SCCER SoE Annual Conference 2017

Hes·so VALAIS WALLIS
Haute Ecole d'Ingénierie
Hochschule für Ingenieurwissenschaften

Challenging onboard measurements in a 100 MW high-head Francis turbine prototype

FlexSTOR

Hes·so VALAIS WALLIS
School of Engineering

KWO GRIMSELSTROM

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Swiss Confederation

Commission for Technology and Innovation CTI

<u>Vlad Hasmatuchi</u>
Jean Decaix
Cécile Münch-Alligné

Maximilian Titzschkau

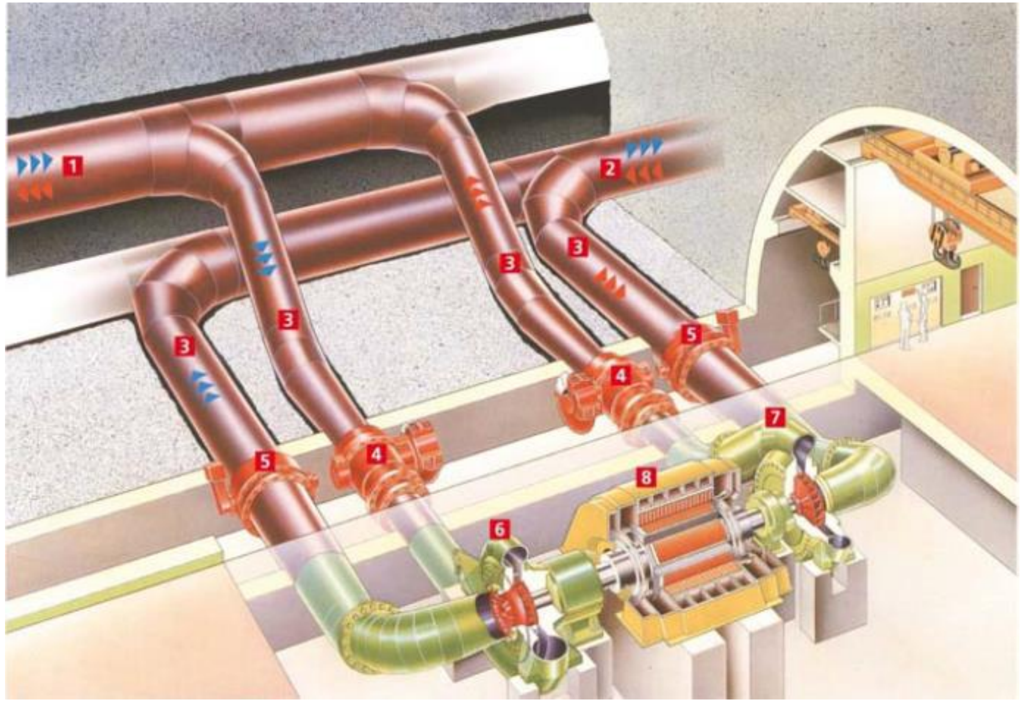
François Avellan

HES-SO Valais-Wallis • rte du Rawyl 47 • C.P. • 1950 Sion 2
+41 27 606 85 11 • info@hevs.ch • **www.hevs.ch**

Birmensdorf - September 15th, 2017

FLEXSTOR - WP6 - Goals & Tasks

Case study: Grimsel II power plant - 100 MW high-head Francis turbine prototype



Source: Schlunegger & Töni, 2013

G6.1 Determination and measurements of the high stresses zones in the turbine

Task 6.1
Definition of the sensor positions using steady numerical simulations

Task 6.2
In-situ measurements on the prototype facility

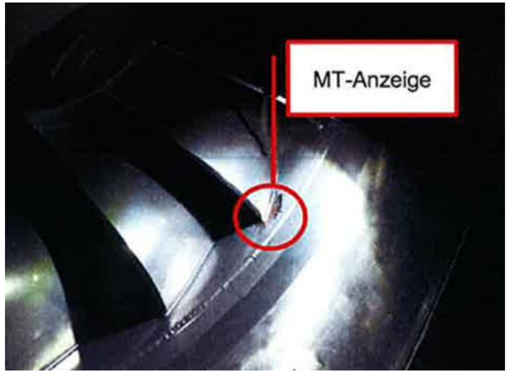
G6.2
Alternative start-up path and stand-by positions

Task 6.3
Proposal of a new start-up path and stand-by position to avoid harmful structural loadings

