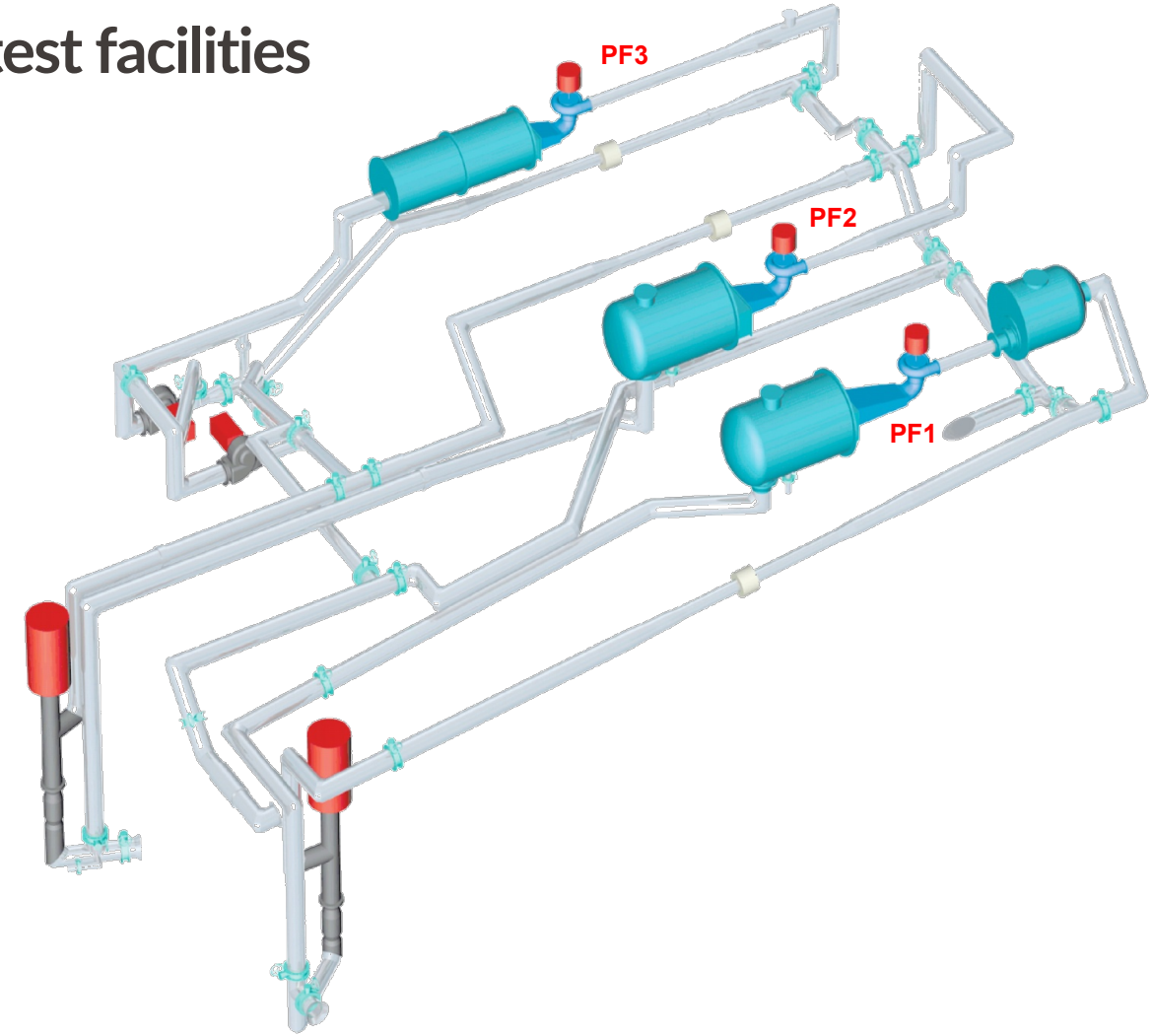
L7 - Model testing and experimental techniques for hydroelectric units

