Challenges in the Design of Pump Turbines

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Golden, CO, USA, November 2012

Challenges in the Design of Pump Turbines

High head, low specific speed

- Head range: 1100–500 m
- Ternary or reversible machines
- 4 stage pump turbine (unregulated)
  to single stage reversible pump turbine

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Challenges in the Design of Pump Turbines

Application to projects: pump storage plant Tierfehd, Switzerland

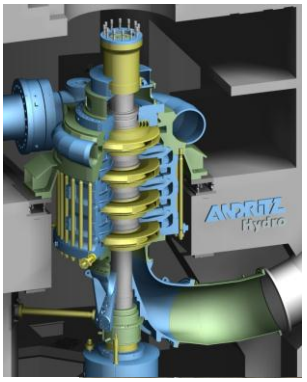
Pump turbine Tierfehd (Nestil)

1 reversible Pump turbine
Customer: Axpo AG, Switzerland

4 stages, non-regulated

Runner diameter	D_1=2262 mm
Head range	H 953.4–1065.7 m
Max power	P=141.2 MW
Speed	n 600 rpm
Specific speed	n_{sq} 130

CFD and model tests well
proven in site tests and experience
Smooth operation behavior



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Challenges in the Design of Pump Turbines

Application to projects: pump storage plant Moralets 2, Spain

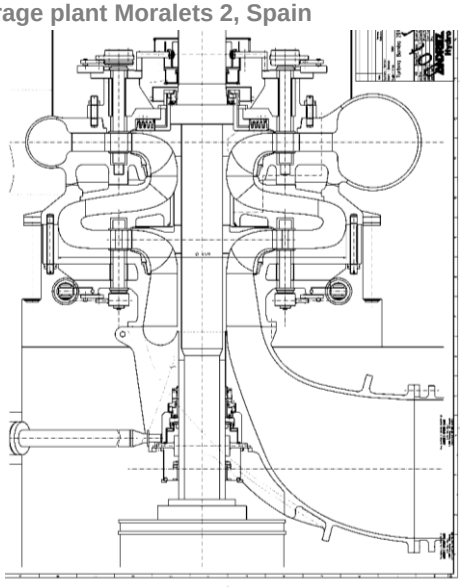
Moralets 2

2 Pump turbines
Customer: Endesa, Spain

Two stages, both regulated

Runner diameter	D_1=2230 mm
Head range	H 700–804.8 m
Max power	P=202.6 MW
Speed	n=750 rpm
Specific speed	n_{sq}156

Engineering study
Hydraulic development in progress
Model test in 2013



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Challenges in the Design of Pump Turbines

Application to projects: Pump storage plant Haeusling, Austria

Ternary plant Haeusling

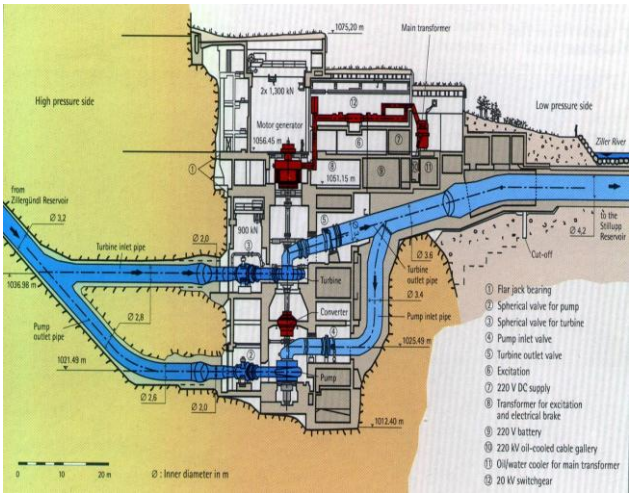
2 Francis turbines

Customer:
Verbund Hydro Power AG,
Austria

Runner Diameter	D_2=1800 mm
Head range	H 568–734 m
Max power	P=175 MW
Speed	n=600 rpm
Specific speed	n_{sq} 92

