Le stockage d'énergie au Portugal : la flexibilité au service de la variabilité

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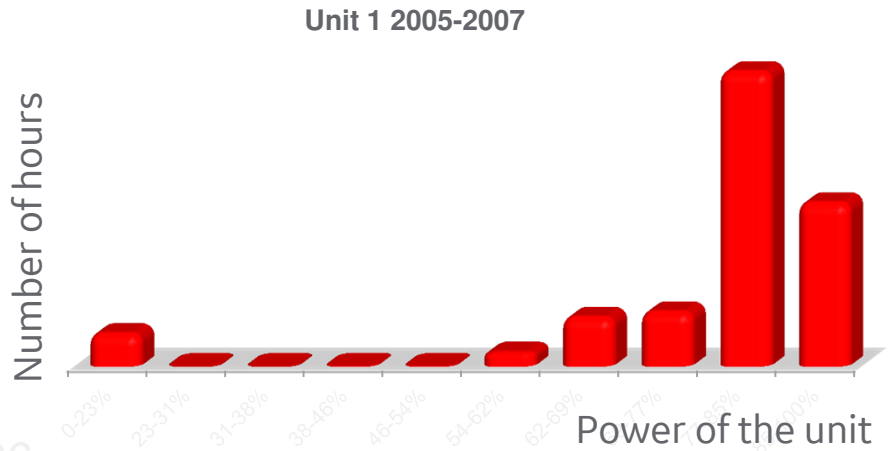
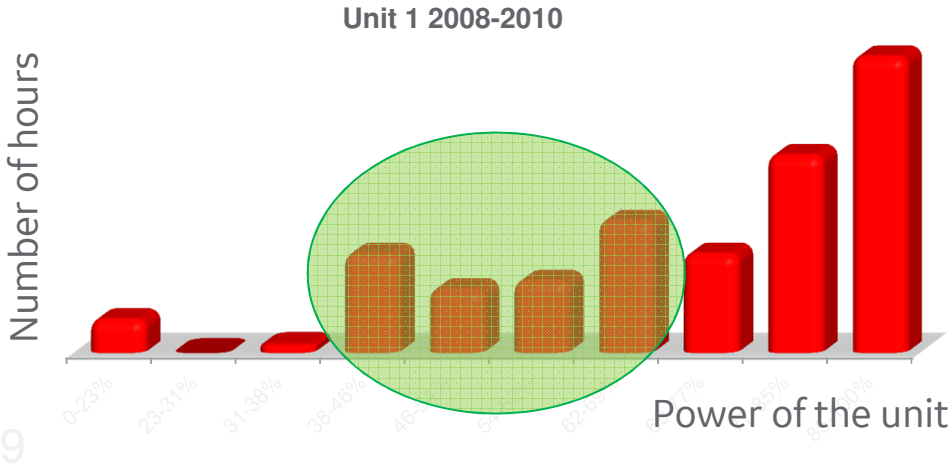
Hydro 21, Grenoble **4 Novembre 2016**

