FLOW MEASUREMENTS AND CONTROL IN HYDRAULIC TURBINES

Michel Cervantes

Hydropower R&D days

23/03-2023

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Research focus

- Flow characterization
  - Velocity, pressure and strain
  - Characterize the turbine operation
  - Validation of numerical simulations
  - Clarify the flow physics
- Flow control
  - Minimize harmful flow conditions
  - Extend the operating range
  - Extend the turbine life

Pressure and strain measurements on a Kaplan prototype; Porjus U9 (A. Soltani, 2018)

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FLOW CONTROL

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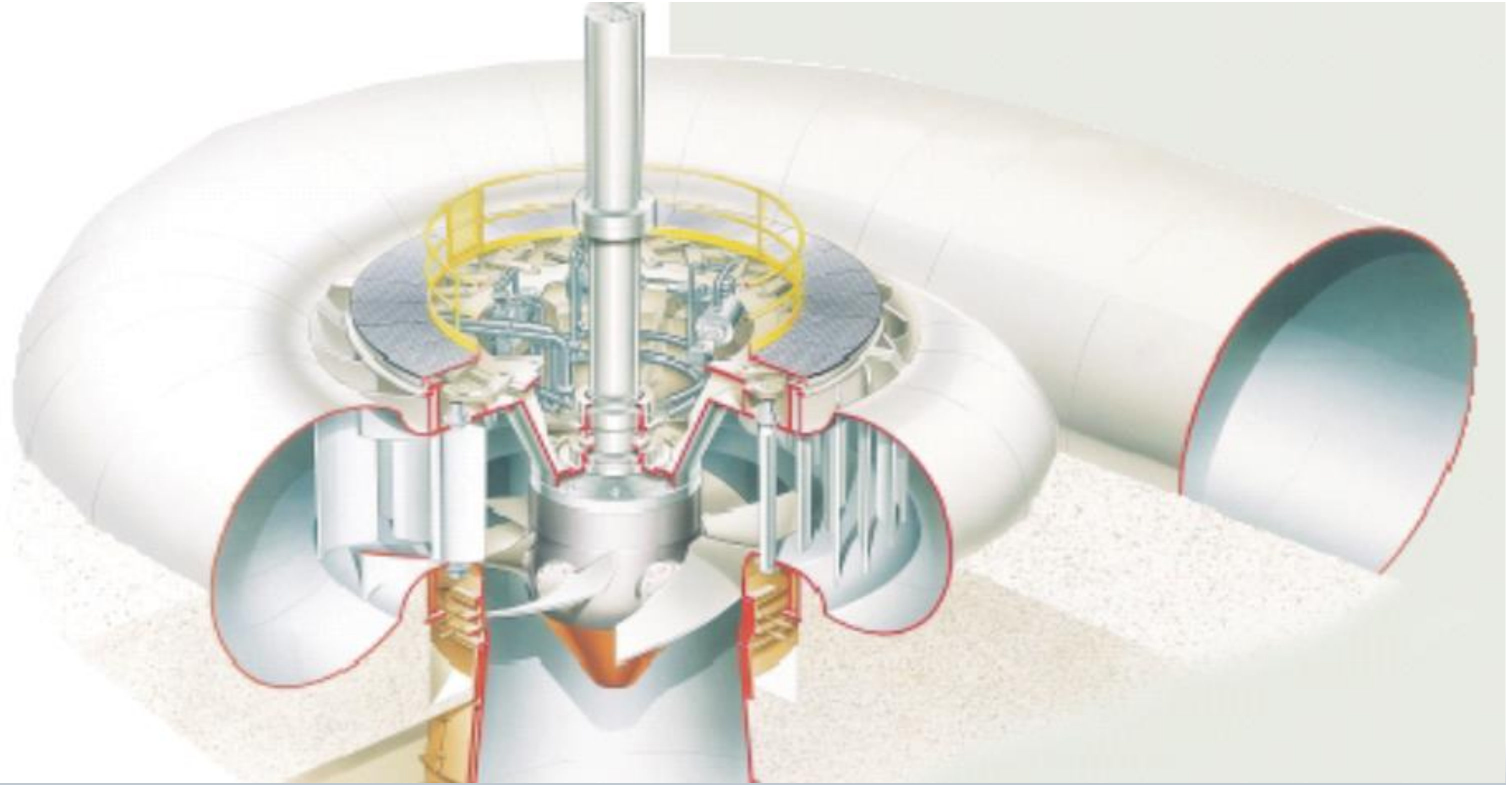
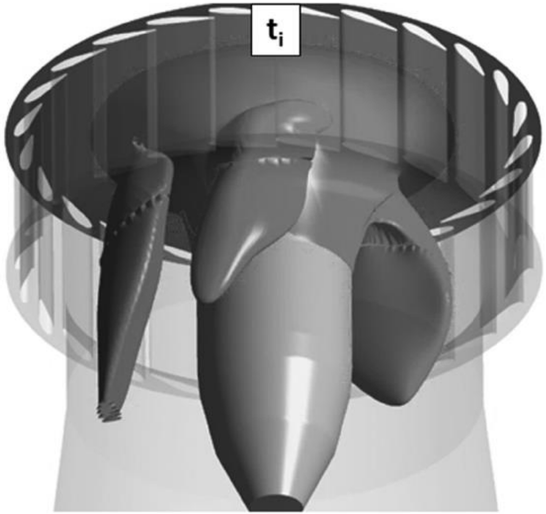