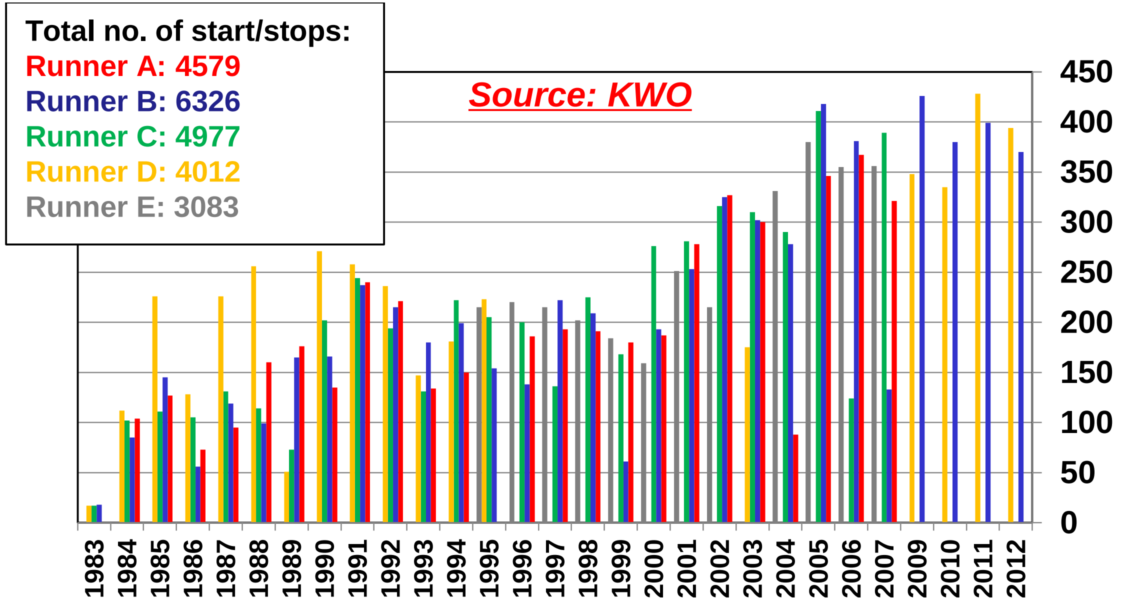
Problematic

- PSPP: subject to increasing number of start/stops
- High-head machines: particular high structural loading during start-up
- Frequent operation under such conditions may conduct to premature fatigue !

- Objective: identification of harmful operating conditions and proposal of a solution to extend the runners lifetime



Source: KWO



Source: KWO

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Applied strategy

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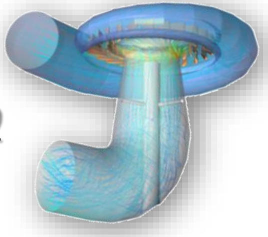
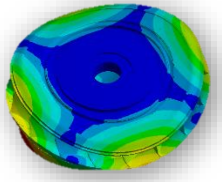
CFD



FEM

RF exp.



SF exp.

1. Identification of harmful sources (start-up, SNL, shut down, BEP and full operating range)

2. Study of an alternative start-up path / SNL OP

3. Tests of the alternative start-up path / SNL OP

Steady flow simulations		Onboard instr. Failed !	SF. instr.	1st campaign (2016)
Unsteady flow simulations	Modal analysis	Onboard instr. successful	SF. instr.	2nd campaign (2017)
	Calculation of stresses			
Unsteady flow simulations				
			SF. instr.	3rd campaign (2018)

Protocol to mitigate harmful operating conditions on different test cases

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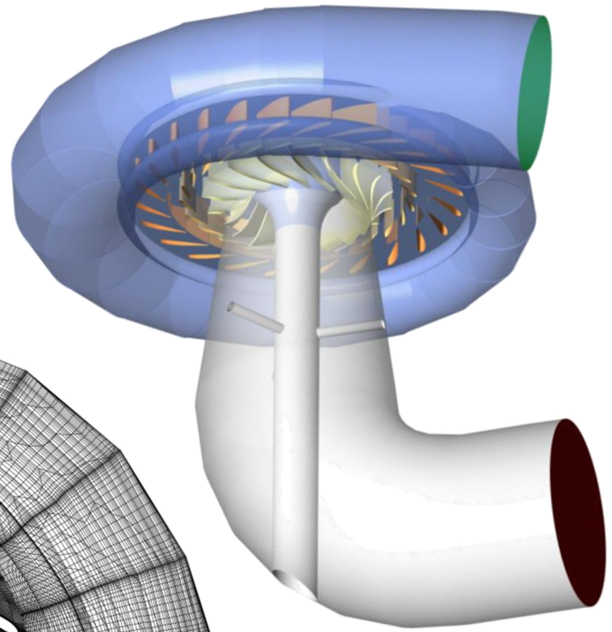
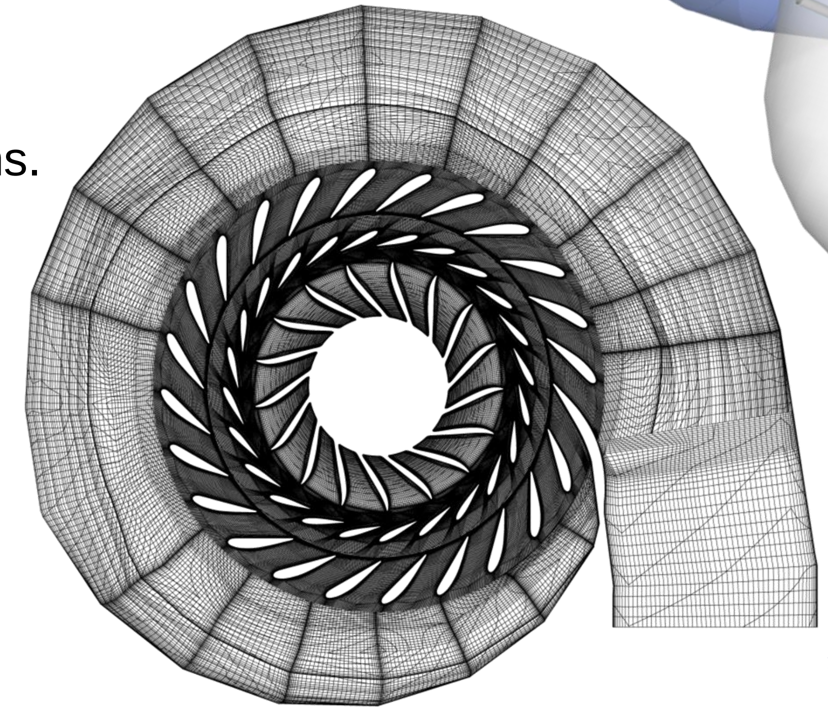
Numerical simulation setup

- Inlet: flow rate or total pressure.
- Outlet: Opening with an averaged pressure.
- Solid: no slip wall.
- Runner domain: rotational velocity N = 750 min^{-1}.
- Frozen/Stage interface.
- SST k-ω turbulence model.
- Number of iterations: 1'000.
- High order scheme for the mean flow equations.
- First order scheme for the turbulent flow equations.