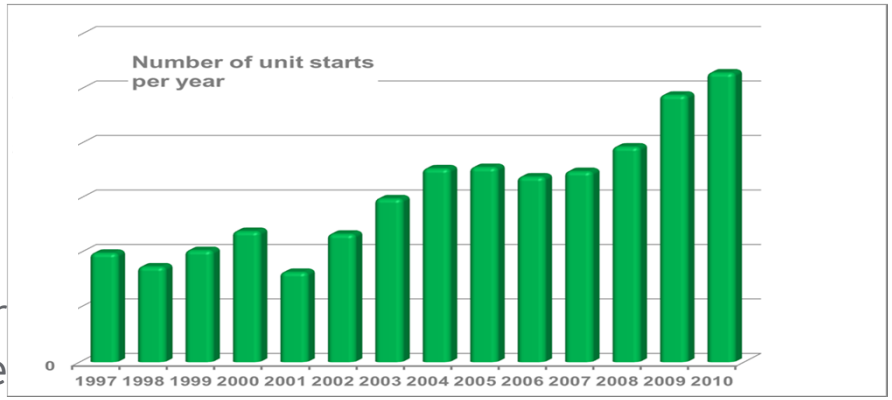
Power regulation need increases

Range of operation of a pump-turbine





Number of Startup / year of a pump-turbine

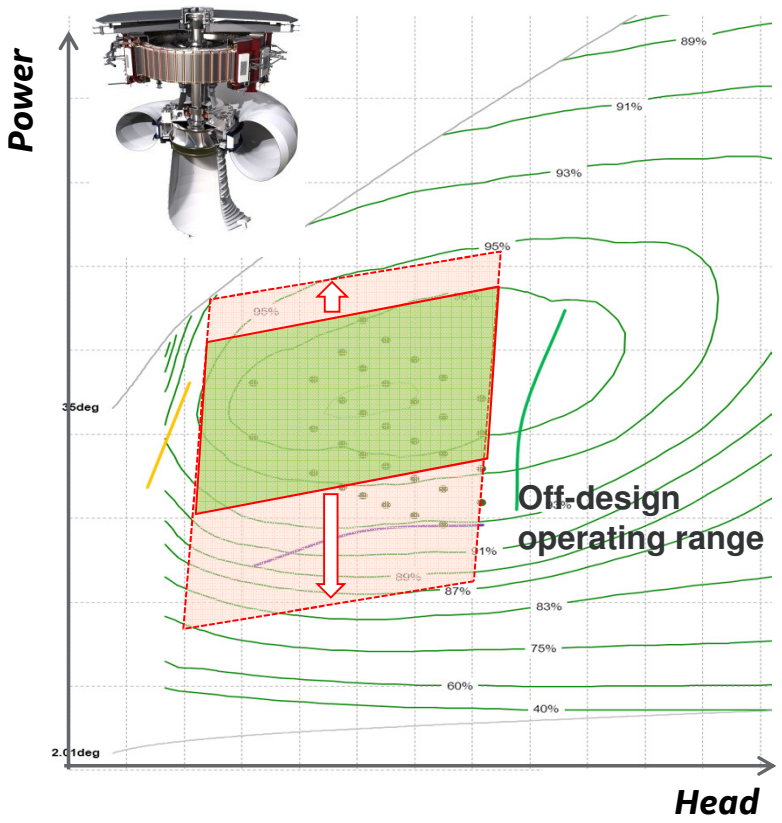


Flexibility: a modern-market requirement

- Increased share of non-dispatchable sources such as wind/solar adds intermittency to the grid
- Flexibility and short response time of power generation offer benefits on the intraday electricity market

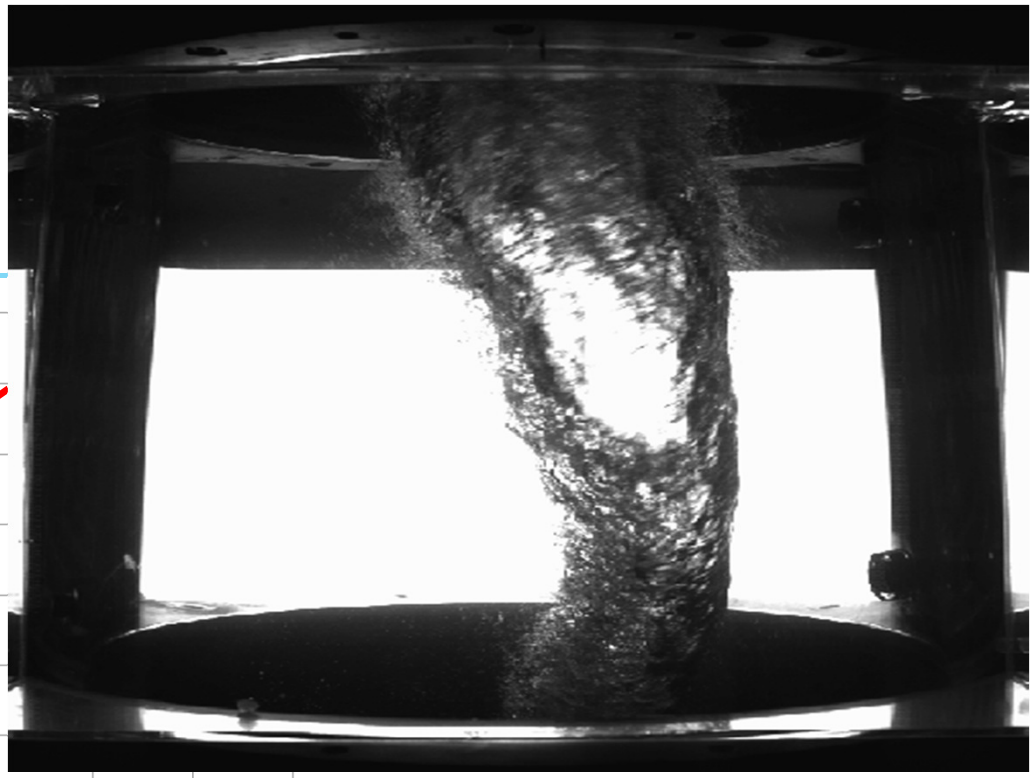
Strong incentive to extend the operating range of hydraulic machines and to increase the number of starts and stops

