Summary of MQXF short model tests, and start of first MQXFA prototype test, for HiLumi LHC IR quads.

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• **Qa/Q2b by CERN**
  - Cold mass with single 7.15 magnet (MQXFB)

• **Q1/Q3 by US (LARP ➔ HL-LHC AUP)**
  - Cold mass with two 4.2 m magnets (MQXFA)
## MQXFA(US)/B(CERN) Design

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>Unit</th>
<th>MQXFA/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil aperture</td>
<td>mm</td>
<td>150</td>
</tr>
<tr>
<td>Magnetic length</td>
<td>m</td>
<td>4.2/7.15</td>
</tr>
<tr>
<td>N. of layers</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>N. of turns Inner-Outer layer</td>
<td></td>
<td>22-28</td>
</tr>
<tr>
<td>Operation temperature</td>
<td>K</td>
<td>1.9</td>
</tr>
<tr>
<td>Nominal gradient</td>
<td>T/m</td>
<td>132.6</td>
</tr>
<tr>
<td>Nominal current</td>
<td>kA</td>
<td>16.5</td>
</tr>
<tr>
<td>Peak field at nom. current</td>
<td>T</td>
<td>11.4</td>
</tr>
<tr>
<td>Stored energy at nom. curr.</td>
<td>MJ/m</td>
<td>1.2</td>
</tr>
<tr>
<td>Diff. inductance</td>
<td>mH/m</td>
<td>8.2</td>
</tr>
<tr>
<td>Strand diameter</td>
<td>mm</td>
<td>0.85</td>
</tr>
<tr>
<td>Strand number</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td>Cable width</td>
<td>mm</td>
<td>18.15</td>
</tr>
<tr>
<td>Cable mid thickness</td>
<td>mm</td>
<td>1.525</td>
</tr>
<tr>
<td>Keystone angle</td>
<td></td>
<td>0.4</td>
</tr>
</tbody>
</table>

G. Ambrosio et al., “First Test Results of the 150 mm Aperture IR Quadrupole Models for the High Luminosity LHC” NAPAC16, FERMILAB-CONF-16-440-TD

Test Status

- **Single Coils:**
  - Short Coil in Mirror Structure (RRP 108/127)
  - Long Coil in Mirror Structure (RRP 108/127)

- **Short Models:**
  - MQXFS1a/1b/1c  (RRP 108/127 and 132/169)
  - MQXFS3a/3b  (RRP 108/127 and 132/169)
  - MQXFS5  (PIT 192 w/out bundle barrier)

- **Prototypes:**
  - MQXFA1 - in progress
    - (RRP 108/127, 132/169, 144/169)
Single Coils in Mirror Structure

- Successful test of single short (1.2 m) and long (4.0 m) coil in mirror structure
  - Large current & temperature margin
  - Very good memory
- → Coil fabrication (materials & processes) is fine
Short Models: Quench History

MQXFS1a/b/c:
- Exceeded requirements with large current and temp. margin
- Very good memory
- 1c: developed a “weakness”, exceeded ultimate op. current

MQXFS3a/b:
- ~Reached ultimate op. current
- Limiting coil
- Increased axial pre-stress helped

MQXFS5:
- Exceeded ultimate op. current
- Very good memory
- Slow training
Short Models: Pre-stress

Exploring pre-stress space (azimuthal & axial)
- Azimuthal up to nominal current looks OK in new magnet
- Axial up to nominal current looks OK in new magnet
- Mixed results when increasing axial pre-load in tested magnets

Note: azimuthal values recalibrated using coil-pole “detachment” during energization (max – 10 Mpa)

Courtesy of: G. Vallone & P. Ferracin
Some MQXFS1/3/5 harmonics were above target

- MQXFS1 focused on **uniform stress**
- MQXFS3/5 assembly focused on **Field Quality**

**Solution: shimming**

- During coil fabrication (S2-glass)
- During coils-pads assembly (Polyimide)
- After magnet assembly (Magnetic shims)

Warm-Cold Harmonics correlation in MQXFS1

Courtesy of: J. DiMarco
Quench Protection

- Outer Layer Heaters are performing as expected
- CLIQ is performing as expected
  - We can protect triplet magnets with redundancy
- Inner Layer Heaters have some detachment issues
  - Work in progress

### Table 11. Failure case analysis.

Simulated hot-spot temperature, peak voltage to ground and peak turn to turn voltage obtained for one failure or two simultaneous failures of QH circuits, at nominal and at ultimate current. Uncertainty ranges are due to the different locations of the initial quench and of the failing QH circuits.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>$T_{\text{hot}}$ [K]</th>
<th>$U_{g,\text{peak}}$ [V]</th>
<th>$U_{t,\text{peak}}$ [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No f</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Nominal current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O-QH</td>
<td>330-345</td>
<td>345-362</td>
<td>363-384</td>
</tr>
<tr>
<td>O-QH + I-QH</td>
<td>251-253</td>
<td>255-266</td>
<td>277-283</td>
</tr>
<tr>
<td>O-QH + CLIQ</td>
<td>236-237</td>
<td>238-240</td>
<td>239-242</td>
</tr>
<tr>
<td>Ultimate current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>O-QH</td>
<td>352-369</td>
<td>364-385</td>
<td>379-406</td>
</tr>
<tr>
<td>O-QH + I-QH</td>
<td>276-279</td>
<td>279-292</td>
<td>301-310</td>
</tr>
<tr>
<td>O-QH + CLIQ</td>
<td>260-262</td>
<td>261-264</td>
<td>262-267</td>
</tr>
</tbody>
</table>

Req. $T_{\text{hot}} < 350$ K

*Courtesy of: E. Ravaioli*
1st MQXFA Prototype

- 4 m long coils (magnetic length)
  - Conductor: RRP 108/127, 132/169, 144/169
- Full length structure (for 4.2 m coils)

Quench History, 1st thermal cycle

- 1st quench: 15.5 kA
- Ult.: 17.89 kA, 143.2 T/m, 12.3 T
- Nom.: 16.47 kA

Courtesy of: M. Anerella

Courtesy of:
P. Ferracin,
S. Stoynev,
H. Bajas,
M. Bajko &
J. Muratore
Summary

- Single coil tests have demonstrated that coil fabrication technology is fine
- Short models have demonstrated that MQXF design can meet requirements
- In progress:
  - Optimization of pre-load
  - Optimization of shimming for Field Quality
  - Fixing inner layer trace/insulation bonding
- Prototype tests are starting…

Thank you!