Part	No. of nodes	No. of elements
Inlet	207'000	197'000
Spiral Case	3'528'000	3'432'000
Stay Vanes	2'920'000	2'753'000
Guide Vanes	3'723'000	3'538'000
Runner	2'786'000	2'637'000
Draft tube	1'574'000	1'534'000
Total	**14'738'000**	**14'091'000**





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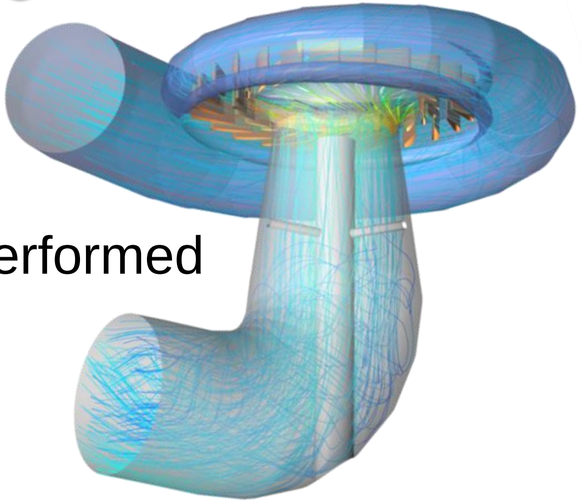
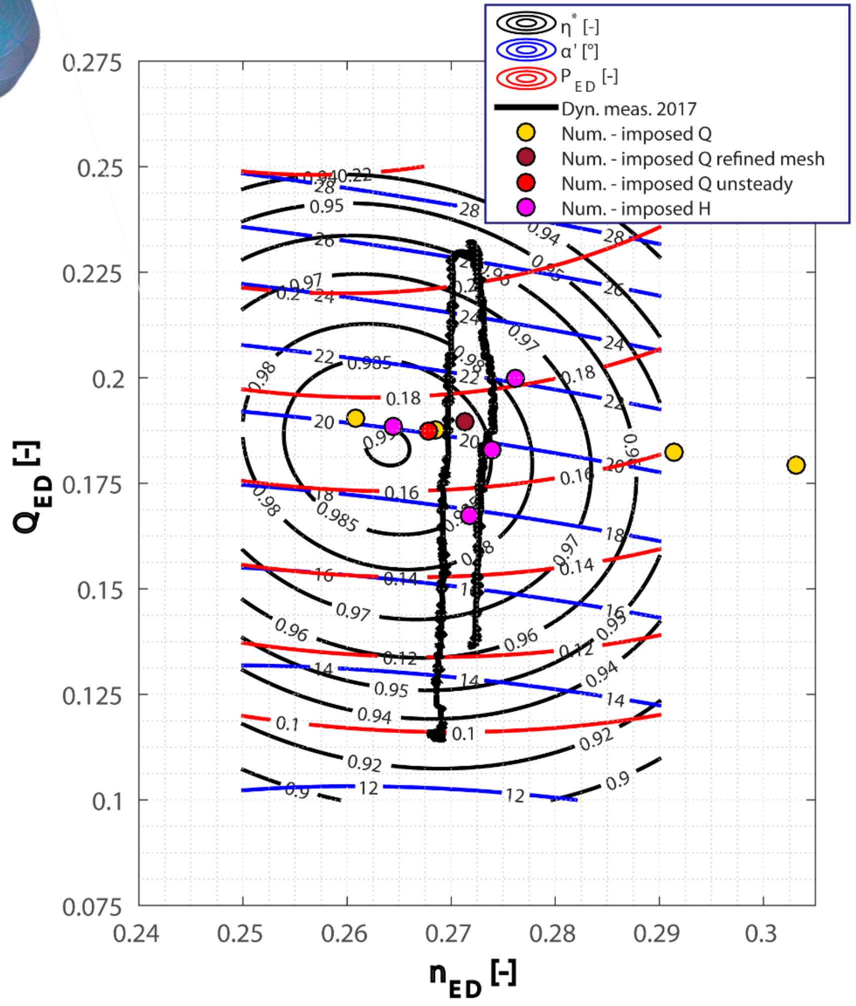
Numerical simulation results

- ✓ Several steady and unsteady numerical flow simulations already performed
- ✓ Numerical setup ready for simulation of an off-design operating point



Boundary conditions	Simulation	Mesh	α [deg]	Q [m³ s⁻¹]	H [m]	P_{mec} [MW]	H [-]
Imposed mass flow rate	Steady	Coarse	20	17	302	45	0.91
				18	327	53	0.92
				20.1	385	72	0.95
				21	408	79	0.95
	Steady	Refined	20	20.1	377	69	0.94
	Unsteady	Coarse	20	20.1	387	72	0.95
Imposed Head	Steady	Coarse	20	19.2	370 (380)	67	0.94
				20.5	397 (410)	74	0.94
			18	17.7	376 (380)	61	0.95
			22	20.8	364 (380)	69	0.92