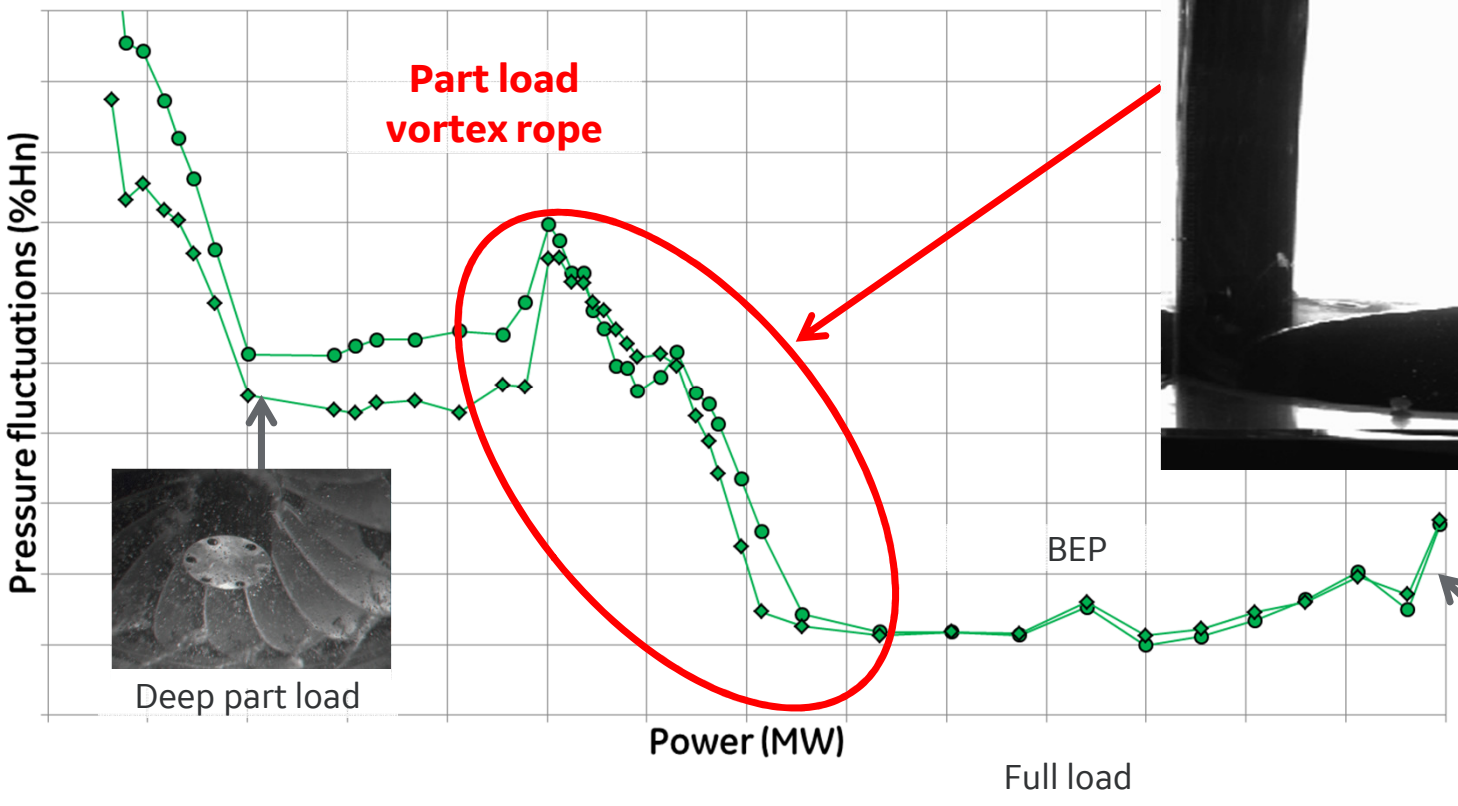
Cost of operation (fatigue, maintenance) at off design not fully known

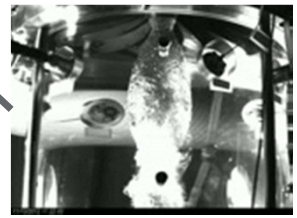


It was off-design for a reason !

Hydraulic phenomena challenge turbine operation

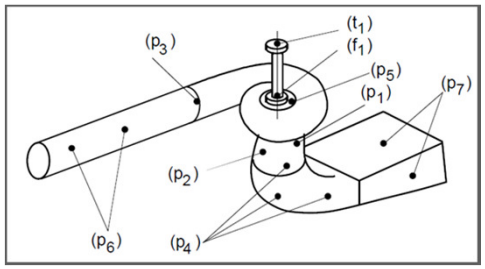


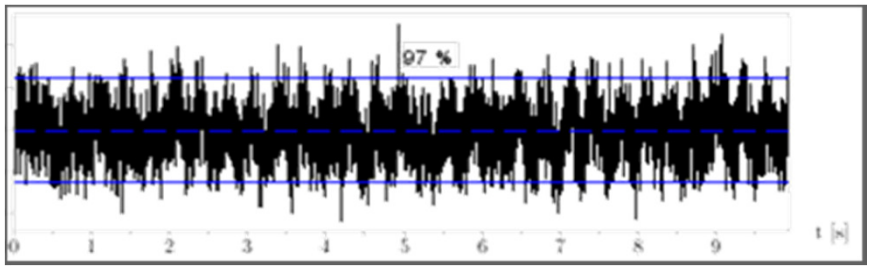




Stability evaluation: today's approach

Pressure pulsation level of individual pressure sensors in stationary frame





Major drawback:
no indication about actual risks
(life time, power stability…)

Flexible Solutions

Partial load operation

Case study

ALQUEVA Hydro Power Plant

	Alqueva I	Alqueva II
N_{proto} : Rotational speed (rpm)	136.4	136.4
D_{proto} : Runner high pressure diameter (m)	6,009	6,048
Pump: delivery net head (m) max/min	72.3 / 45.9	73.5 / 53.0
H_0 : Turbine rated net head (m)	71.1	72.0
P_0 : Turbine rated output (MW)	129.6	133.6
nq : Specific speed	72	72
Number of units	2	2

Partial load operation

Case study

SALAMONDE II – PUMP STORAGE UNIT

General Characteristics	
Construction works (started)	2010
Year of commissioning	2015
Installed capacity	207 MW
Annual Average Capacity	274 GW.h
Rotational speed (rpm)	166.7
Runner high pressure diameter (m)	4.330
Pump: delivery net head (m) max/min	128.3/109.2
Turbine: rated net head (m)	118.0
Turbine: rated output (MW)	208.9
Specific speed (nq)	53.2
Number of units	1