World record head for Francis turbines

In operation since 1986



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Challenges in the Design of Pump Turbines

Application to projects: Bhira

Bhira, India

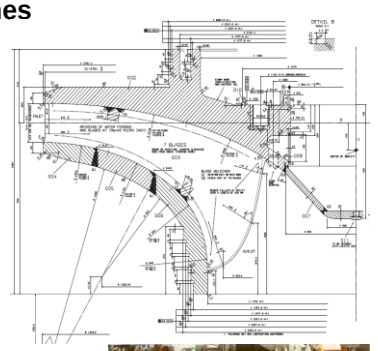
1 Pump turbine, 1992

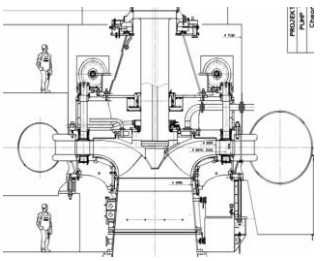
Customer: Tata Electric Companies, India

Runner Diameter	D_1=3761mm
Head range	H 510–530m
Max power	P=165 MW
Speed	n=500 rpm
Specific speed	nsq 90

Runner band welded from three segments

Successfully in operation





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Challenges in the Design of Pump Turbines

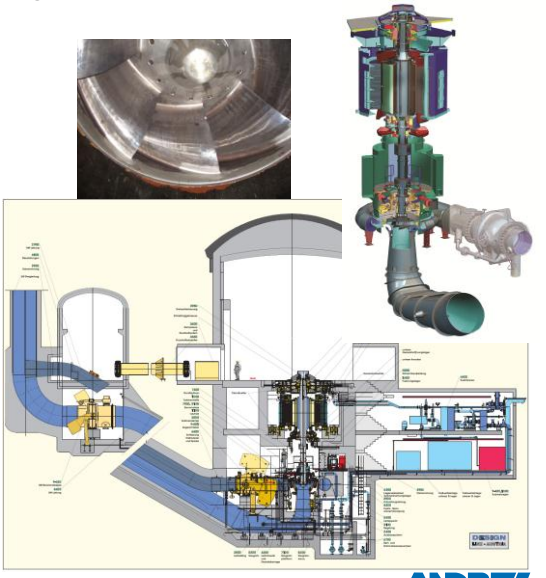
Application to projects: Hintermuhr

Customer: Salzburg AG, Austria

Runner outlet diameter	D_1=1870 mm
Head range	H 455–517 m
Max power	P=71.5 MW
Speed	**n=1000 rpm**
Specific speed	n_{sq} 126

Scope of supply:
1 Pump Turbine
Motor Generator
Governer
1 Butterfly valve
1 spherical valve

Existing cavern for two Pelton units
Guide vanes and labyrinth rings coated with tungsten carbide SXH70



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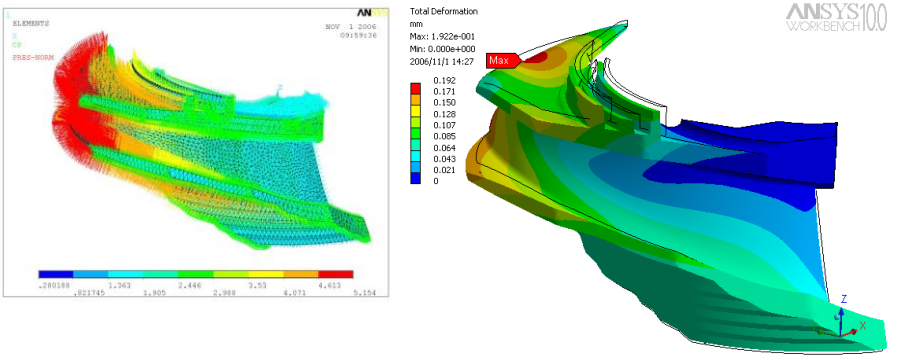
Challenges in the Design of Pump Turbines

