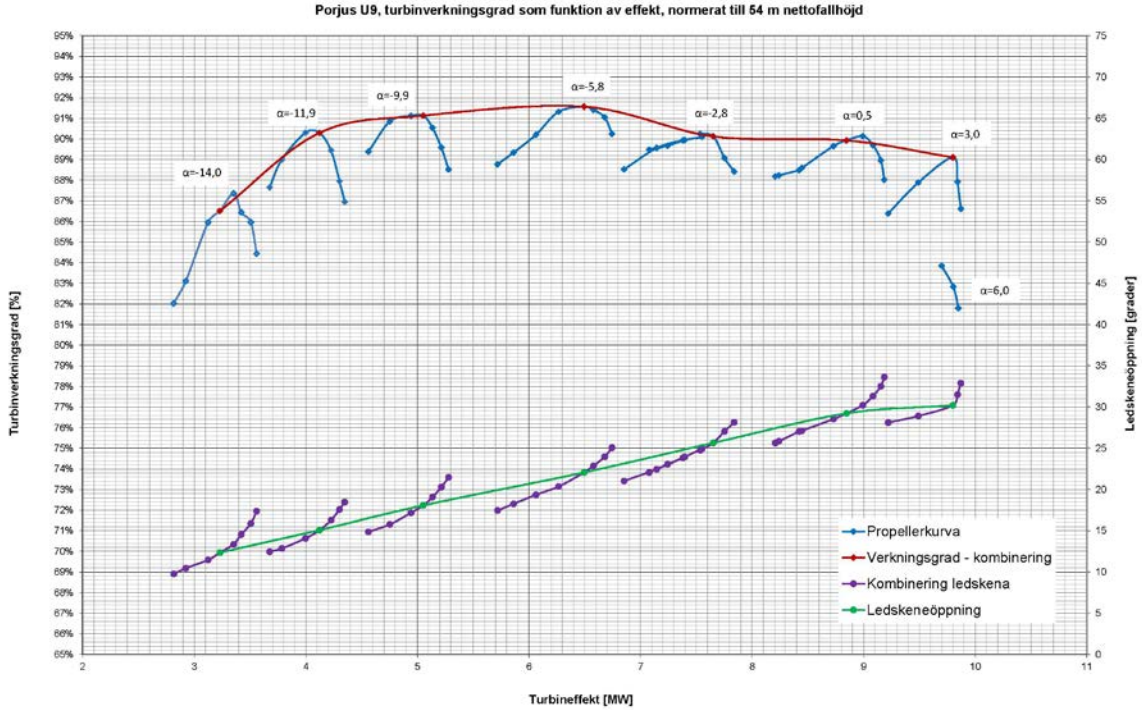
A non-dimensional number (SR) is defined as:

$$SR = \frac{S_{blade}}{S_{torsion}}$$

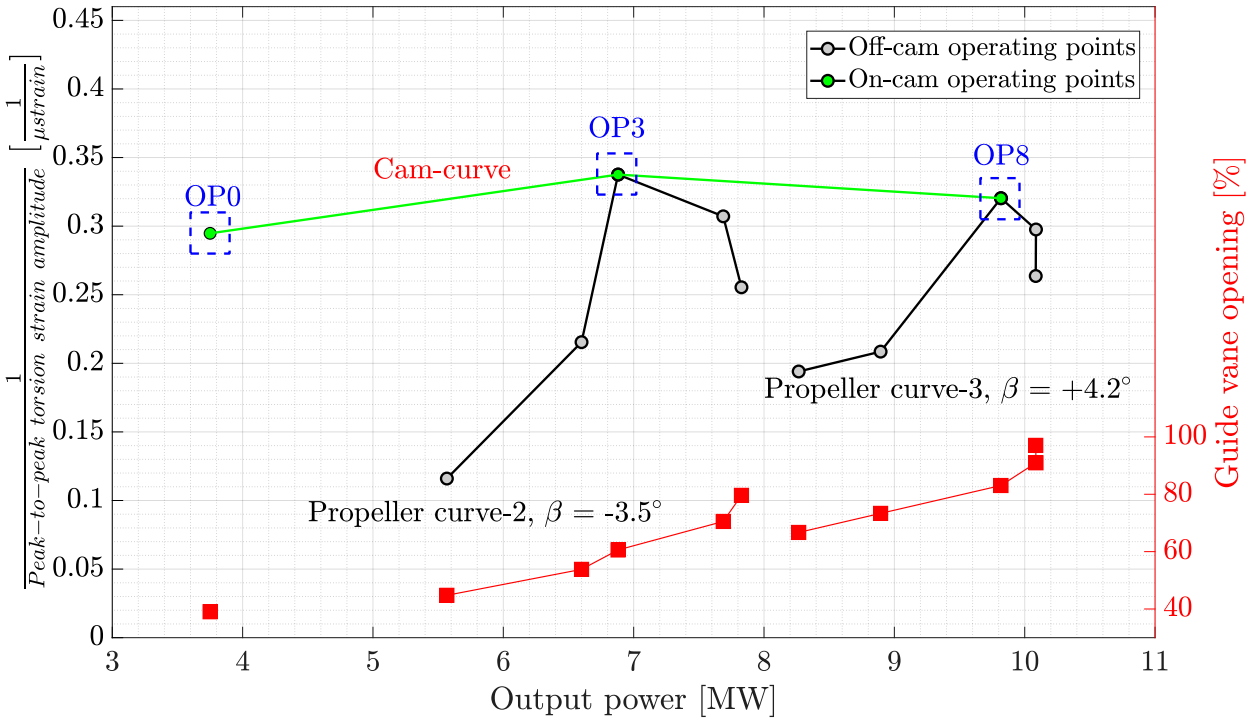
where S is the peak-to-peak strain amplitude.



SR variation at OP0-OP10.



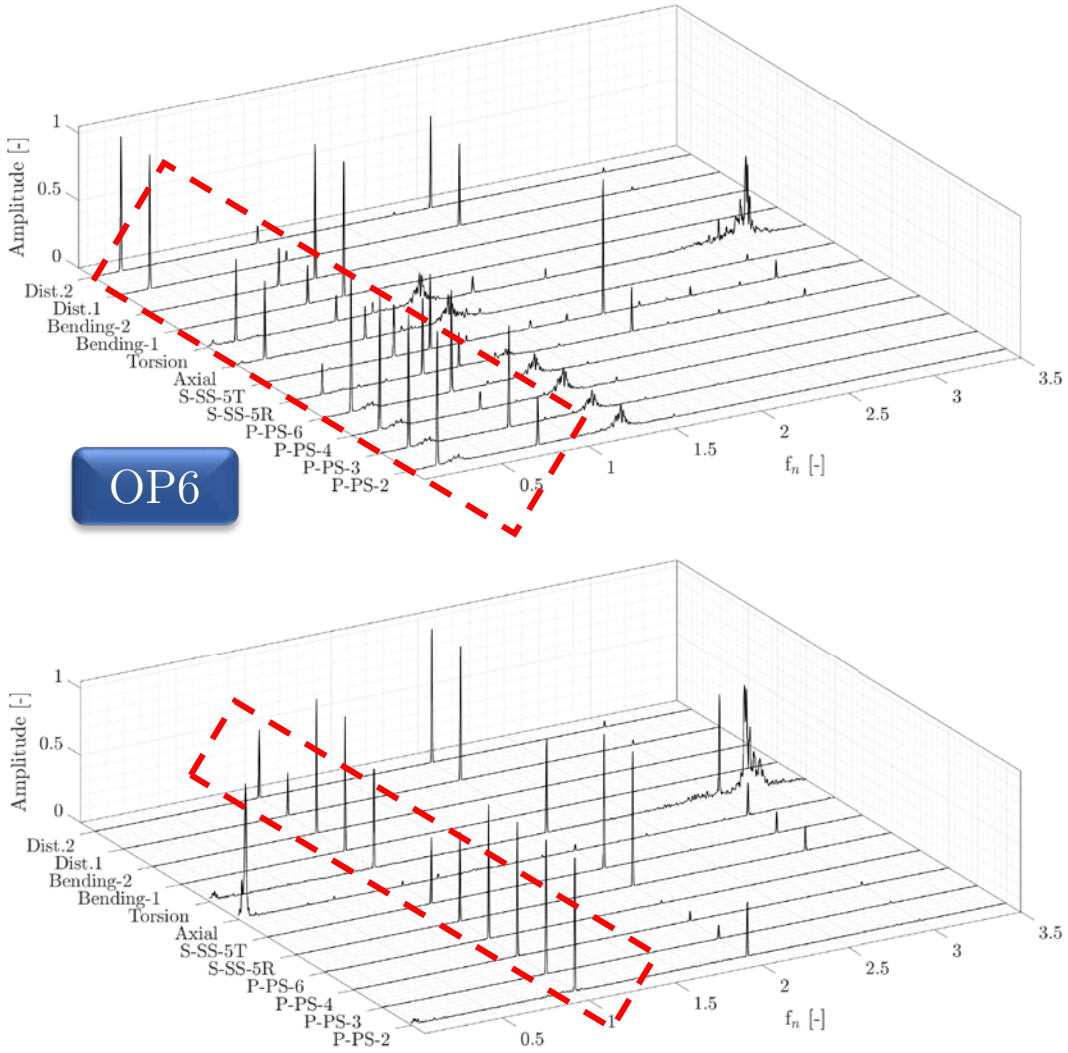
Obtained by Sweco.