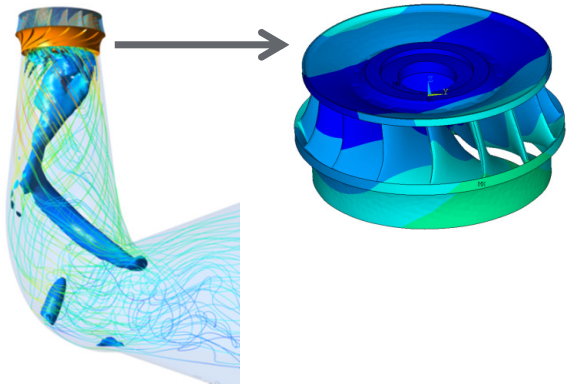
Complementary simulation and testing

Numerical simulation

Unsteady CFD and FEA to model hydraulic and mechanical behavior

Balancing between two targets at design stage

For validated application range: fast and reliable



Reduced scale model testing

Instrumented runners respecting hydraulic and mechanical similitude

Mechanical information for the entire operating range, at design stage

On-site measurement

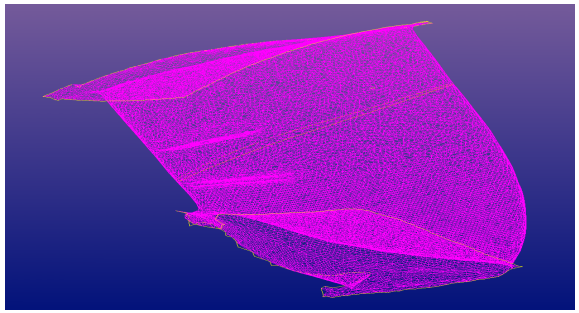
Prototype data without model uncertainties or transposition issues

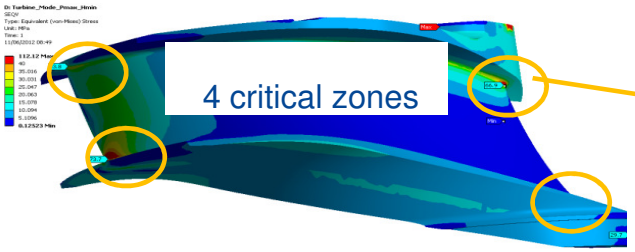
Validation of mechanical model test

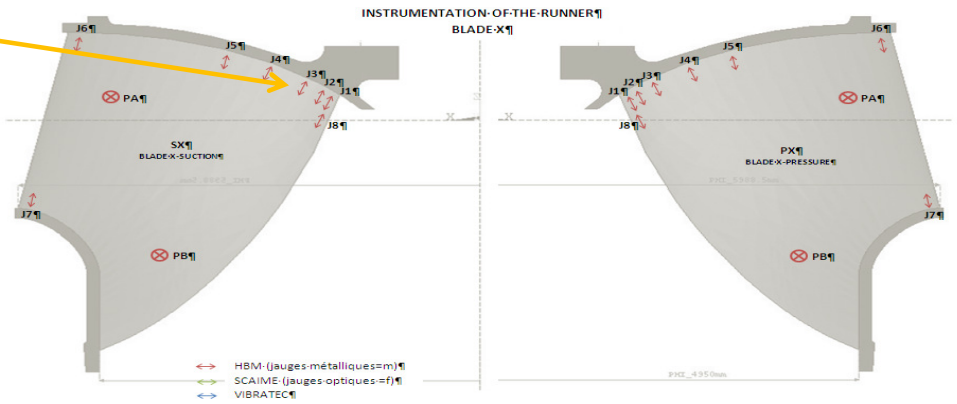
Limited flexibility with respect to operating range

Step 1 : digital twin (facsimile) of the runner blades

Compute the twin to define the places where stresses will be high, which will be the locations where to install the strain gages







Criteria for gages location:

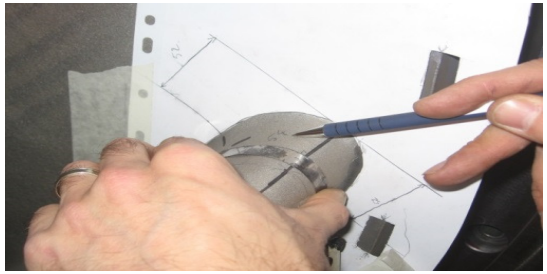
⇒ **As close as possible to max stress locations**