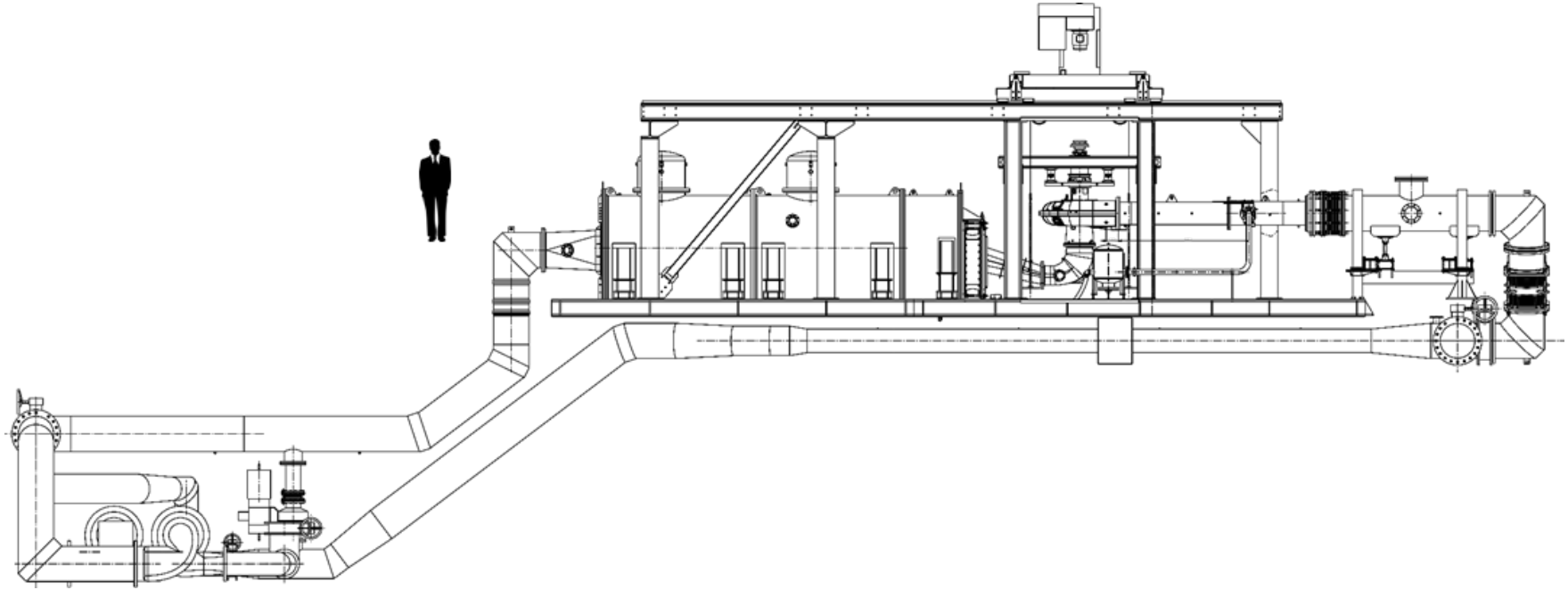
École
polytechnique
fédérale
de Lausanne

EPFL PTMH model test facilities

- All types of hydraulic machines
- Efficiency Uncertainty < 0,3%
- Complying with IEC 60193 Standards
- Geometrical Similitude: Dimensional Checks
- Kinematic Similitude: operating conditions defined by non-dimensional coefficients or factors to have same velocity triangles
- Dynamic Similitude: Reynolds Scale Effects
- Cavitation Similitude: Thoma number



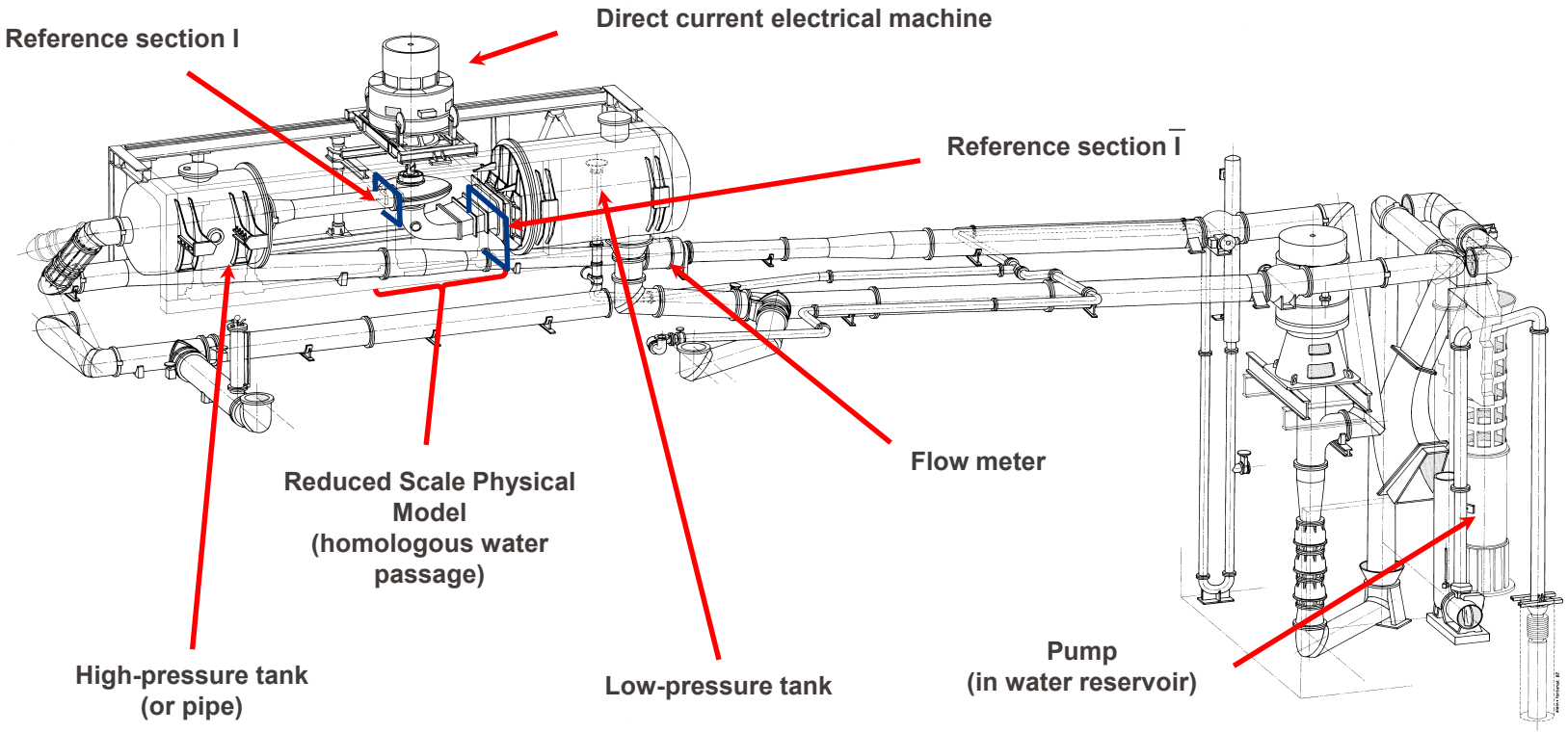
Practical implementation
Instrumentation and test rig set-up