Structural integrity: Static analysis



Load on the runner: pressure field calculated with numerical flow simulation
Standard stress analysis for a pump turbine runner comprises 4 load cases
Load case 1: Pump operation at maximum head (Pu-H_{max})
Load case 2: Pump operation at minimum head (Pu-H_{min})
Load case 3: Turbine operation at maximum head (Tu-H_{max})
Load case 4: Runaway, *Speed-no-Load*

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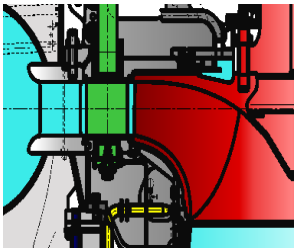
Challenges in the Design of Pump Turbines

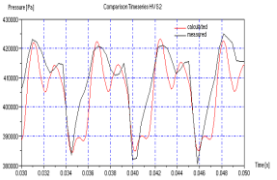
Rotor/stator interaction in a pump turbine

Unsteady pressure fields from flow analysis

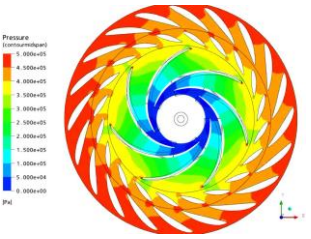


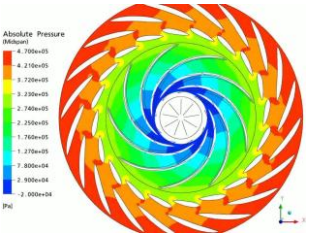
- Runner blades pass through wake of wicket gates
- Time-dependent pressure field
- Unsteady pressure distribution on runner blades
- Unfavorable blade number combinations can lead to higher pressure fluctuation

- 7 runner blades
- Pressure fluctuations in the 3. harmonic: 21*n
- Rotating pressure mode with runner rotation: +Mode



- 9 runner blades
- Pressure fluctuations in the 2. harmonic: 18*n
- Rotating pressure mode against runner rotation: –Mode





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Challenges in the Design of Pump Turbines

Rotor/stator interaction in a pump turbine

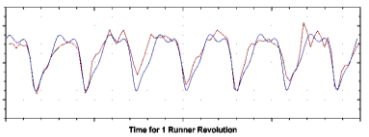
Dynamic analysis of the structure

Unsteady pressure fields from unsteady flow calculation for critical operating points

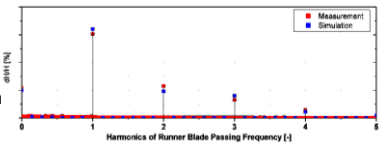
FEM analysis for specific excitation frequencies (harmonic response)

Pressure fields from CFD

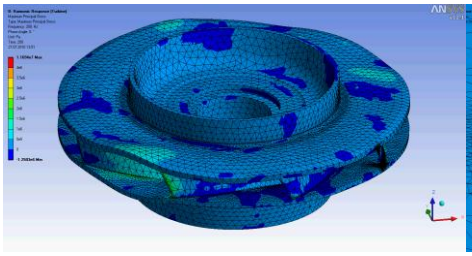
Time domain

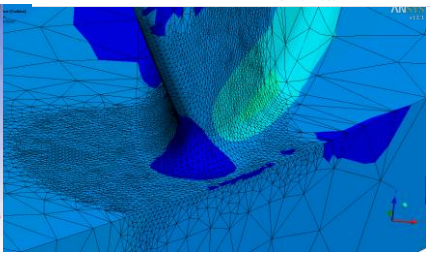


Frequency domain



Distribution of principal stresses





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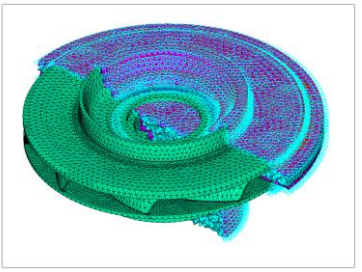
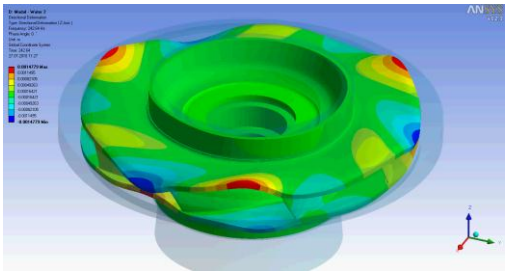
Challenges in the Design of Pump Turbines