⇒ **A few other at safe locations (low stress, no cavitation) for reference**

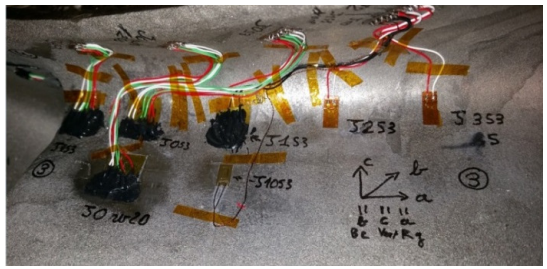
Digital twin is GE know how

Step 2 : instrument the runner

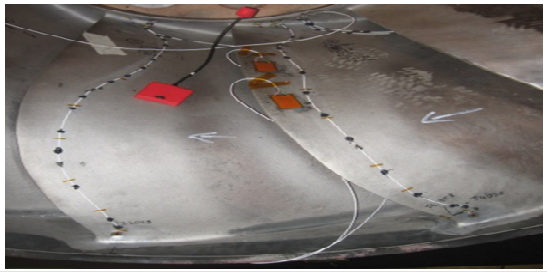
1. **Gages pattern design**



2. **Gages bonding**



3. **Cabling**

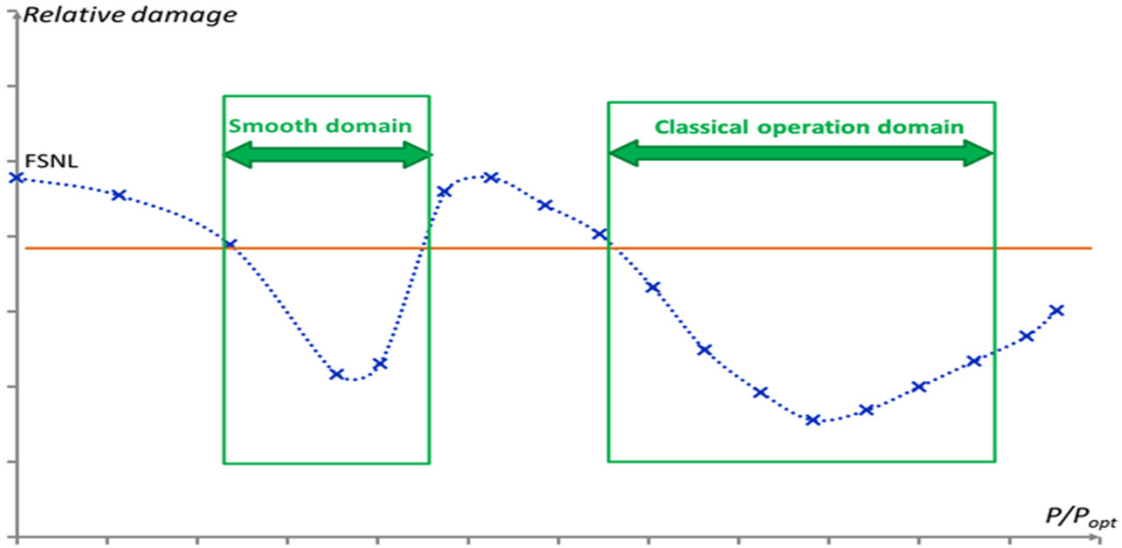


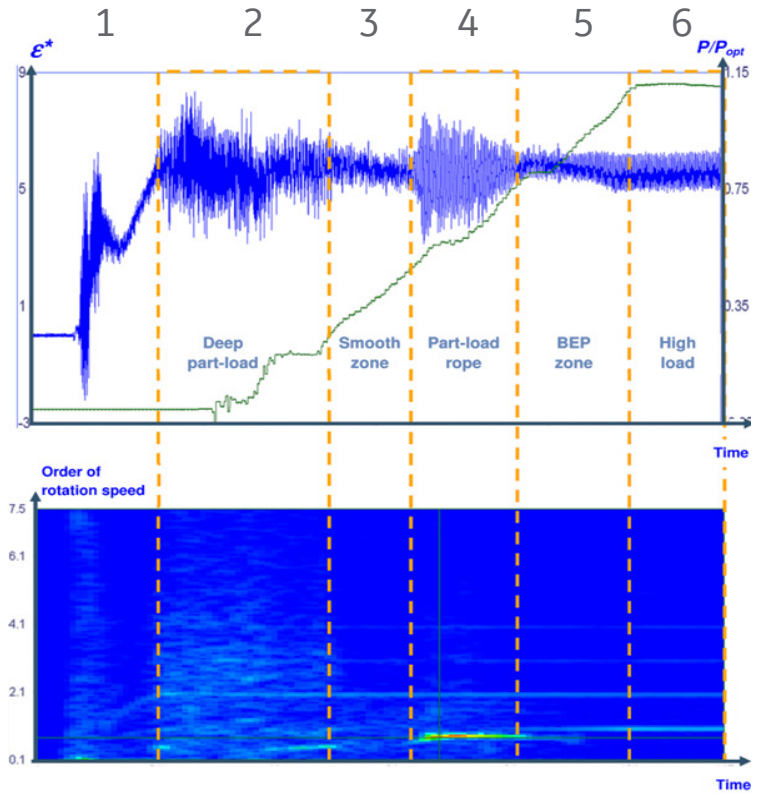
4. **Protection**

GE experience

Dynamic stress and hydraulic operating point

Stress measurement on prototype during load ramp





For the tested head, it was already clear that there was a possibility to extend the operating area where the stresses were not higher than in the initial operating area

Numerical simulation possible for some cases

CFD – hydraulic behavior

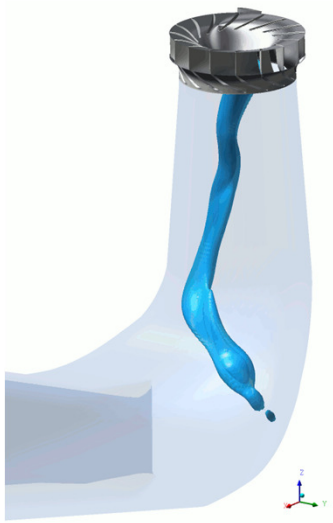
Unsteady calculation to predict part load vortex rope