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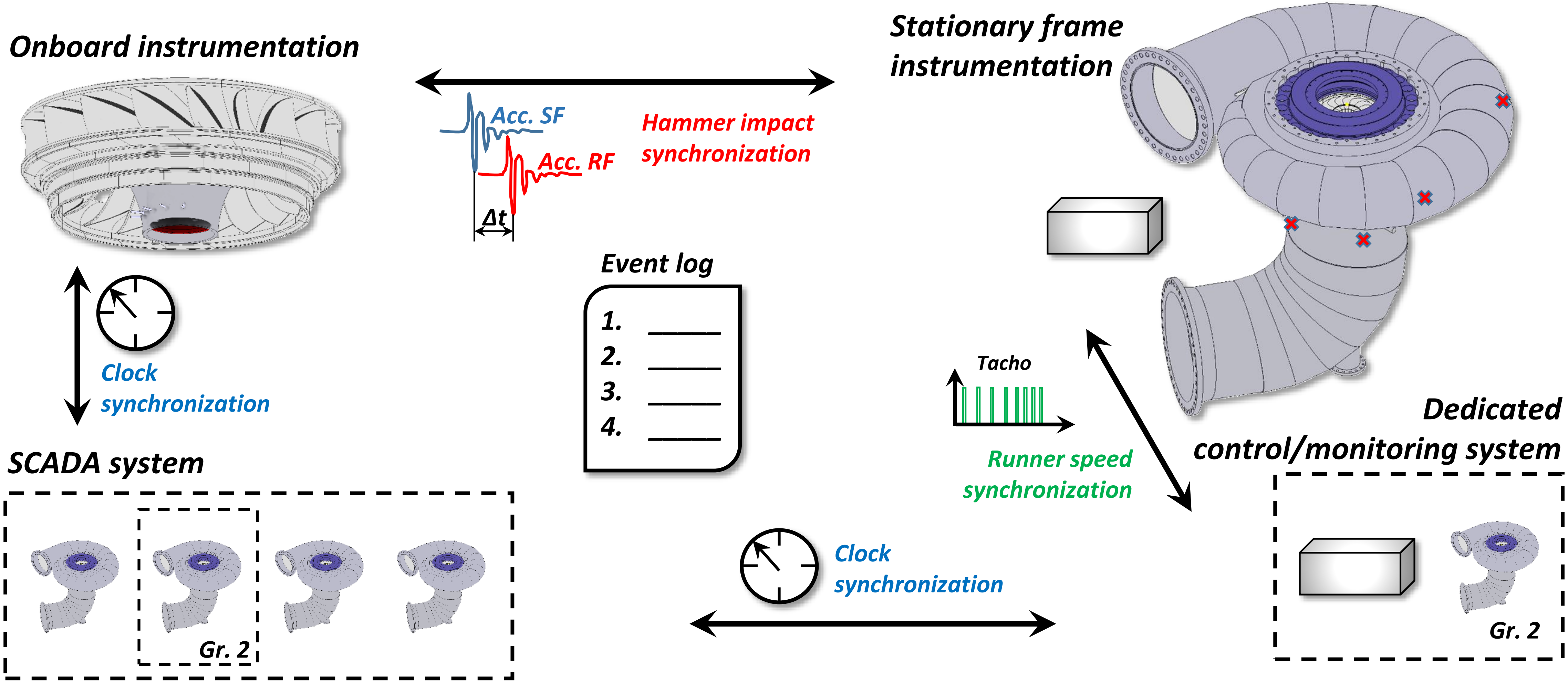
Experimental instrumentation architecture



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Onboard system – challenges

- ✓ Relatively high static pressure operating conditions: up to 17 bars
- ✓ Important centrifugal forces: runner speed of 750 rpm
- ✓ Particular geometrical configuration of the machine:
  - Horizontal axis shaft: requires a robust fastening of components inside the chamber
  - Presence of a central tube inside of the diffuser: impossible frontal access to the instrumented chamber
  - Impossibility to communicate with the system from outside during the operation:
    - Autonomous power supply (high-capacity batteries)
    - Autonomous continuous acquisition of signals
    - Autonomous remote data storage