Dynamic analysis of the structure

Modal analysis





Nodal diameter 3: counter phase of hub and shroud

- Natural frequency of the runner considering casing, gaps and added mass of water
- Natural frequency of critical nodal diameter has to have safe distance from excitation frequency (blade passing frequency)
- Analysis of nodal diameters 1 to 10

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Challenges in the Design of Pump Turbines

Medium head, medium specific speed

- Head range: 200–500 m
- Reversible machines

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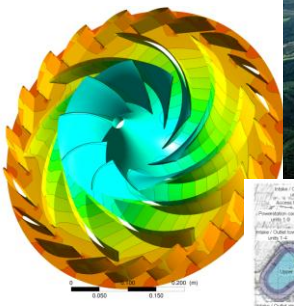
Challenges in the Design of Pump Turbines

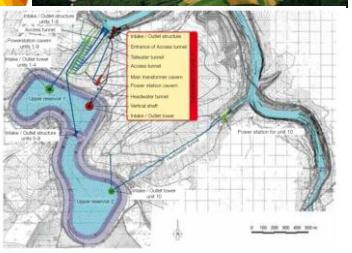
Vianden M11

Customer: Societe Electrique de l'Our

Extension of existing pumped storage plant
from 1100 MW to 1300 MW

Runner Diameter	D_1=4286 mm
Head range	H 269.4–294.6 m
Max power	P=200.4 MW
Speed	n=333.33 rpm
Specific speed	n_{sq} 156





Scope of supply:

1 Pump Turbine

1 Motor/Generator, governor

1 Spherical valve

Draft tube gate

Single guide vane servo motors

Mechanical synchronization of guide vane openings by synchronization ring

Hydraulically pre-stressed guide vane bearings

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Challenges in the Design of Pump Turbines

Low head, high specific speed

- Head range: H<200 m
- Reversible machines
- Compared with low specific speed machines for same power:
  - Higher discharge
  - Bigger dimensions

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Challenges in the Design of Pump Turbines

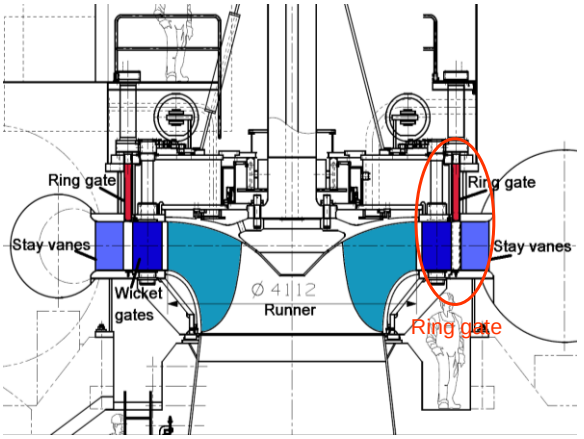
Baixo Sabor Montante

Customer: EDP, Portugal

Runner Diameter	D_1=4112 mm
Head range	H 68.8–104.6 m
Max power	P=76.9 MW
Speed	n =214.29 rpm
Specific speed	n_{sq} 212