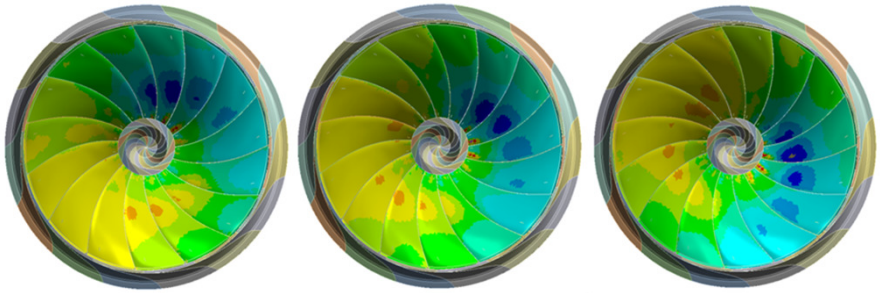
Pressure fields acting on runner are exported and used as FEA input

FEA – mechanical behavior

Full runner geometry used

Successive time steps calculated using CFD pressure fields to calculate the dynamic stresses

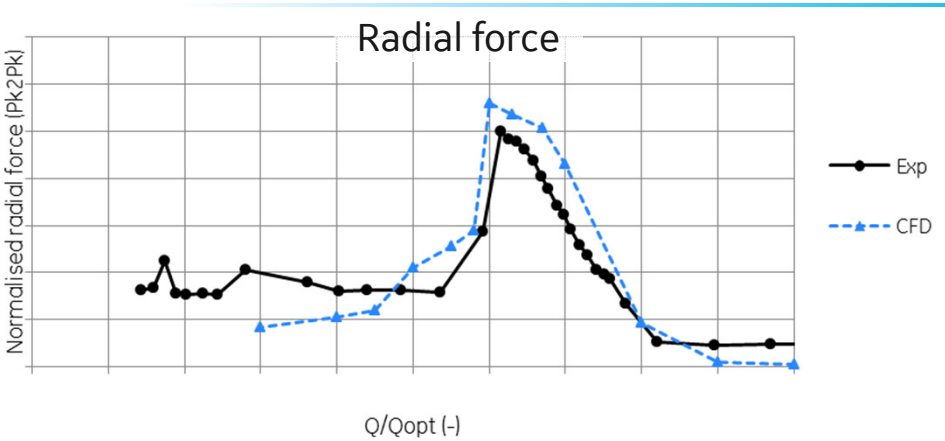


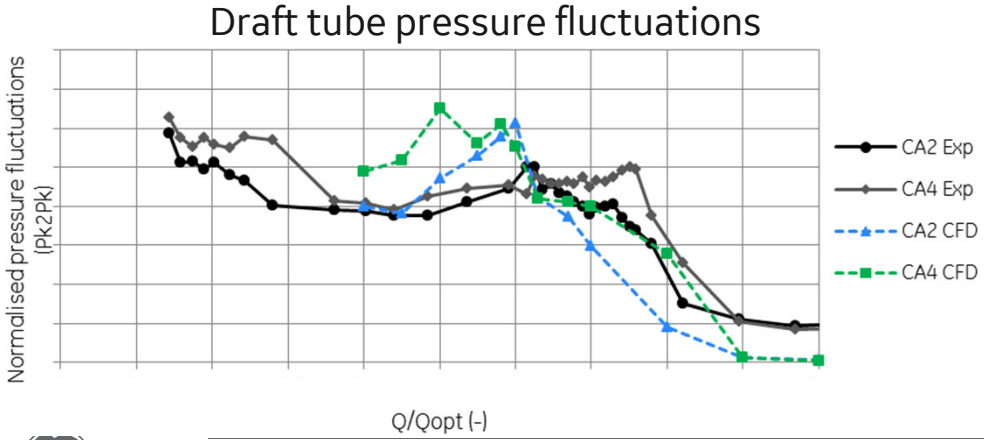


Three consecutive dynamic pressure fields – movement of the vortex rope visible

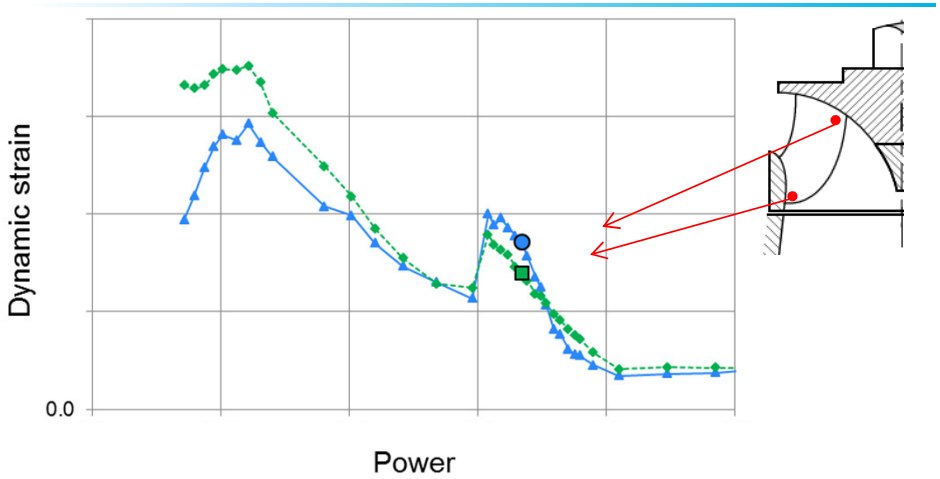
Results

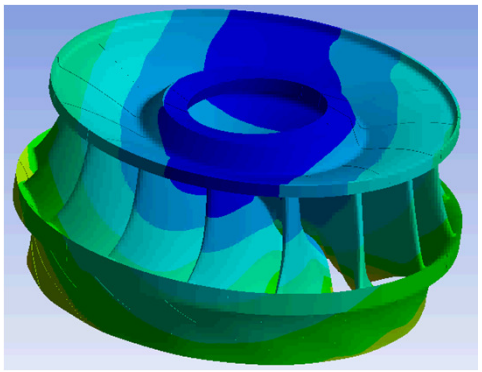
CFD