Example: 1:16 reduced scale model on EPFL test rig

Practical implementation

Instrumentation and test rig set-up



Practical implementation

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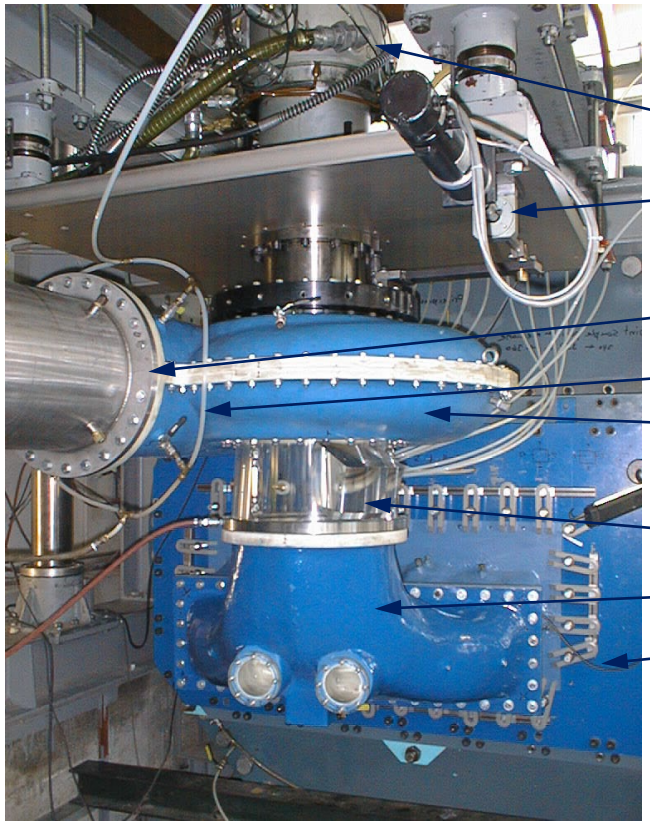
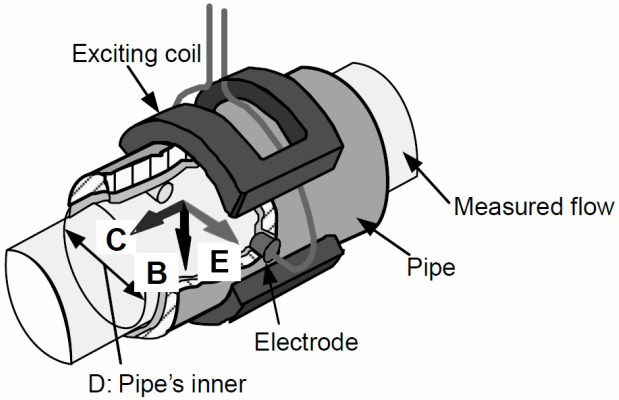


- Balanced Hydrostatic Bearing
- Guide Vanes Opening Drive
- Inlet
- *p*-lines for Head Measurements
- Spiral Case
- Transparent Draft Tube Cone
- Elbow Draft Tube
- Tail Water Tank

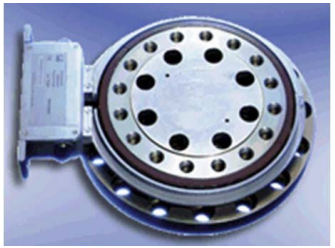
Practical implementation
Instrumentation and test rig set-up