Onboard instrumentation

1x Gantner Q.brixx acquisition system

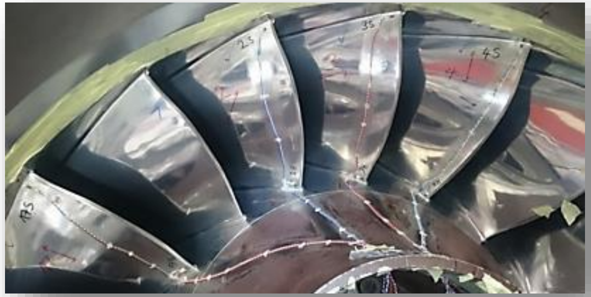
2x 21 Ah, 22.2 VDC LiPo batteries

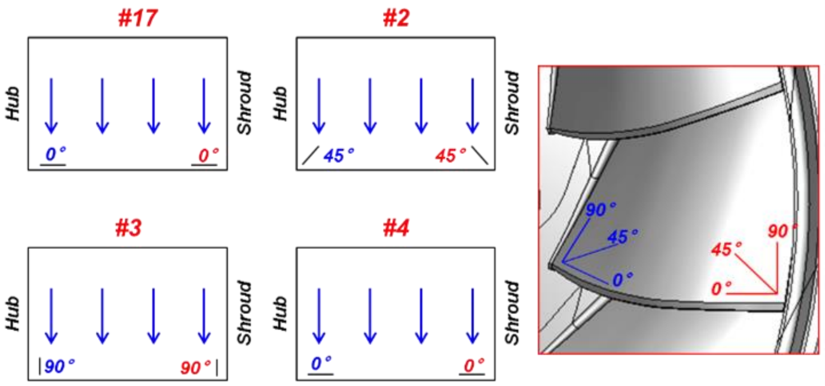
1x power supply protection electronics

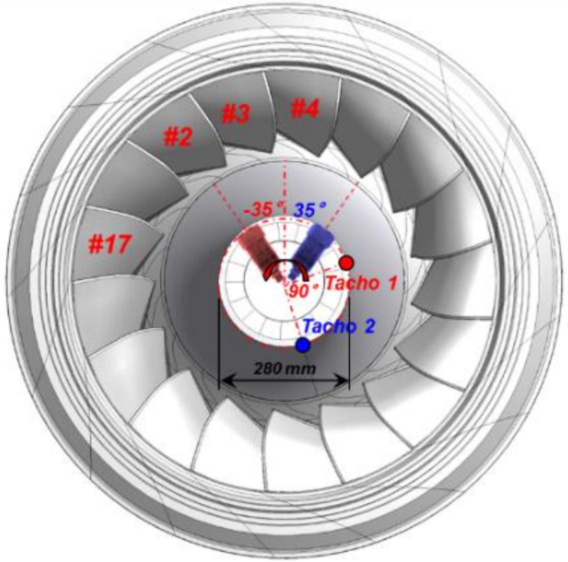
8x quarter bridge strain gauges

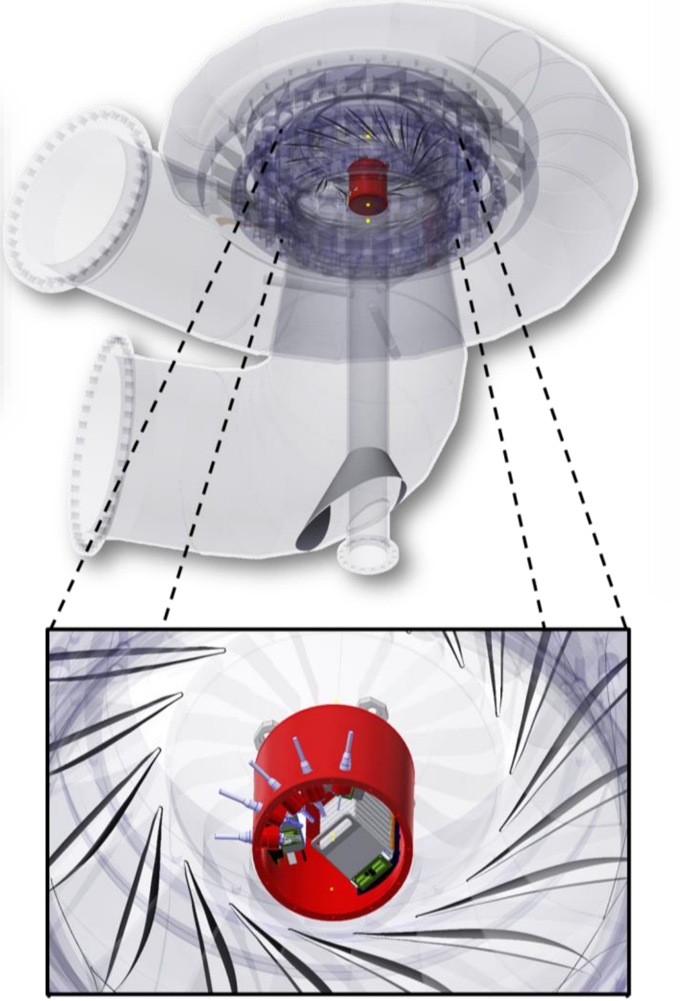
2x single-axis IEPE accelerometers

2x inductive tachometers









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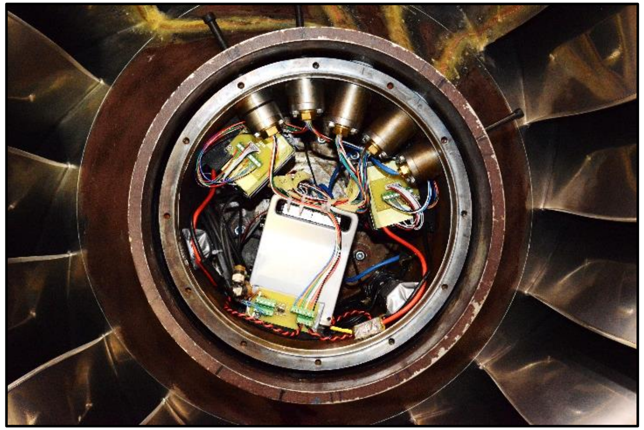
Onboard instrumentation

- Main features:
  - Autonomous multichannel synchronous 10 kHz continuous acquisition
  - Data storage capacity: 2xUSB 16GB
  - Autonomy of power supply : > 20h
  - Protection relay against deep discharge of the batteries
  - Waterproof connectors ensuring data downloading, fast controlled recharging of batteries and system power switch on/off



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Rotating/stationary frames synchronization