Operational condition away from BEP

Speed-no-load

$Q \ll Q_{BEP}$

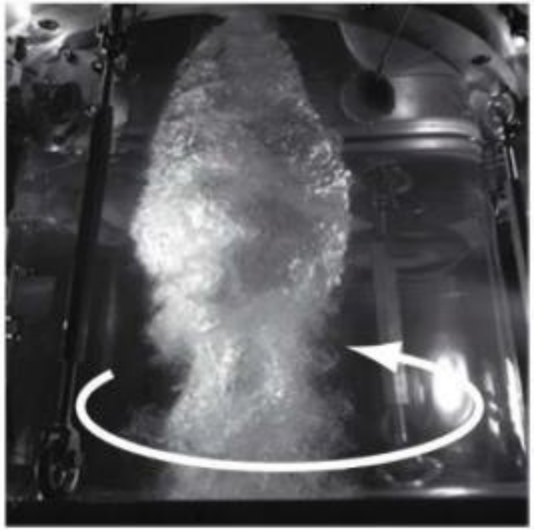


Part load

$Q < Q_{BEP}$

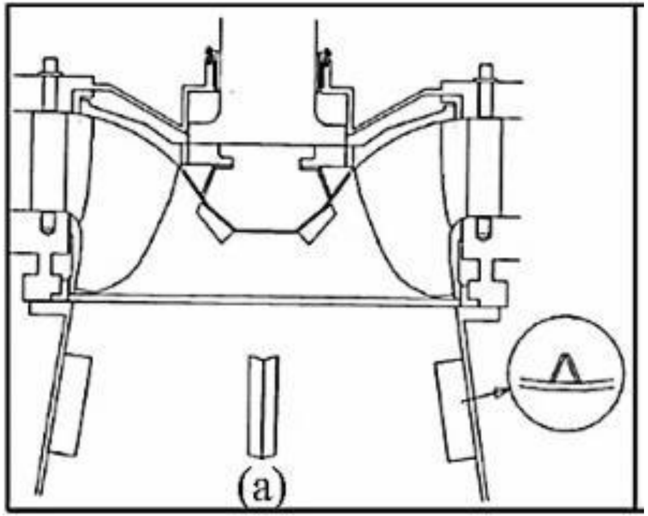
Full load

$Q > Q_{BEP}$



Existing and tested mitigation technique

- Fluid injection
  - Water
  - Air (most common)
- Geometrical modifications
  - Fins
  - Grooves
  - Extension of the runner cone
  - Guide vanes
    - Newly tested in an EU project (HYDROFLEX) with promising results



Finns installed in a draft tube

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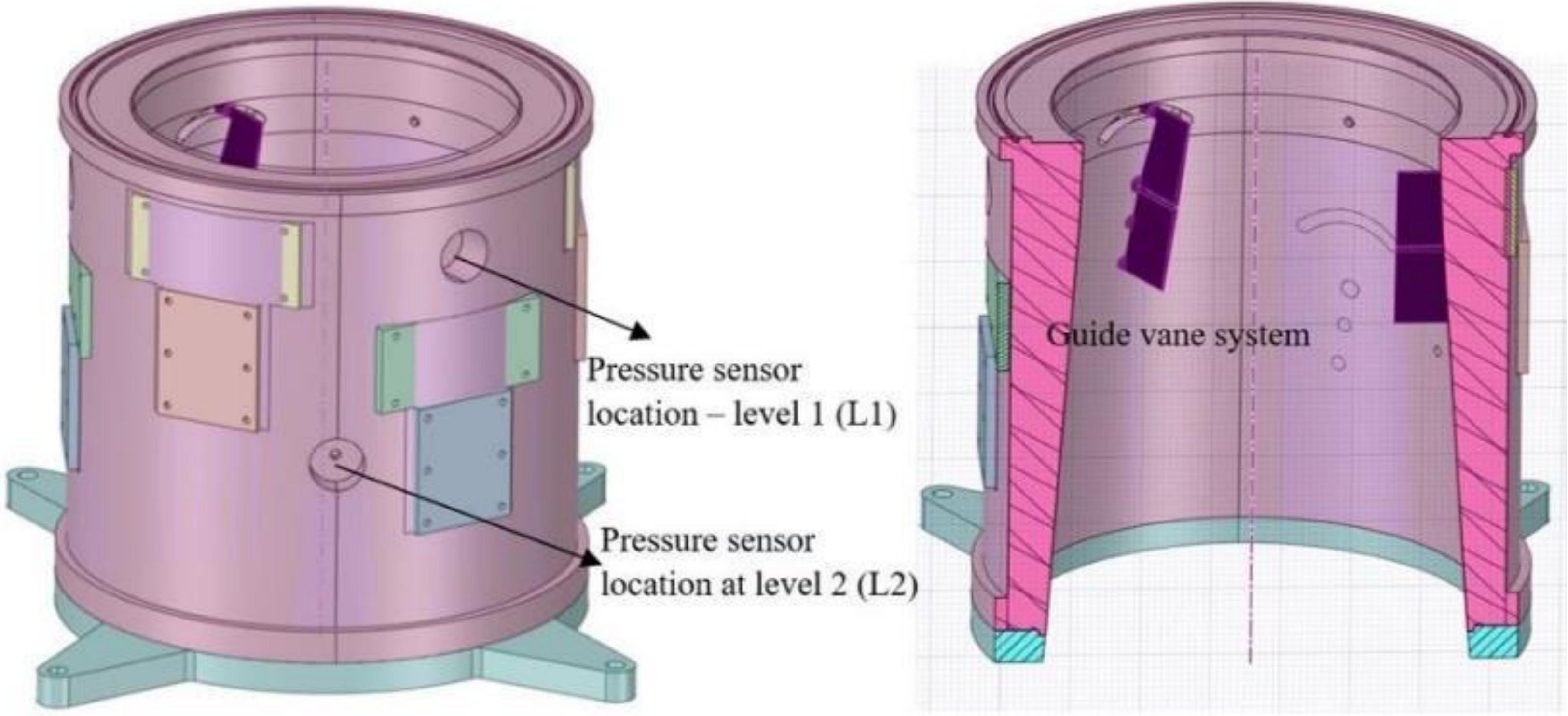
HYDROFLEX guide vane concept