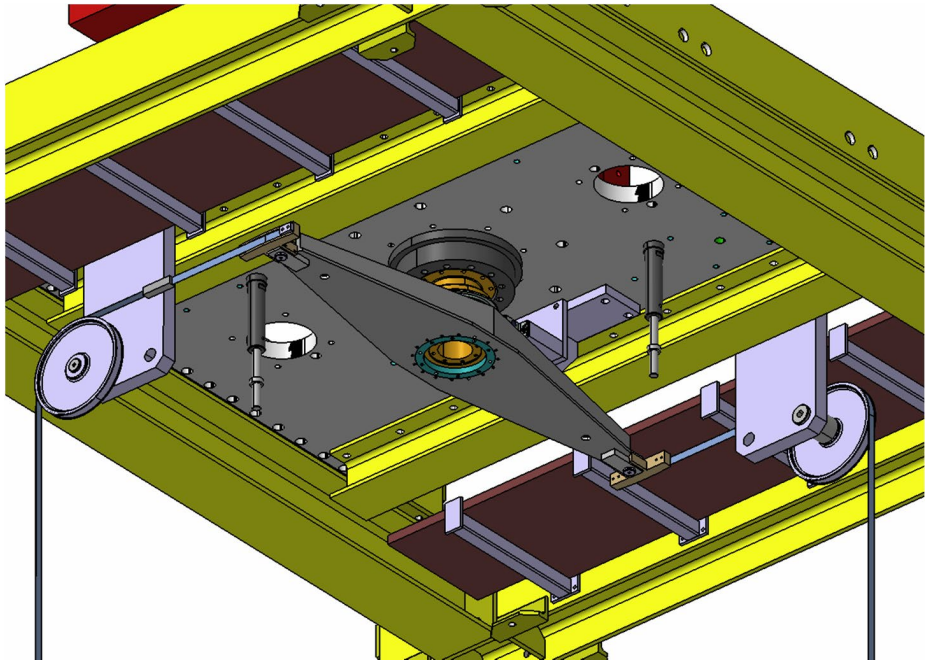
- Discharge Q
  - Magnetic Flowmeter
- Specific Energy
  - Differential p-Sensor
  - Magnetic Flowmeter
- Hydraulic Power $P_h = \underbrace{\rho}_{\text{Therm.}} \times Q \times E$
  - Thermometerlat

$$E = \underbrace{\left(\frac{p}{\rho}+gZ\right)_I - \left(\frac{p}{\rho}+gZ\right)_{\bar{I}}}_{\text{Differential } p\text{-sensor}} + \underbrace{\left(\frac{1}{A_I^2}-\frac{1}{A_{\bar{I}}^2}\right)}_{\text{Dimensional Checks}} \times \underbrace{\frac{Q^2}{2}}_{\text{Magnetic Flowmeter}}$$

Practical implementation
Instrumentation and test rig set-up

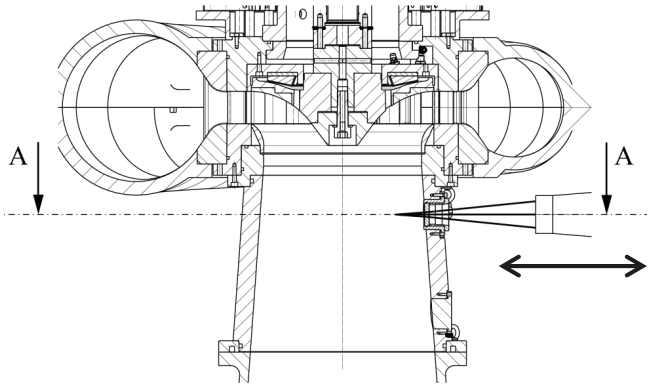


- Torque T_m
  - Torque meter
- Speed ω
  - Frequency-meter
- Internal Mechanical Power
  - $P_m = \omega \times T_m$

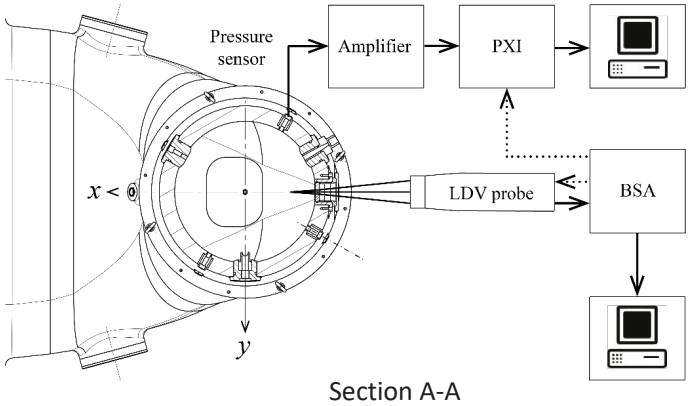


Practical implementation
Instrumentation and test rig set-up

Laser Doppler Velocimetry (LDV)