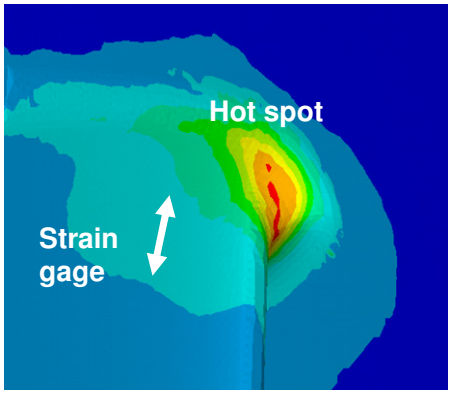




FEA

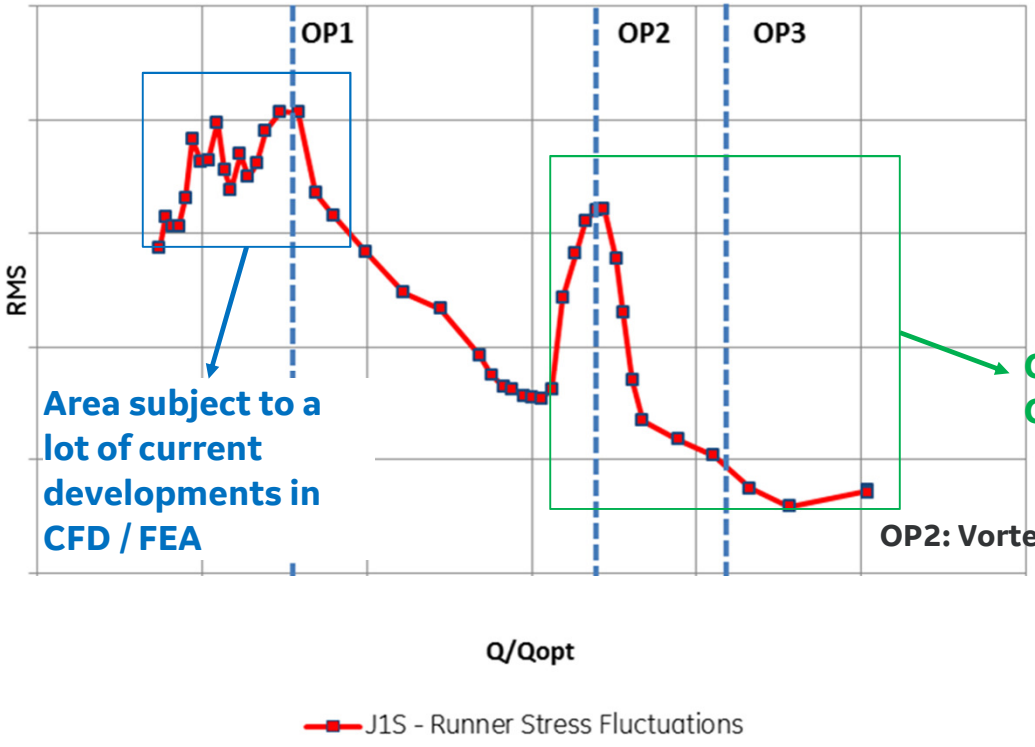


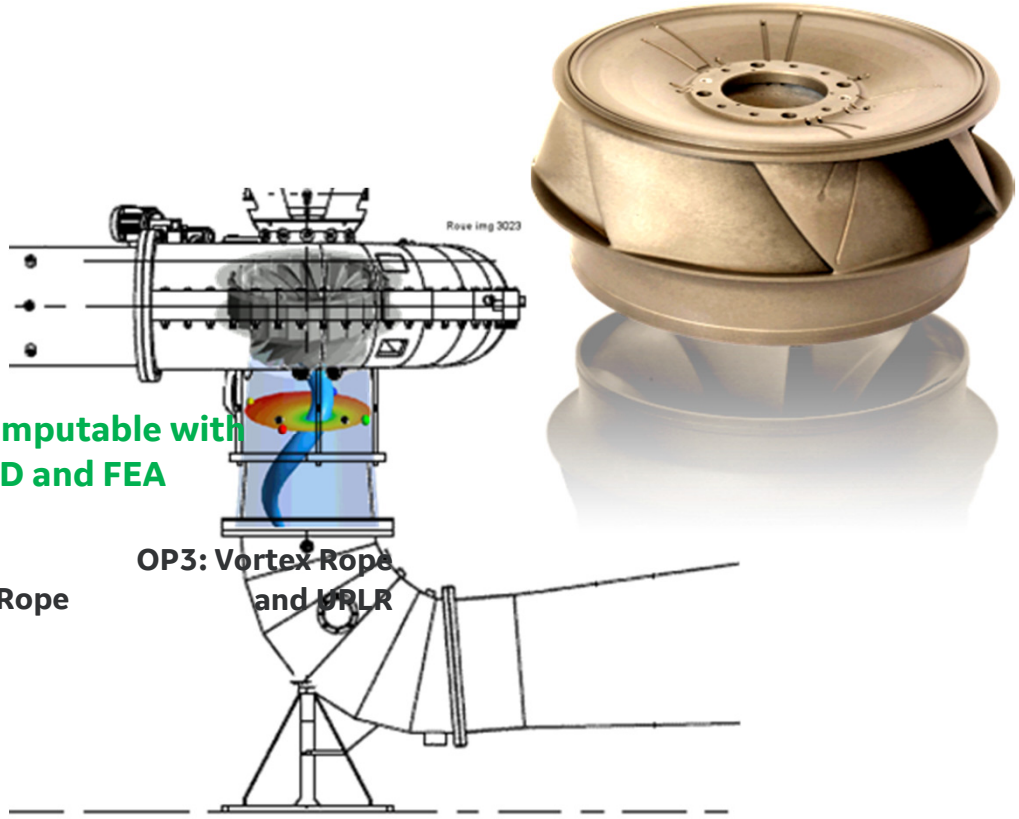




Reduced scale model testing

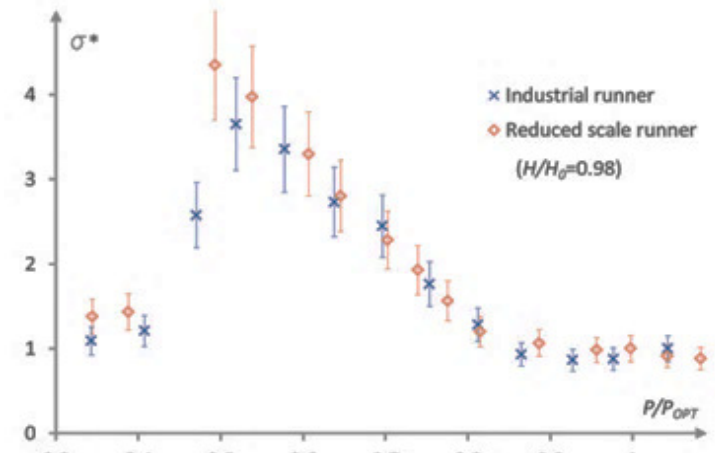
Mechanical data for the entire operating range



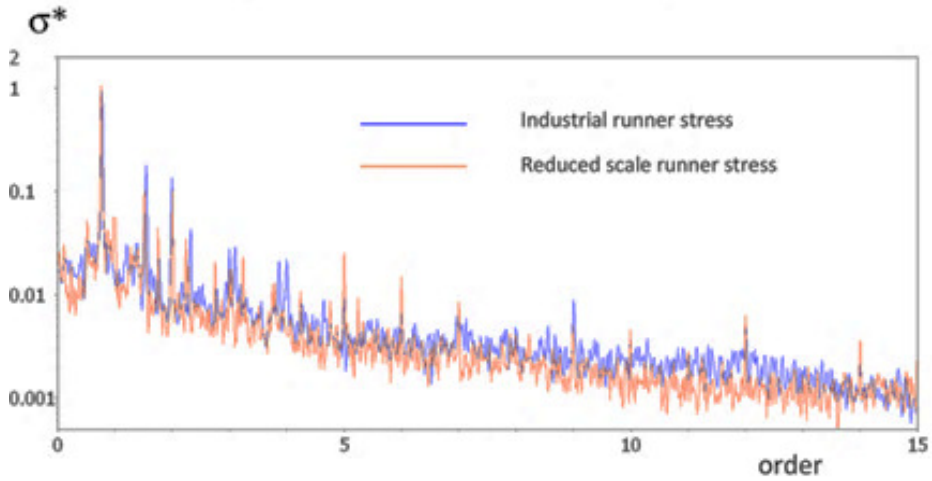


Mechanical model test

Validation with prototype measurement



Non-dimensional dynamic stress for model and prototype



Load spectrum at part load for model and prototype

- Agreement of model and prototype dynamic behavior for low-frequency and broad-band hydraulic excitation
- Limitations relating to resonance phenomena and excitation close to the natural frequency of model or prototype runner (RSI)

Extending the operating range

Hill chart of dynamic response: knowledge about mechanical properties

+37%
Of the continuous operating range

+50%
Of the total operating range

- Identify iso-lines of critical dynamic strain
- Informed definition of admissible operating range
- Restricted operating range defined on runner life-time calculations
- Low load operation and safe long-term behaviour