J. Joy, 2023

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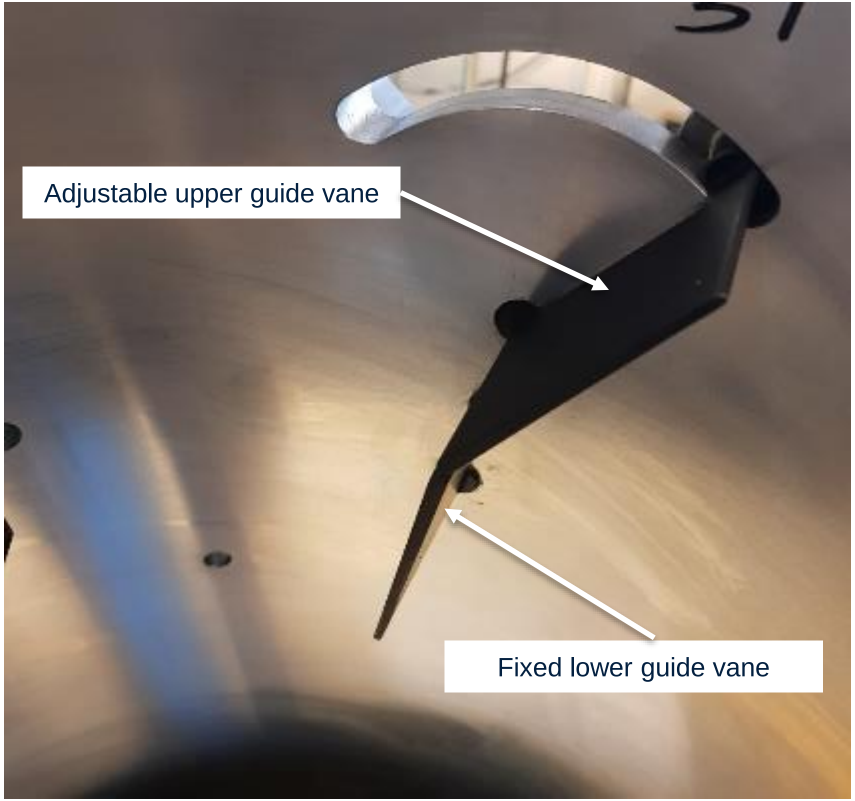
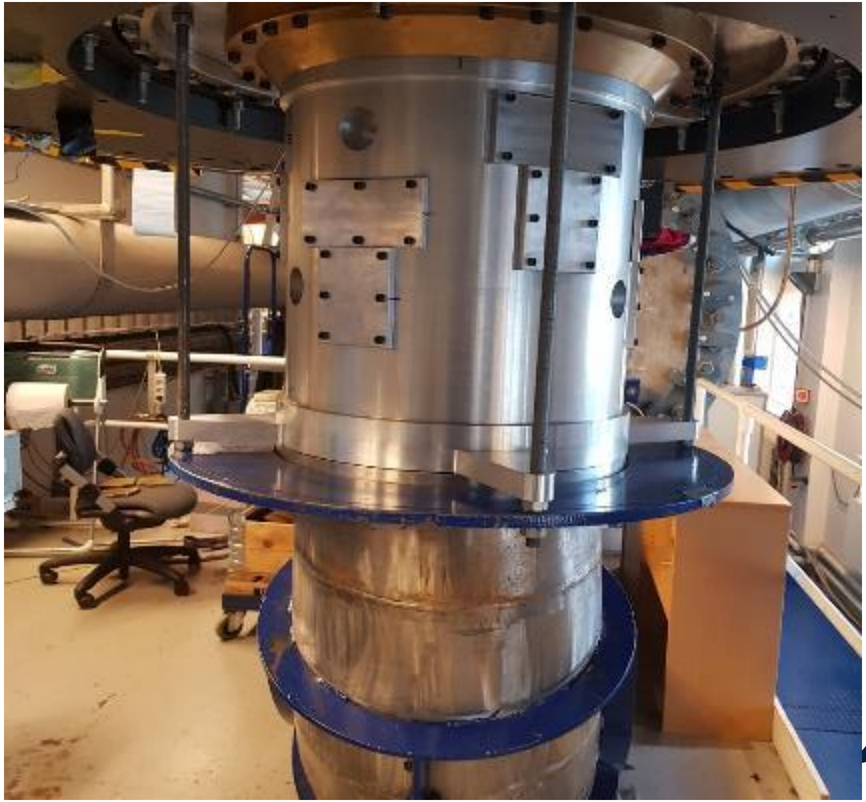
Experiment performed at NTNU





- Several operational conditions
  - Part-load 1: DPL (5.4 deg)
  - Part-load 2: PL (6.72 deg)
  - Best efficiency: BEP (9.81 deg)
  - High load: HL (12.44 deg)
- Drat tube guide vane system tested with different angles