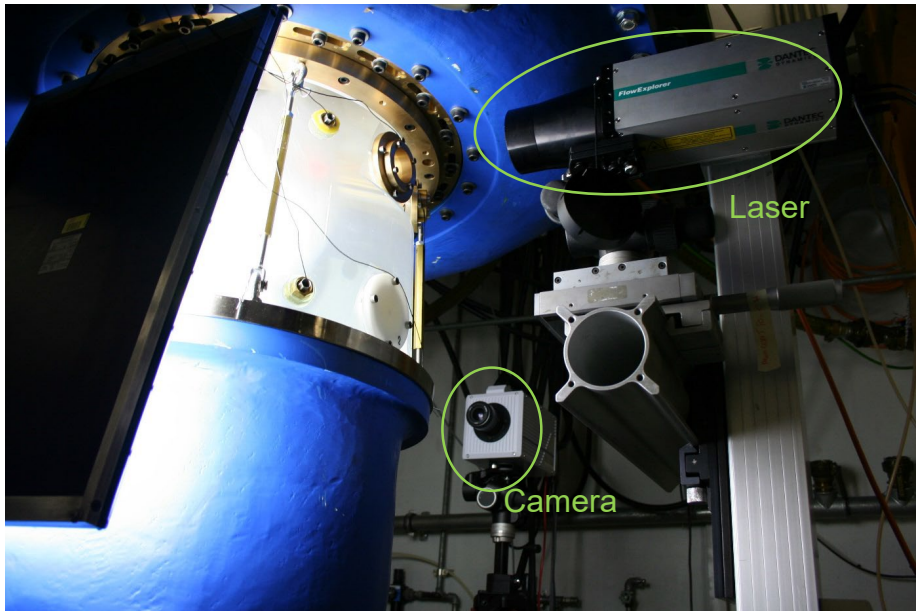
Laser installed on traversing system
for radial displacement



Synchronized acquisition of
LDV and wall pressure measurements

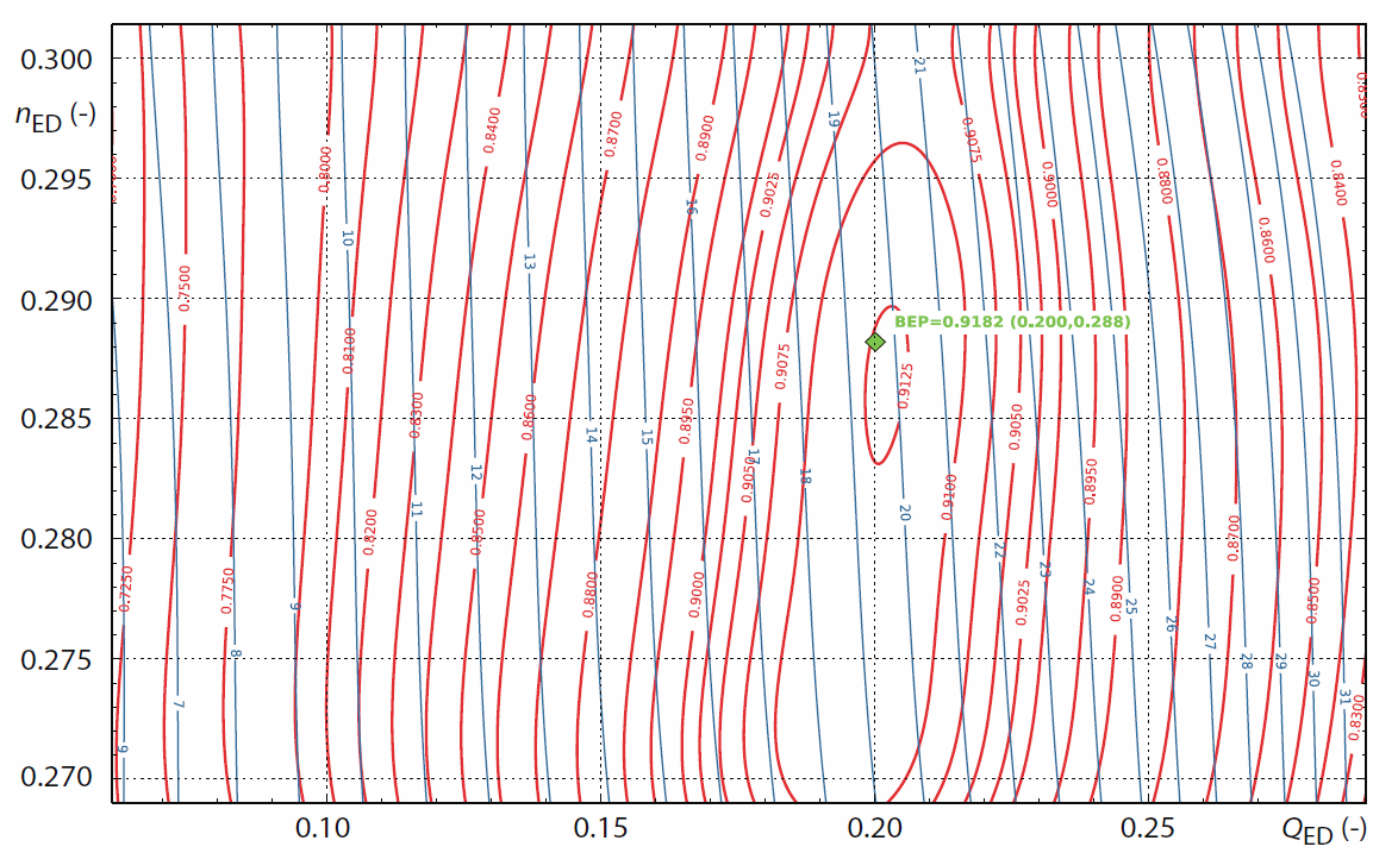
Practical implementation
Instrumentation and test rig set-up