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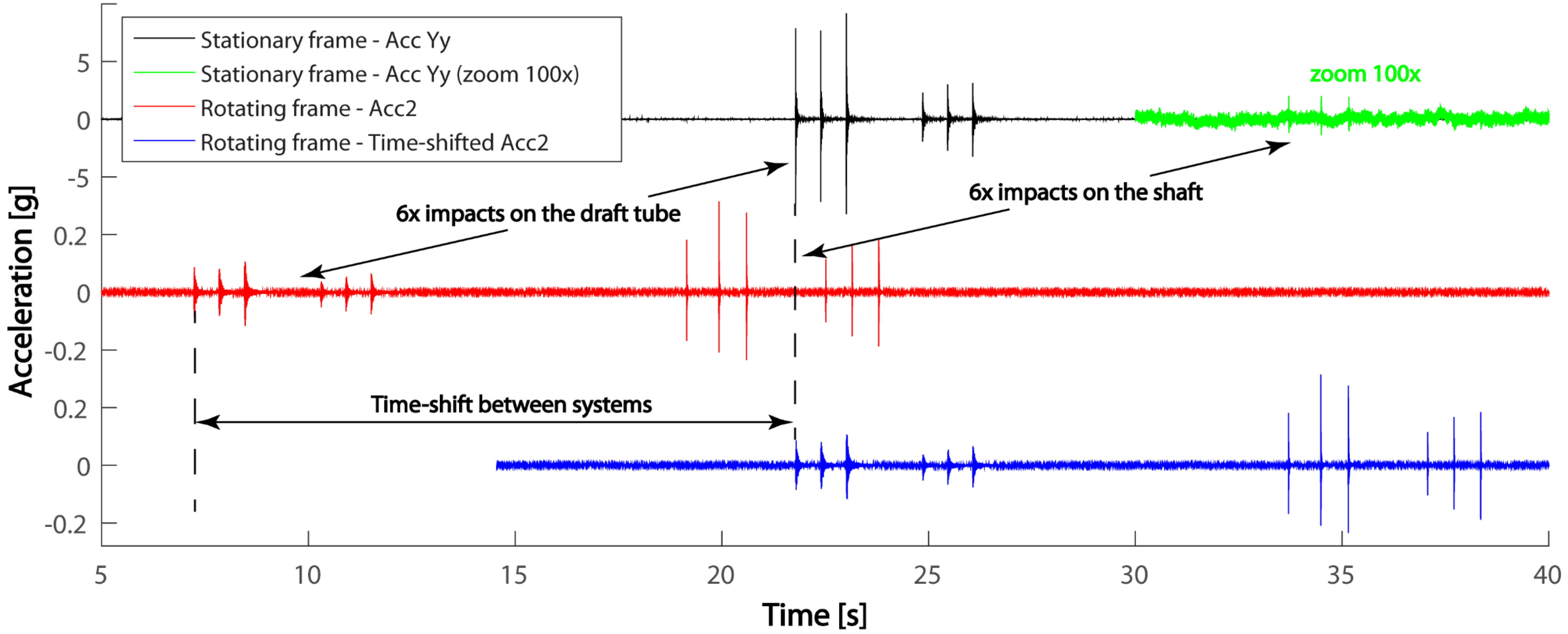
✓ Based on hammer impacts detected by the employed accelerometers



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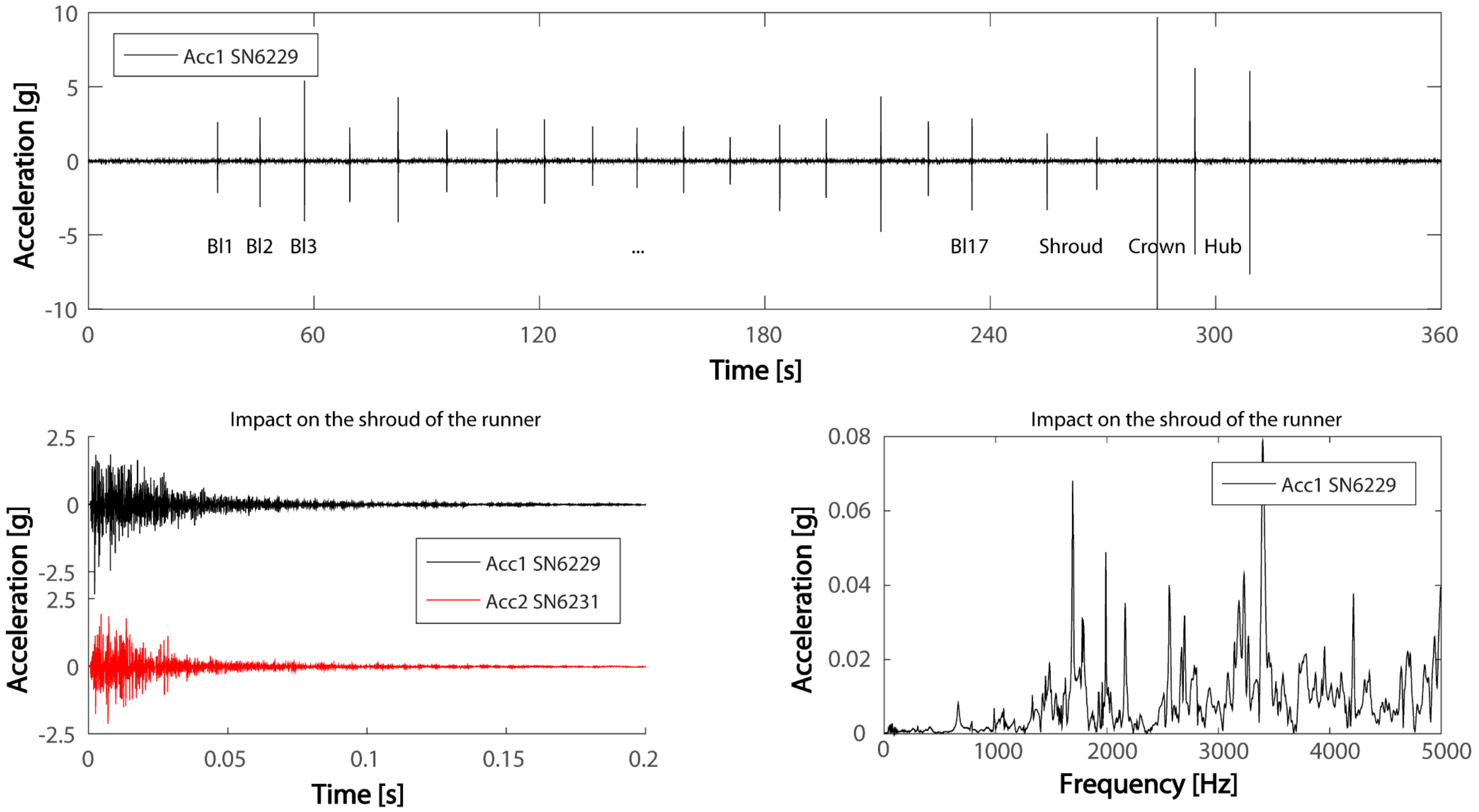
Basic modal analysis (in air) of the runner



