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
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runner diameter D₁</td>
<td>2262 mm</td>
</tr>
<tr>
<td>Head range H</td>
<td>953.4–1065.7 m</td>
</tr>
<tr>
<td>Max power P</td>
<td>141.2 MW</td>
</tr>
<tr>
<td>Speed n</td>
<td>600 rpm</td>
</tr>
<tr>
<td>Specific speed nₛₚₚ</td>
<td>130</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runner diameter D₁</td>
<td>2230 mm</td>
</tr>
<tr>
<td>Head range H</td>
<td>700–804.8 m</td>
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<tr>
<td>Max power P</td>
<td>202.6 MW</td>
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<tr>
<td>Speed n</td>
<td>750 rpm</td>
</tr>
<tr>
<td>Specific speed nₛₚₚ</td>
<td>156</td>
</tr>
</tbody>
</table>

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 \( H = 568 \text{–} 734 \) 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

Challenges in the Design of Pump Turbines
Application to projects: Bhira

Bhira, India
1 Pump turbine, 1992
Customer: Tata Electric Companies, India

Runner Diameter \( D_1 = 3761 \) mm
Head range \( H = 510 \text{–} 530 \) m
Max power \( P = 165 \) MW
Speed \( n = 500 \) rpm
Specific speed \( n_{sq} = 90 \)
Runner band welded from three segments
Successfully in operation
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
Governor
1 Butterfly valve
1 spherical valve

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

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
Challenges in the Design of Pump Turbines

Rotor/stator interaction in a pump turbine

Unsteady pressure fields from flow analysis

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

- 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

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

Dynamic analysis of the structure

Unsteady pressure fields from unsteady flow calculation for critical operating points
FEM analysis for specific excitation frequencies (harmonic response)

Distribution of principal stresses
Challenges in the Design of Pump Turbines

Dynamic analysis of the structure
Modal analysis

- 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

Nodal diameter 3: counter phase of hub and shroud

Challenges in the Design of Pump Turbines

Medium head, medium specific speed

- Head range: 200–500 m
- Reversible machines
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
Challenges in the Design of Pump Turbines

Baixo Sabor Montante

Customer: EDP, Portugal

Runner Diameter \( D_1 = 4112 \text{ mm} \)

Head range \( H = 68.8–104.6 \text{ m} \)

Max power \( P = 76.9 \text{ MW} \)

Speed \( n = 214.29 \text{ rpm} \)

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

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

Challenges in the Design of Pump Turbines
Challenges in the Design of Pump Turbines

Baixo Sabor Jusante

Customer: EDP, Portugal

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

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

Wide head variation

- 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