High speed camera acquisition and LDV

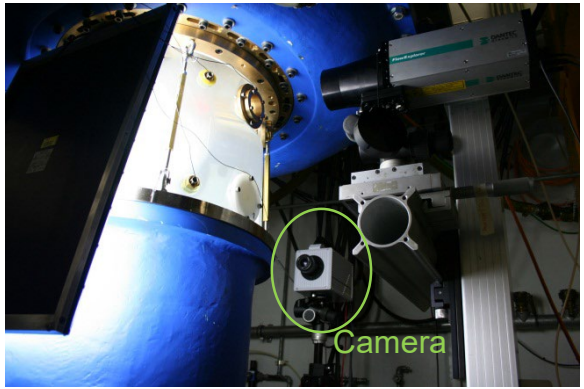


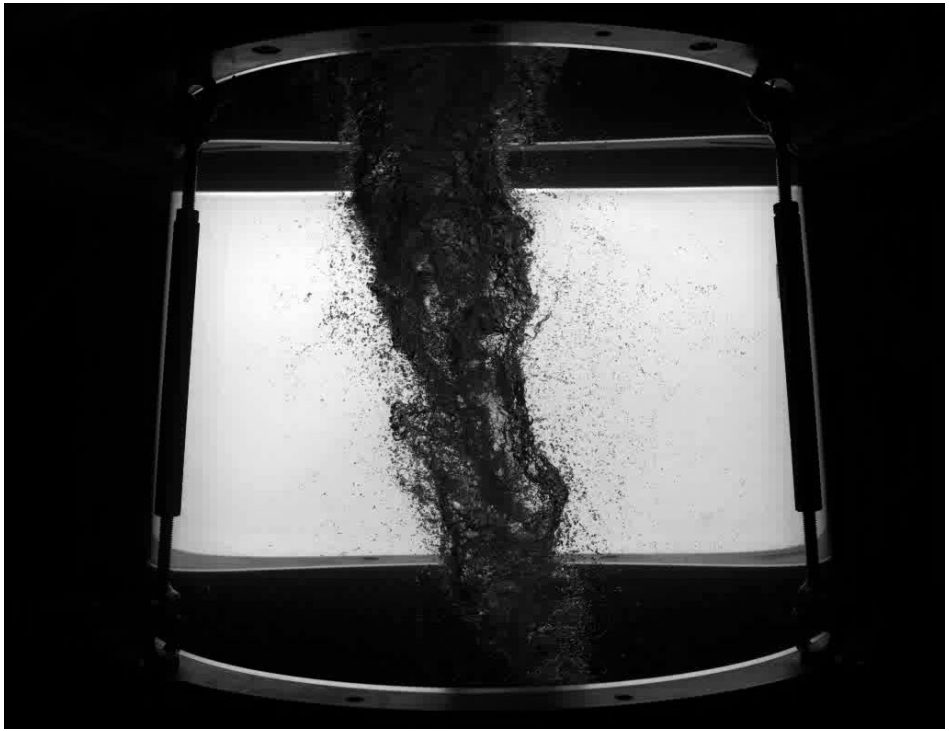
Results Example

Francis turbine hillchart

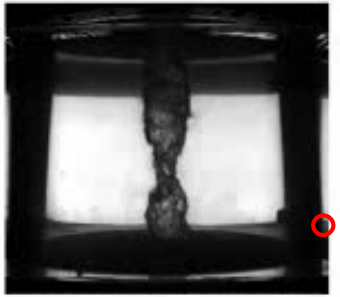


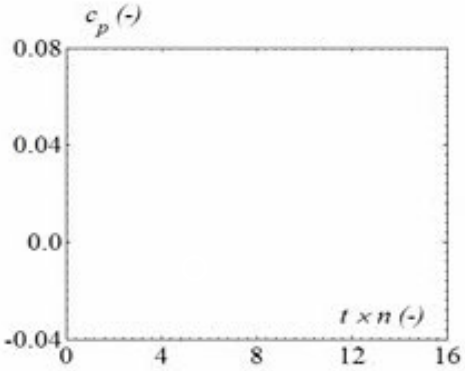
Results Example
Francis turbine cavitation