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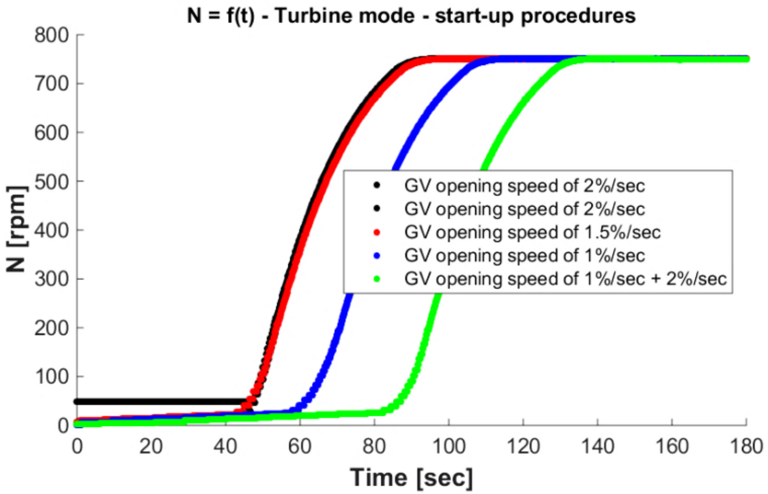
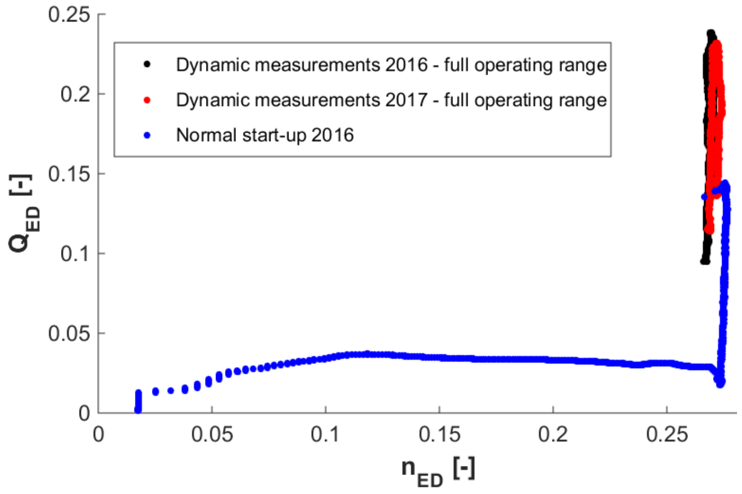
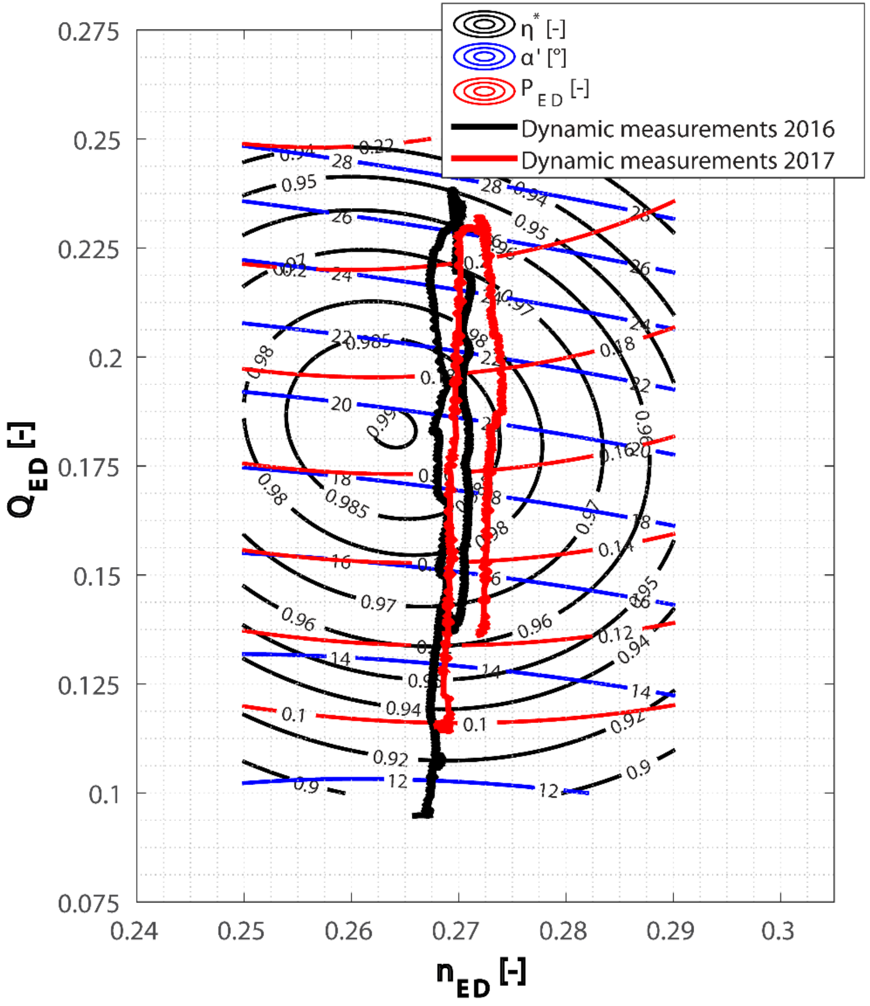
Tested operating conditions