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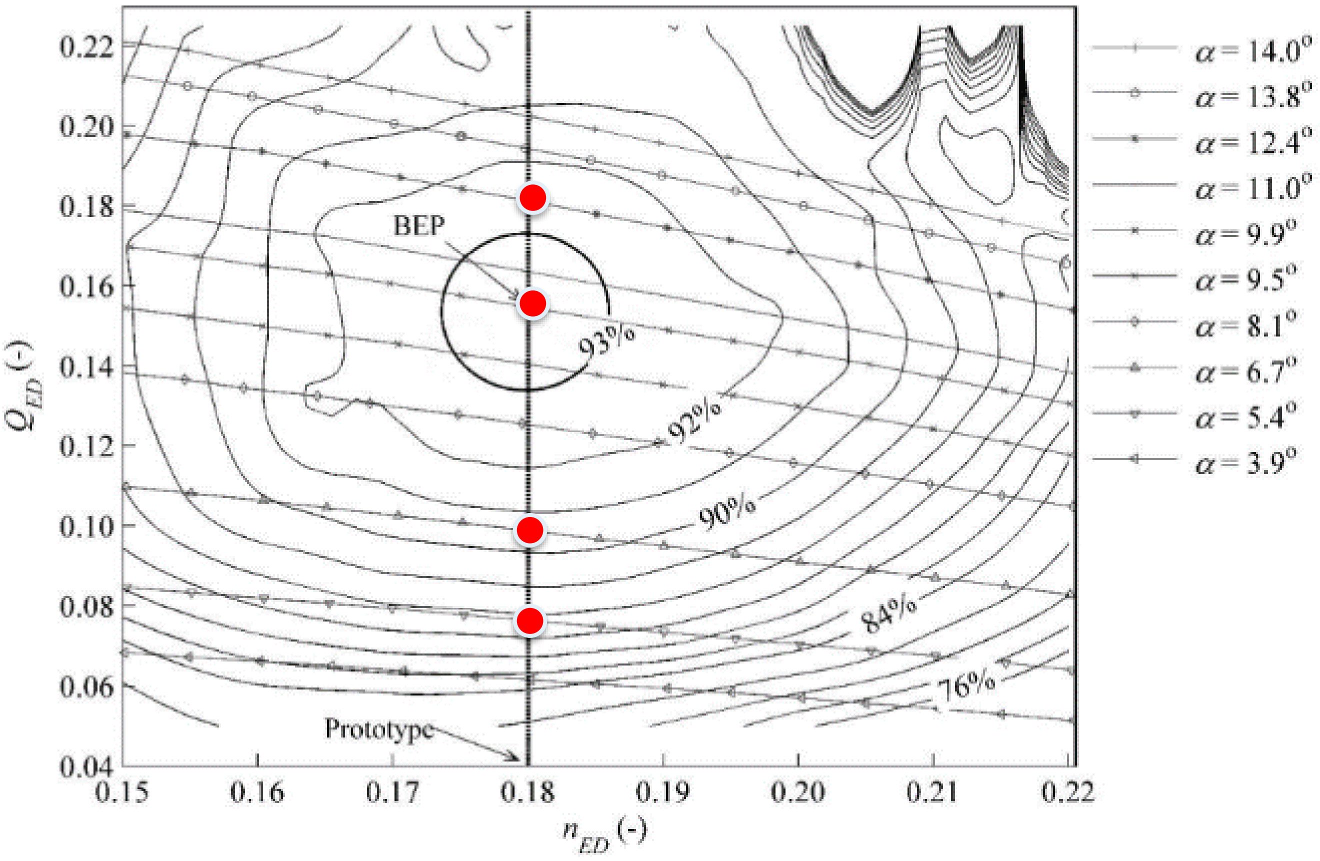
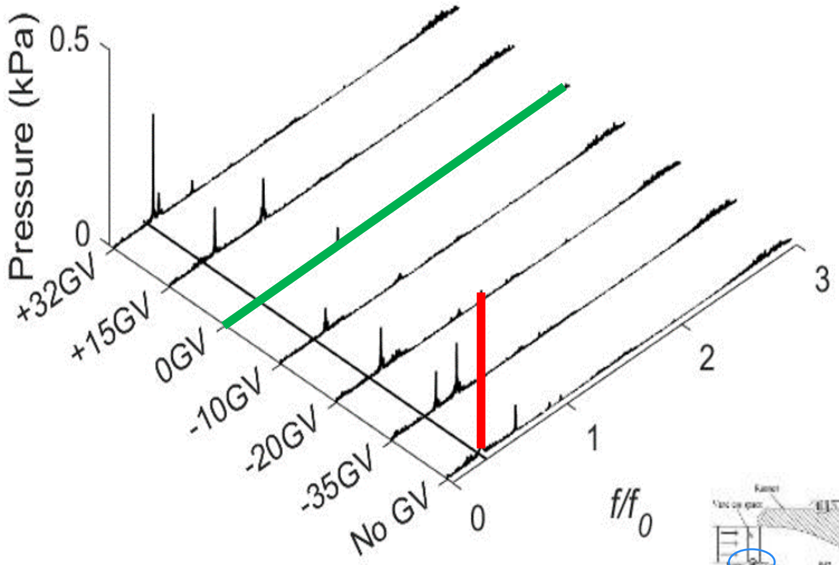
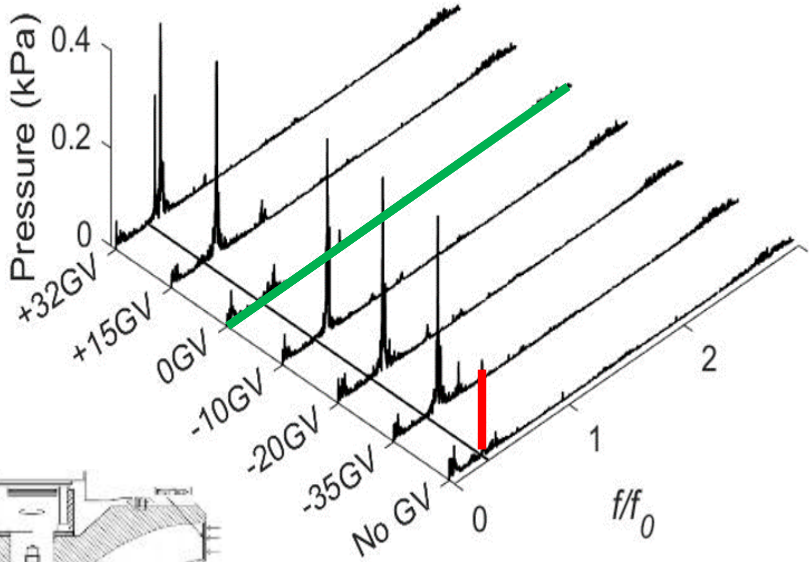
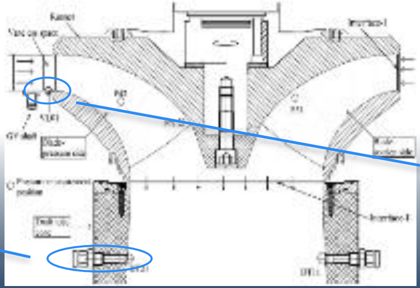