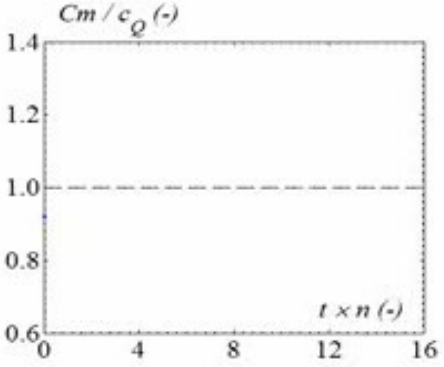


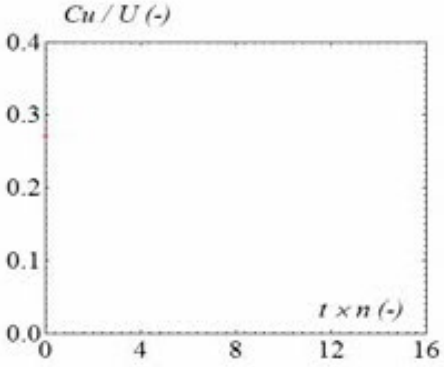


Results Example
Francis turbine cavitation





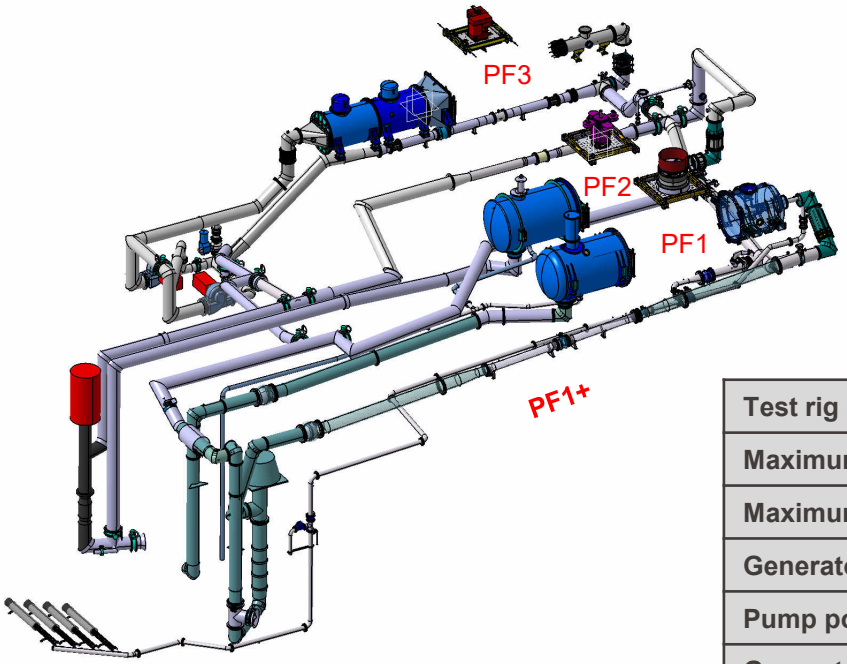




- Flow visualization
- Wall pressure measurements
- Raw LDV data
  - Axial & tangential velocity components

EPFL PTMH model test facilities

Operation Condition of test rig 1+

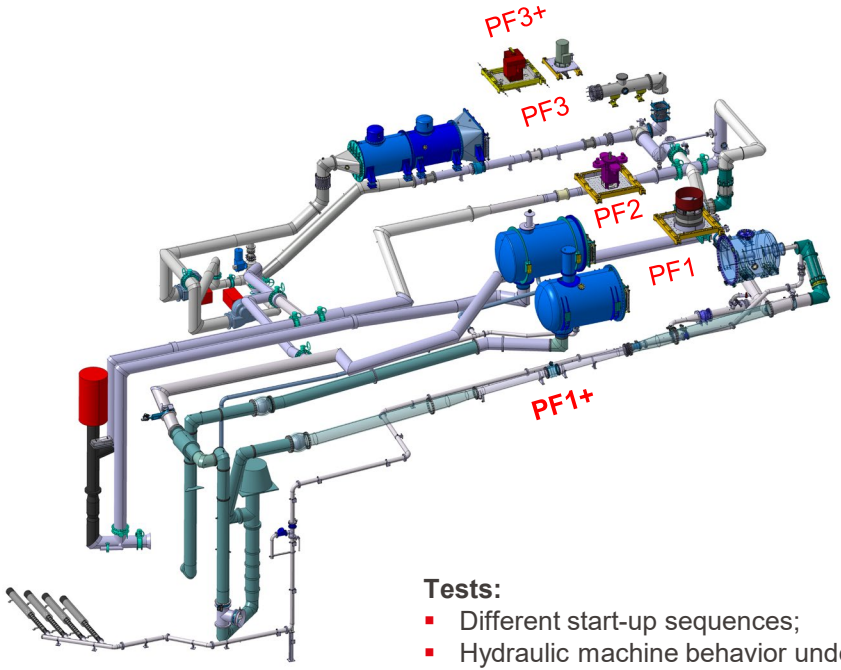


- **Head**: between 50 and 400 m
- **Discharge**: between 0.05 and 0.30 $m^3 \cdot s^{-1}$
- **Rotational speed**: between 0 and 2000 min^{-1}
- **Vertical axis**
- **Asynchronous motor**