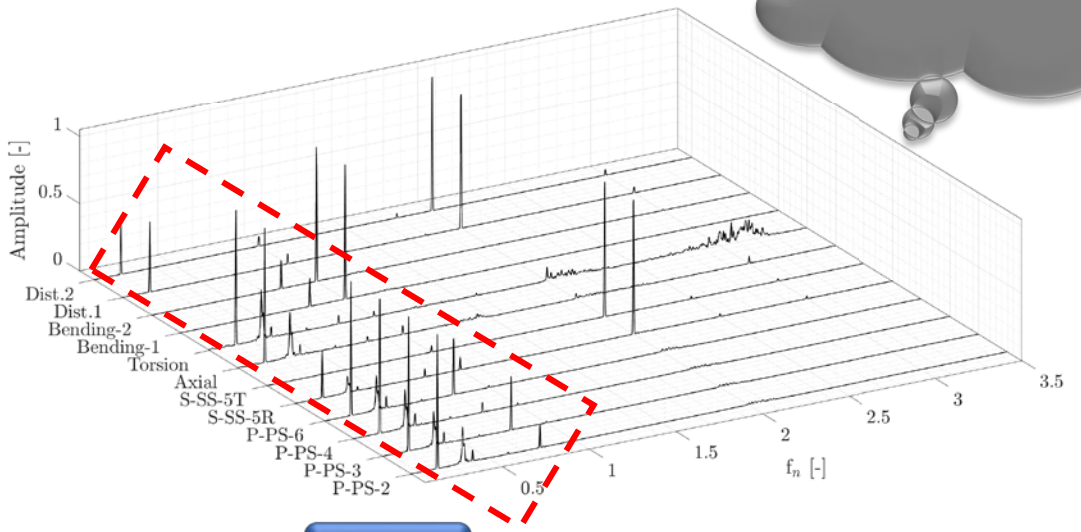
Inverse of peak-to-peak torsion strain amplitude obtained on the shaft as a function of turbine output power. The red line is a hypothetical cam-curve.

Spectral analysis of parameters on the shaft

The amplitudes are normalized.



OP6



OP7

OP10

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).

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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	✓	✓	✓	✓	✓	✓	✓
$f_n = 1$	✓	✓	✓	✓	✓	✓	✓
$f_n = 2$	✓	✓	✓	✓	✓	-	✓
$f_n = 20$	✓	✓	✓	✓	-	-	-

Conclusion

- 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.


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