0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
Q_{ED} (-)
0.15
0.16
0.17
0.18
0.19
0.20
0.21
0.22
n_{ED} (-)
BEP
93%
92%
90%
84%
76%
Prototype
$\alpha = 14.0°$
$\alpha = 13.8°$
$\alpha = 12.4°$
$\alpha = 11.0°$
$\alpha = 9.9°$
$\alpha = 9.5°$
$\alpha = 8.1°$
$\alpha = 6.7°$
$\alpha = 5.4°$
$\alpha = 3.9°$

Results at PL1 (DT1 och VL1)







DT1

VL1

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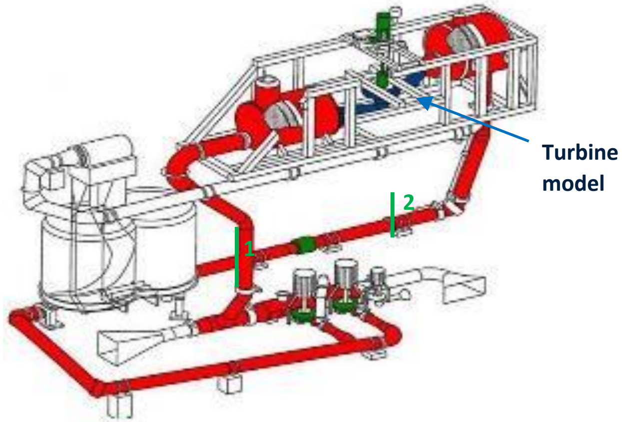
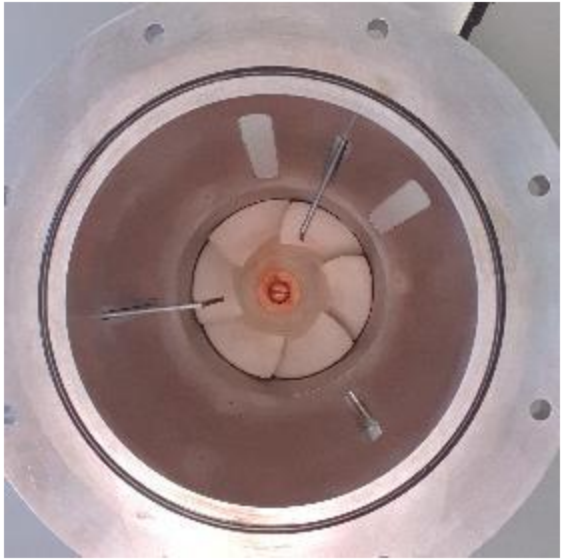
Hydraulic efficiency

	DPL		PL		BEP		HL	
Draft tube guide vane angle	η (%)	Δ (%)	η (%)	Δ (%)	η (%)	Δ (%)	η (%)	Δ (%)
No GV	**88.36**	-	**90.47**	-	**92**	-	**91.32**	-
-35GV	87	-1.54 %	89.41	-1.2 %	92	-	91.11	-0.23 %
-20GV	87.51	-0.96 %	89.79	-0.75 %	92.07	+0.08 %	91.20	-0.13 %
-10GV	87.74	-0.70 %	90	-0.52 %	92.04	+0.04 %	91.16	-0.18 %
0GV	87.87	-0.55 %	90	-0.52 %	92.11	+0.12 %	91.02	-0.33 %
+15GV	88	-0.41 %	90.1	-0.41 %	92.09	+0.1 %	91.01	-0.34 %
+32GV	88.1	-0.29 %	90.32	-0.17 %	92.07	+0.08 %	91.90	+0.64 %

Next step

- Develop and test a draft tube guide vane system (DTGV) to improve the flexibility and life of axial hydraulic turbines such as Kaplan and propeller turbines without penalties in hydraulic efficiency





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People involved

- Dr Joel Sundström
- Prof. Khalid Atta
- Prof. Mehrdad Raisee
- Dr Shervin Khayamyan

- Alessia Fabbri
- Jelle Kranenbarg
- Mehrdad Kalantar Neyestanaki
- Mohammad Amin
- Nahale Sotoudeh
- Robert Mirut
- Shahab Shiraghaee

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FLOW MEASURMENTS

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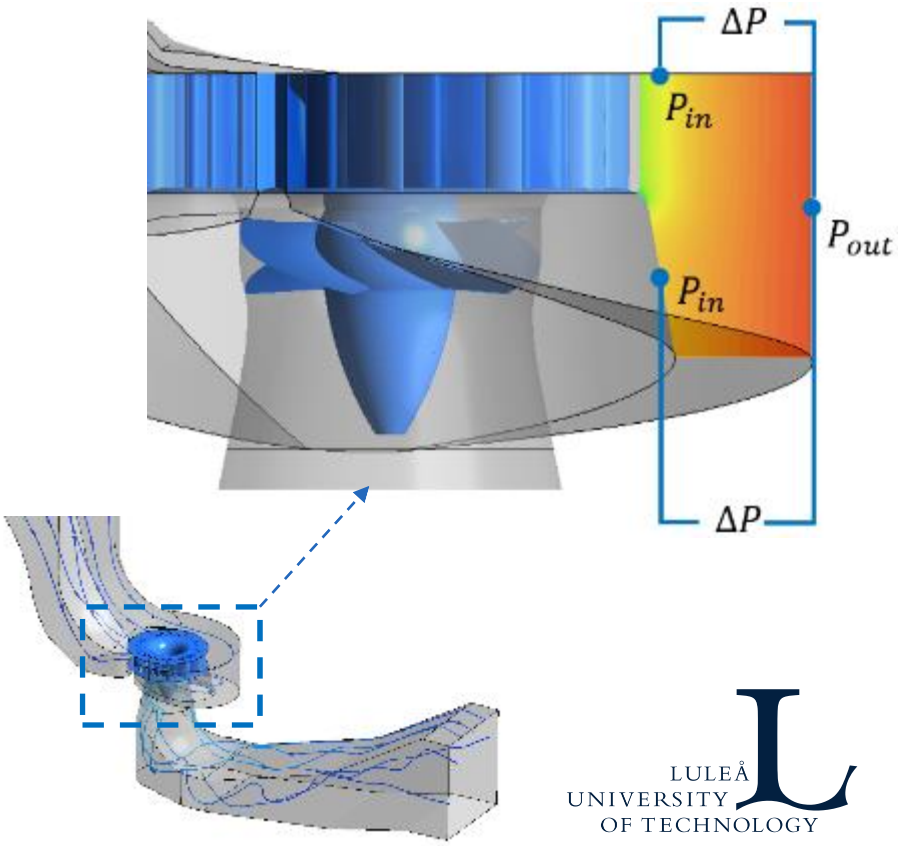
Flow rate measurements in Sweden