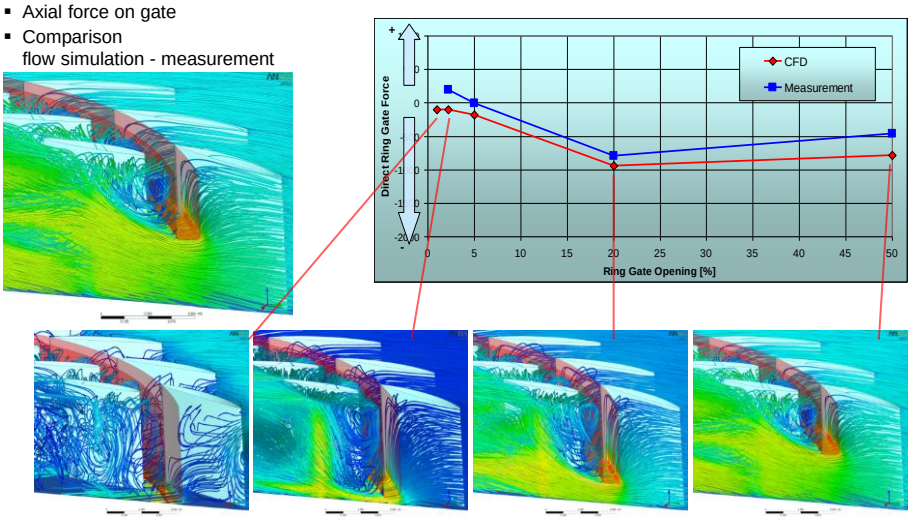
Scope of supply:
2 Pump Turbines
Motor/Generator
Governor
Ancillary equipment
Hydraulic steel structures

Wide head variation
Equipped with ring gate



Challenges in the Design of Pump Turbines

Ring gate
- Axial force on gate
- Comparison
  flow simulation - measurement



Challenges in the Design of Pump Turbines

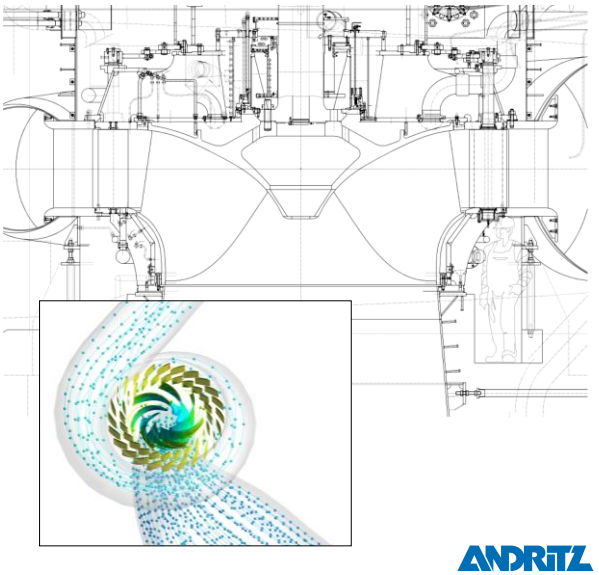
Baixo Sabor Jusante

Customer: EDP, Portugal

Runner Diameter	D_1=3948 mm
Head range	H 26.2–35.2 m
Max power	P=17.8 MW
Speed	n=150 rpm
Specific speed	n_{sq} 264

Scope of supply:
2 Pump turbines
Motor/generator
Governor
Ancillary equipment
Hydraulic steel structures

Wide head variation



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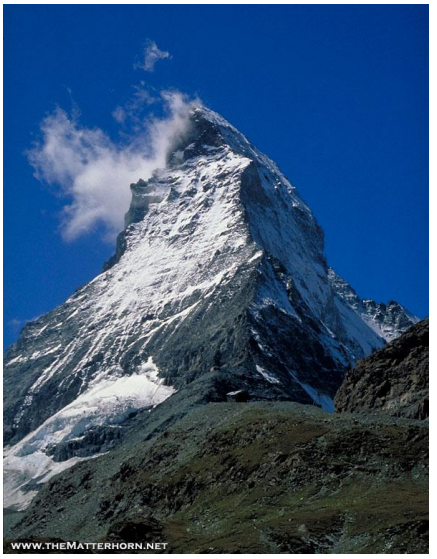

- Pumped storage plants can vary significantly in size, head and discharge
- In most cases, the electro-mechanical equipment (turbines and generators) is custom made specific to the site
- Specific technical challenges depending on size, head and discharge
- Technical challenges relate to hydraulic performance and mechanical integrity
- Design processes have to consider the operating regime (e.g. number starts and stops)

Thank you for your attention

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