HQ design and analysis

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Outline

• Magnet design
• Magnetic analysis
  – Conductor peak field
  – Magnet parameters
  – Field quality and saturation effect
• Mechanical analysis
  – Pre-load conditions
  – Coil and structure stress
• Conclusions
Cable and coil design

- **Cable**
  - 35 strands
  - Width: 15.150 mm
  - Mid-thickness: 1.437 mm
  - Keystone angle: 0.750
  - Insulation thick.: 0.1 mm

- **Coil**
  - Aperture: 120 mm
  - 4 blocks
  - 46 turns
Magnet design
Cross-section

• Aluminum collars
  – 25 mm thick
  – OD = 570 mm
• 4-split iron yoke
• Bolted iron pads
  – Gaps for coil end support and cooling channels
• Iron masters
  – 2 bladders 50 mm wide
  – 2 interference keys
• Bolted aluminum collars for azimuthal alignment
• G10 sheet between coil and collars
Magnet design
3D components

- Yoke laminations, 50 mm thick with tie rods
- Iron pad laminations, 50 mm thick tie rods
- Collar laminations, 50 mm thick with tie rods
- Iron masters
  - Easy insertion and removal of coil pack (large clearance)
  - Continuous surface
  - Pad-yoke alignment
  - Improved tolerances
Magnet design
Axial support

• Stainless steel (Nitronic 40) end plate
  – 50 mm thick

• Aluminum axial rods
  – 34 mm diameter

• Axial pre-load provided by additional plate and piston
  – Piston actuated to spread apart the two end plates
  – Nuts to lock the pre-compression
Magnet design
Alignment

- Pins shell – yoke
- Master keys pad – yoke
  - Trapezoidal shape
  - Interference keys
  - Alignment keys
- Pad – Collar
- Collar – coil
  - Alignment keys
    - Under compression from assembly to excitation
Magnet design
From TQS to HQ

TQS

LQS

HQ
2D magnetic analysis
Conductor peak field and magnet parameters

- $J_c$ of 3000 A/mm$^2$ (4.2 K, 12 T)

- About 0.7 T difference between layer 1 and layer 2

<table>
<thead>
<tr>
<th>Layer 1</th>
<th>Layer 2</th>
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<tbody>
<tr>
<td>Temp.</td>
<td>Current</td>
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<tr>
<td>K</td>
<td>kA</td>
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<tr>
<td>4.4</td>
<td>17.73</td>
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<tr>
<td>1.9</td>
<td>19.45</td>
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</table>

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2D magnetic analysis
Iron saturation and field quality

- \( R_{\text{ref}} = 40 \text{ mm} \)
- At 120 T/m
  - All allowed harmonics below 0.5 units
- Saturation effect
  - \( b_6 \pm 1 \text{ unit from 0 to 20 kA} \)
3D magnetic analysis
Conductor peak field

- Peak field in the end located on pole turn, layer 2

- Stainless steel pad over ends
  - About 1% lower peak field in the end with respect to straight section
2D mechanical analysis
Parameters and model

• Computational steps
  – Bladder pressurization
  – Key insertion
  – Cool-down
  – Excitation

• Impregnated coil surfaces: bonded

• All other surfaces: 0.2 friction factor

• Contact pressure (or tension <20 MPa) between pole and coil

• Two gradient considered
  – 219 T/m: limit conditions
  – 180 T/m: coil peak stress <150 MPa

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<th>Grad</th>
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<th>180</th>
<th>219</th>
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<td>N/mm</td>
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</table>
2D mechanical analysis
Bladder pressure and shell tension

• Pre-loading for 180 T/m
  – Bladder pressure: 23 MPa
  – Key interference: 0.3 mm
  – Shell tension:

• Pre-loading for 219 T/m
  – Bladder pressure: 46 MPa
  – Key interference: 0.6 mm
  – Shell tension:
2D mechanical analysis

Coil peak stress after cool-down

- **Pre-loading for 180 T/m**
  - Coil peak stress: 150 MPa
    - Pole area, inner radius, layer 1

- **Pre-loading for 219 T/m**
  - Coil peak stress: 192 MPa
    - Pole area, inner radius, layer 1
2D mechanical analysis
Coil peak stress with e.m. forces

- Pre-loading for 180 T/m
  - Coil peak stress: 144 MPa
    - Mid-plane, inner radius, layer 1

- Pre-loading for 219 T/m
  - Coil peak stress: 193 MPa
    - Mid-plane, inner radius, layer 1
3D mechanical analysis
Parameters and model

• Computational steps
  – Bladder pressurization
  – Key insertion
  – Cool-down
  – Excitation

• Impregnated coil surfaces: bonded

• All other surfaces: 0.2 friction factor

• Contact pressure between pole and coil
Comparison 2D-3D models
3D mechanical analysis
Aluminum rod tension and coil-pole

- Pre-loading for 219 T/m
  - E.m. force: 1372 kN
  - 620 kN applied at 4.2 K
  - <20 MPa tension at 219 T/m
3D mechanical analysis
Alignment key collar-coil

• Contact between collar and alignment key
Conclusions

• HQ is a field quality quadrupole with a 120 mm bore and an expected maximum gradient
  – 199 T/m at 4.4 K and 219 T/m at 1.9 K

• The shell based structure is based on the experience from TQS and LQS
  – Maintains the coil in contact with the pole in the straight section and in the end region up to short sample
  – Provides alignment to coil and structural components

• The coil peak stress can be maintained below 150 MPa with a pre-load for 180 T/m