- The Winter-Kennedy is widely used:
  – Relative method
  – Could be used for continuous measurements
  – Need of calibration

➡ Pressure time-method



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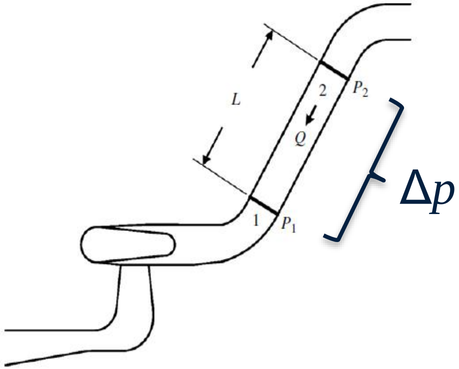
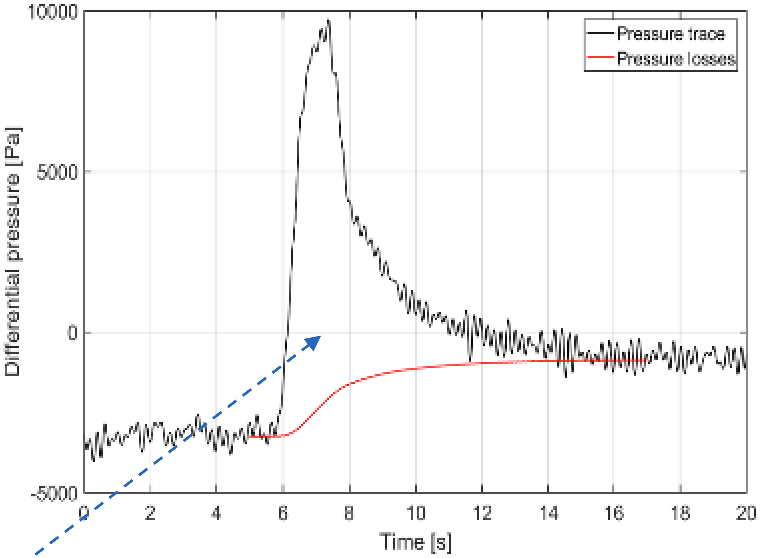
Pressure-time method

- Principle: based on the transformation of momentum into pressure and vis versa
  - Included in the IEC0041
  - Some limitations
- Need to development the method for low head machines and adapt it to operations





$$Q = \frac{A_c}{\rho L}\int_0^{t_f}\left(\Delta p + \Delta p_f\right) dt + q$$

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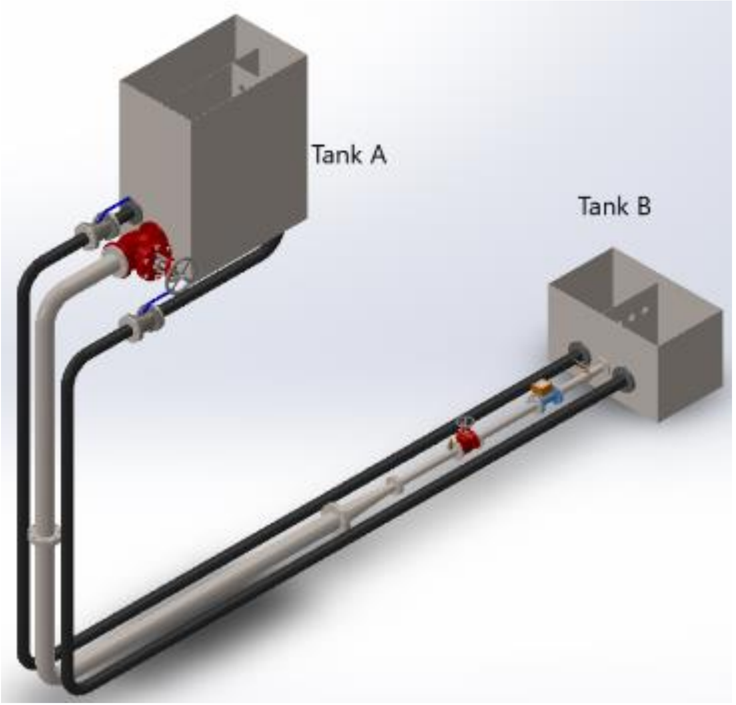
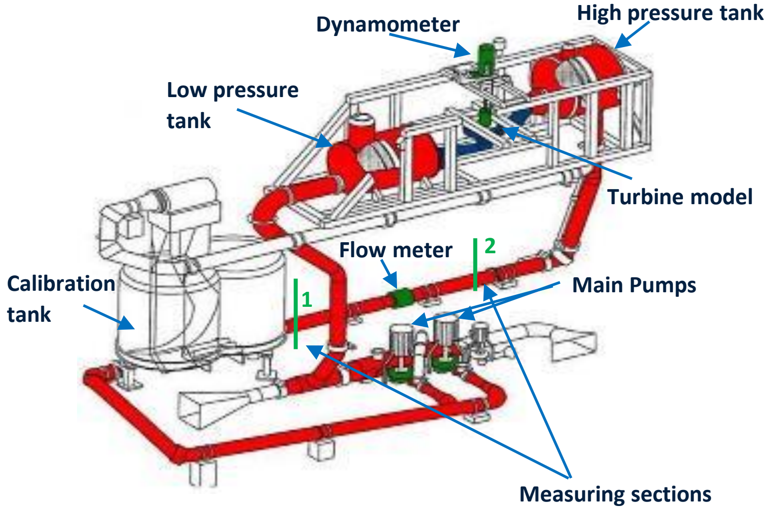
- Main limitations fixed
  - $U \times L > 50\ m^2/s$ → fixed (P. Jonsson)
  - Friction modelling → fixed (P. Jonsson, J. Sundström)
  - Compressibility → fixed (G. Dunca)