Test rig characteristics	PF1	PF1+	PF2	PF3
Maximum head (m)	100	400	100	100
Maximum discharge ($m^3 \cdot s^{-1}$)	1.4	0.3	1.4	1.4
Generator power (kW)	435		300	300
Pump power (kW)	900	4x230	1000	2x400
Generator maximum speed (min^{-1})	1500	2000	2500	2500
Year of construction	1969	**2022**	1979	1989

EPFL PTMH model test facilities

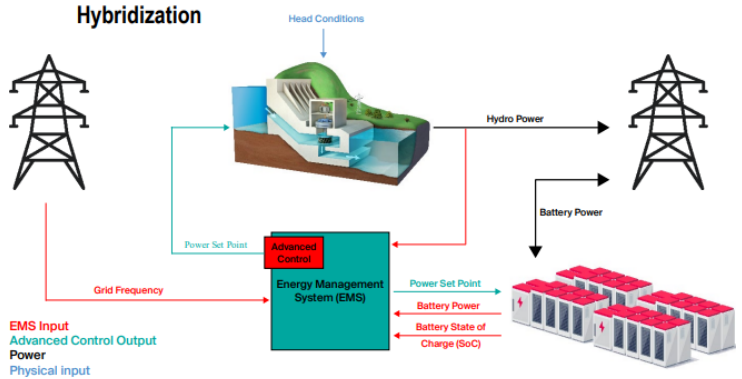
Operation Condition of test rig 3+



- Synchronous machine: 100 kW, 1500 rpm
- Frequency variation : +/- 10%.
- Maximum torque : 573 Nm
- Batteries : 100 kVA
- Grid emulator : 100 kVA

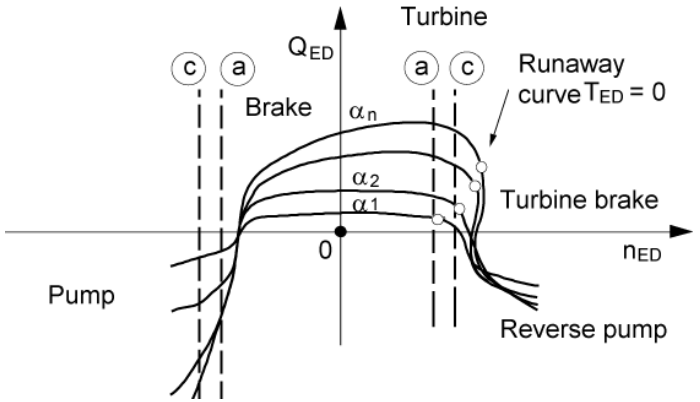
Tests:

- Different start-up sequences;
- Hydraulic machine behavior under real grid conditions
- Multiple control techniques for: fixed, variable speed units and hybrid units with a battery energy storage systems (BESS);
- Frequency regulations



Performance measurements

Phase of model testing



Productivity	Liability					
Preparatory Test	Efficiency	Cavitation	Pressure Pulsation	Axial Thrust	Other hydraulics loads	Off-design operation
Pressure Taps Checks Reynolds Effects	Best Efficiency Point	Cavitation break-down curve	Evolution of the amplitude of pressure pulsation from runaway to full-load operation	Evolution of the hydraulic thrust from runaway to full-load operation	Evolution of the guide vane torque from runaway to full-load operation	Runaway
						Reverse pump
	Full Hillchart		Evolution of the amplitude of pressure pulsation from instability to minimum head	Evolution of the hydraulic thrust from instability to minimum head	Evolution of the guide vane torque from instability to minimum head	Instability zone Zero-discharge
						Full 4-quadrants for Pump-Turbines

Global Reach

A selection of the largest hydropower plants in the world

Hydropower Plant	Country	Capacity (MW)	Energy (TWh)	Capacity Factor	EPFL Model Testing	Type
Three Gorges	China	22'500	98.5	0.50		Storage
Itaipú	Brazil-Paraguay	14'000	98.3	0.80	✓	Storage
Xiluodu	China	13'860	57.1	0.47	✓	Storage
Belo Monte	Brazil	11'233	-		✓	Run-of-River
Guri (Raúl Leoni)	Venezuela	8'850	53.4	0.69	✓	Storage
Tucurui	Brazil	8'370	41.4	0.56	✓	Storage
Grand Coulee	USA	6'809	20.0	0.34	✓	Storage
Longtan	China	6'426	18.7	0.33		Storage
Xiangjiaba	China	6'400	NA	NA		Storage
Krasnoyarsk	Russia	6'000	20.4	0.39		Storage
Robert Bourassa (LG2)	Canada	5'616	26.5	0.54	✓	Storage
Churchill Falls	Canada	5'428	35.0	0.74		Storage