- ✓ Normal turbine operation
- ✓ Deep part-load operation
- ✓ Normal turbine start-up:
  - GV opening speed of 2%/sec
- ✓ Modified slower turbine start-up:
  - GV opening speed of 1.5%/sec
  - GV opening speed of 1 %/sec
  - GV opening speed of (1 + 2)%/sec
- ✓ Normal pump start-up







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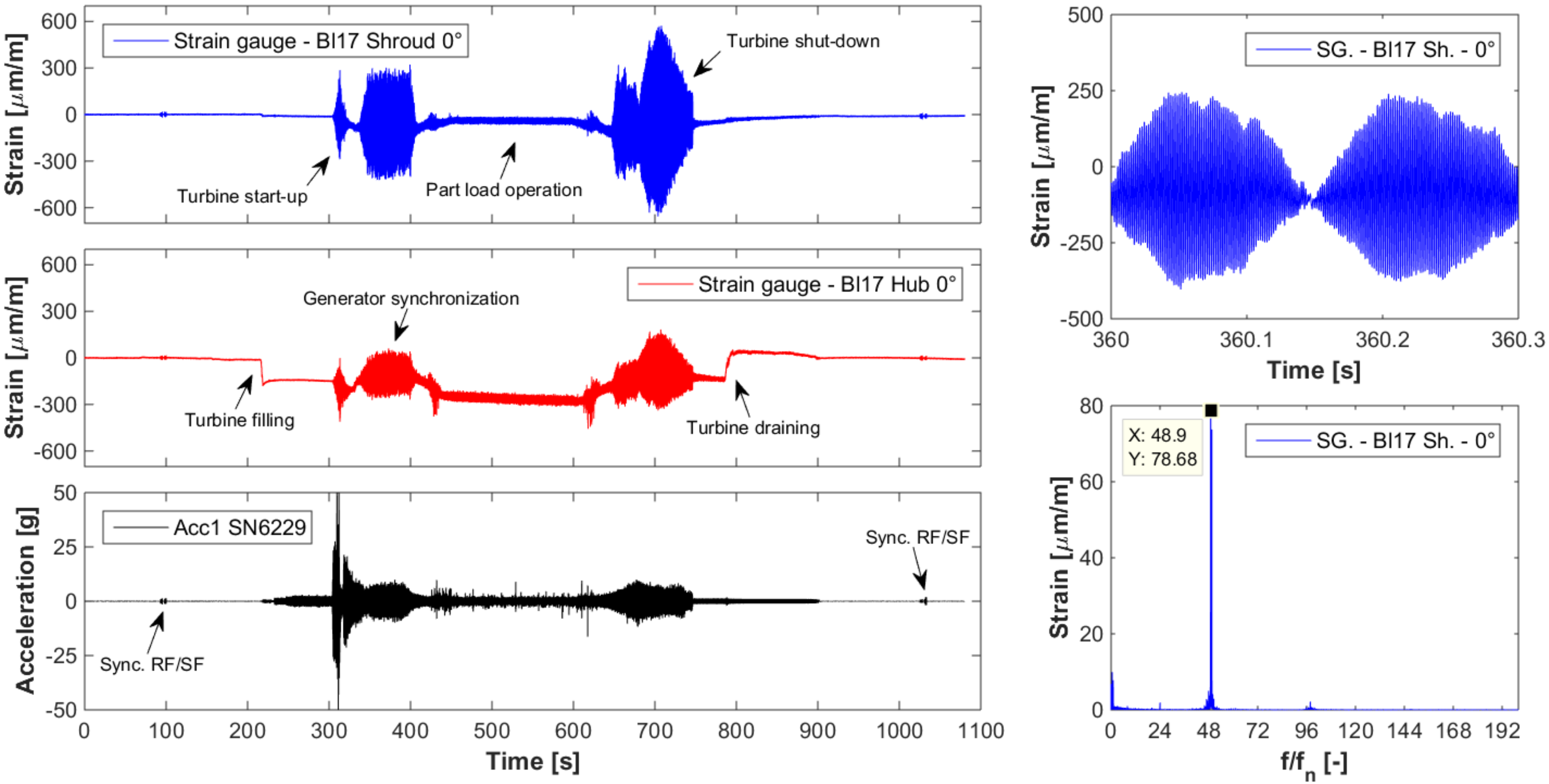
Evidence of harmful structural loading



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Conclusions & Perspectives

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- ✓ Successful challenging onboard measurements in a 100 MW high-head Francis turbine
- ✓ The SNL operating conditions encountered for several tens of seconds during each start-up and shut down procedures seems to be the main source of fatigue (also noticed in Gagnon et al. 2010)
- ✓ Seek for a feasible simple technical solution to reduce the harsh structural loading on the turbine runner during start-up and shut down procedures
- ✓ Setup of a 3rd experimental campaign using only simplified instrumentation to test the new proposed start-up method(s)
- ✓ Establishment of a diagnosis protocol based on a simplified instrumentation set to identify harsh operating conditions on different hydropower units

Acknowledgements

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Haute Ecole d'Ingénierie
Hochschule für Ingenieurwissenschaften

Development team of FLEXSTOR - WP6 (CTI no. 17902.3 PFEN-IW-FLEXSTOR)

HES-SO VS: V. Hasmatuchi, J. Decaix, C. Cachelin, O. Walpen, L. Rapillard, C. Münch-Alligné

EPFL-LMH: A. Renaud, F. Avellan

KWO: M. Titzschkau

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