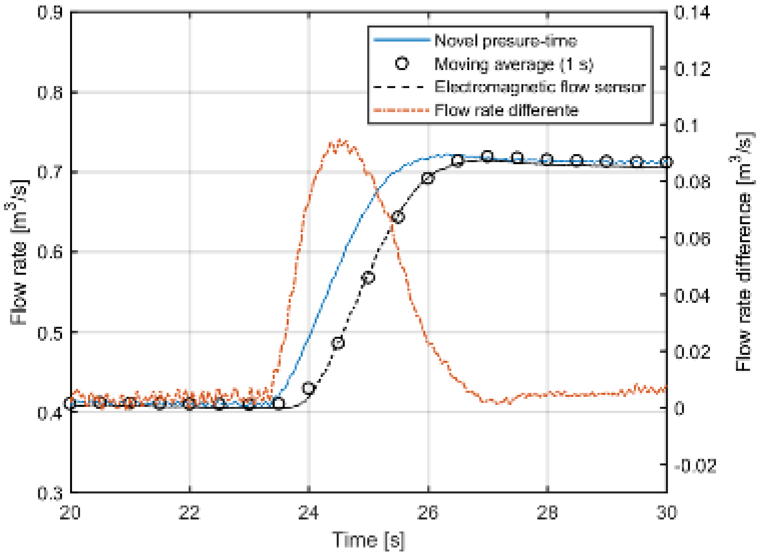
- Main limitations being fixed
  - 1 dimensional → 3 dimensional (M. Kalantar work on it, see his poster)
  - Complete shut-down → partial shut-down



Test rig developped at LTU to study the pressure-time method.

- Development of the pressure-time method for partial guide vane closure
  - New formulation of the method
  - Tested experimentally at Vattenfall laboratory
  - Flow rate before, under and after the transient determined





Variation of flow rate as a function of time for the new method and the electromagnetic flow sensor used as a reference

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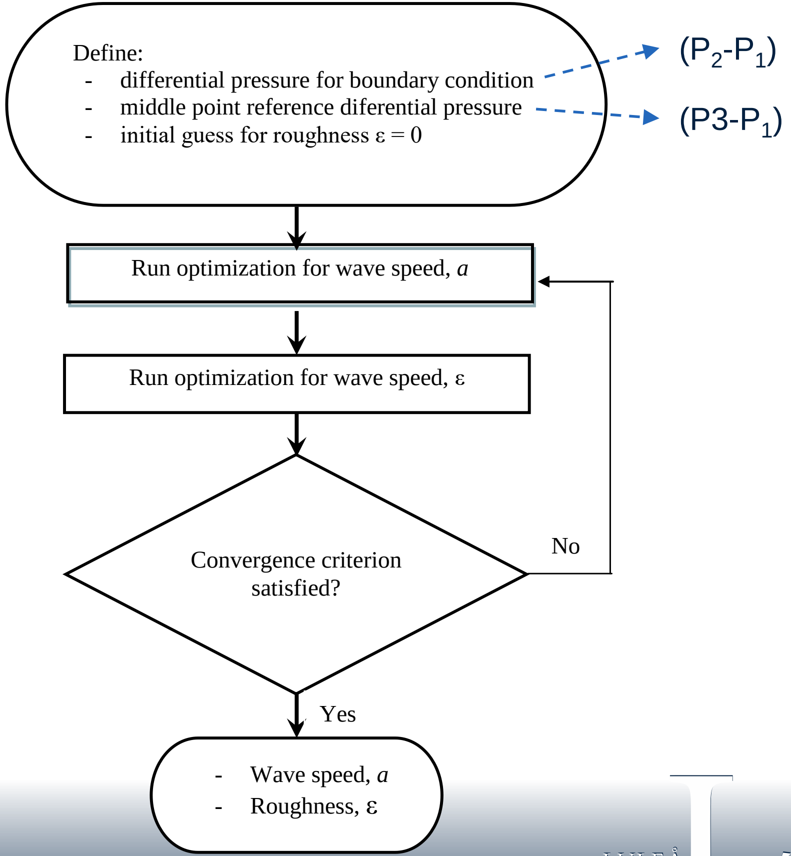
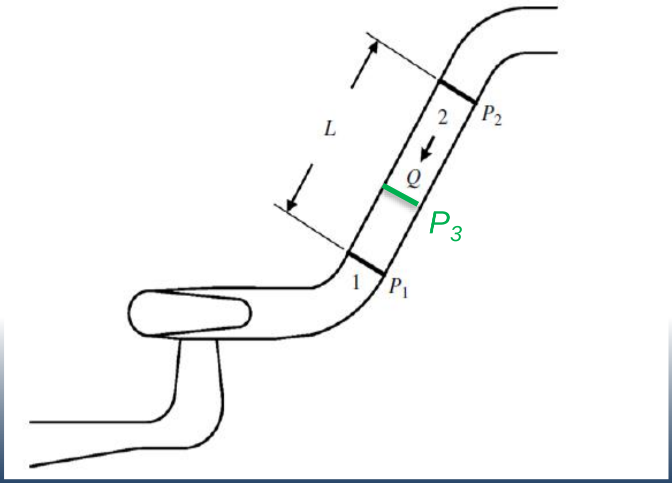
- Many constant to determined
  - Wave speed, roughness
  - Pipe radius, length between the sections
- Development of model free pressure-time method
  - Introduction of a new measurements to determine the remaining constant
  - Work going on

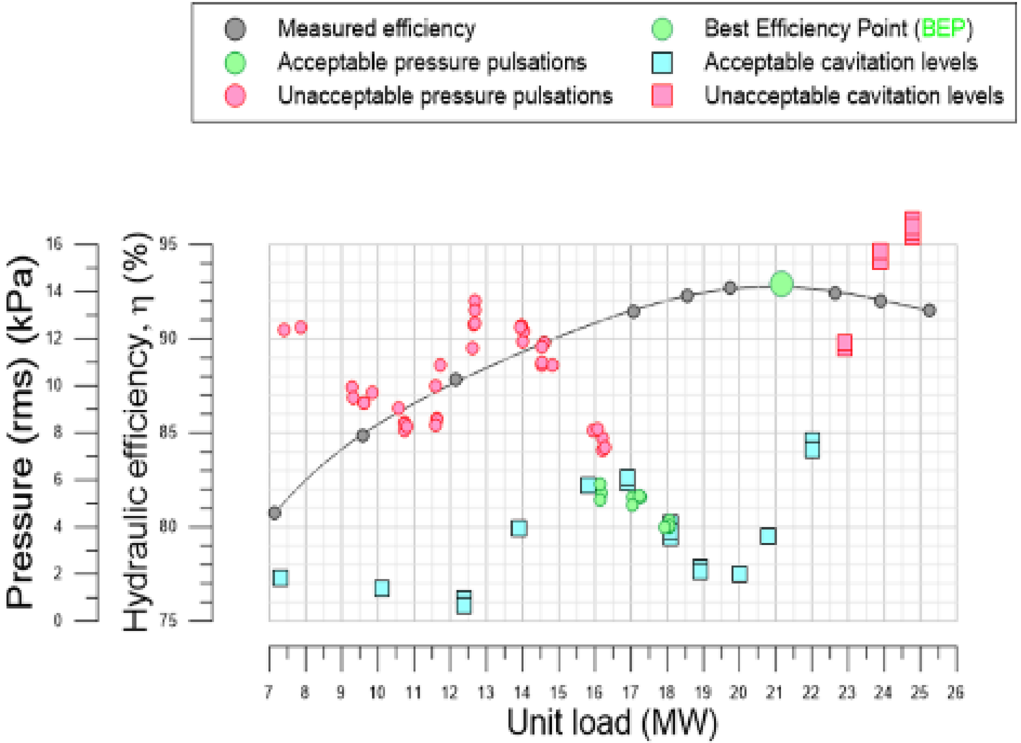


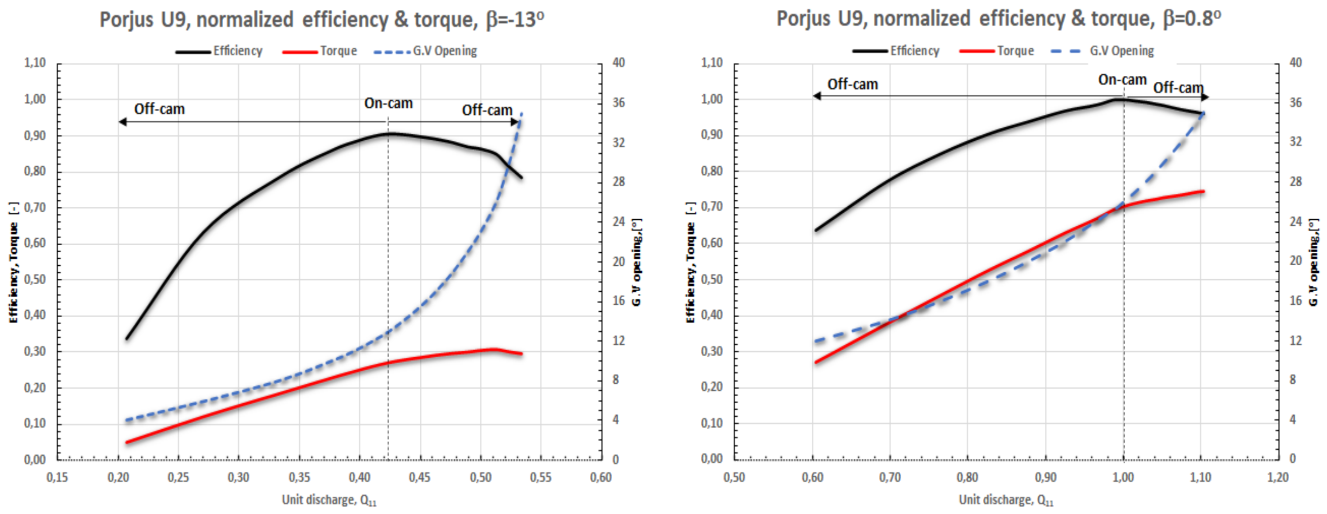


Consequences

- Limited operation
- Increases maintenance and cost
- Machine life expectancy negatively affected

➡ Need of a solution




Porjus U9, normalized efficiency & torque, β=-13°
Efficiency
Torque
G.V Opening
Off-cam
On-cam
Off-cam
Efficiency, Torque [-]
G.V opening,[°]
Unit discharge, Q11
Porjus U9, normalized efficiency & torque, β=0.8°
Efficiency
Torque
G.V Opening
Off-cam
On-cam
Off-cam
Efficiency, Torque [-]
G.V opening,[°]
Unit discharge, Q11