IT quadrupoles: summary of test results

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on behalf of the MQXF collaboration

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CERN
Acknowledgments

• **CERN**

• **BNL**
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• **FNAL**

• **LBNL**
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• **NHMFL**
  - Lance Cooley
Outline

• Introduction

• Assembly and loading

• Test results
**Introduction**

HiLumi low-β quadrupole MQXF

- **Target:** 132.6 T/m
  - 150 mm aperture, 11.4 T $B_{peak}$

- **Q1/Q3** (by AUP)
  - 2 magnets MQXFA with 4.2 m
    - Series: 20 magnets

- **Q2a/Q2b** (by CERN)
  - 1 magnet MQXFB with 7.15 m
    - Series: 10 magnets

- Different lengths, same design
  - Identical short models
## Introduction

### Tests
- **2 single-coil tests**
  - MQXFSM1 (1.2 m)
  - MQXFAM1 (4.0 m)
- **4 short models (1.2 m)**
  - MQXFS1
  - MQXFS3
  - MQXFS5
  - MQXFS4
- **2 MQXFA prototypes**
  - MQXFAP1 (4.0 m)
  - MQXFAP2 (4.2 m)

### Assembly MQXFB prototype (7.15 m) in progress

### Total of 31 coils “used”

#### Parameters of coil used in short models and prototypes

<table>
<thead>
<tr>
<th>Coil</th>
<th>Laboratory</th>
<th>Strand</th>
<th>Cross-section</th>
<th>$L^5$ (m)</th>
<th>Magnet</th>
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<td>RRP 108/127</td>
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<td>1.19</td>
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Electrical tests

• Coil to QH (requirement)
  • 52 coils, tested in the range 2500-3700 V, all passed

• Coil to floating part (QC)
  • Coil to end-shoe
    • 2 MQXFA coils did not pass (binder issue)
  • Coil to pole
    • Weak insulation (from 20 to 800 MΩ) coil to pole in CERN coils
    • No issue for US coils except 1
Outline

- Introduction
- Assembly and loading
- Test results
MQXF mechanical structure
Room temperature pre-load

- Pole key – collars
  - from 0.100 interf to 0.200 mm gap.
- Coil pre-load
  - from -60 to -110 MPa
Pre-load after cool-down

• Different level of pre-load achieved
  • Low pre-load in MQXFS1a → unloading before $I_{\text{nom}}$
  • Full pre-load in MQXFS3s → unloading at $I_{\text{ult}}$
• Same approach axially

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Outline

- Introduction
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Test results
Single coil tests

- MQXFSM1, 1.2 m and MQXFAM1, 4.0 m
- Iron structure (“mirror”), load-line similar to MQXFS
- Successful validation of coil design and fabrication procedure → bout 87% of $I_{ss}$

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Test results MQXFS1

- 1\textsuperscript{st} generation coils, RRP 108/127 and 132/169
- MQXFS1a, then increase of azimuthal (MQXFS1b)
  - $I_{\text{ult}}$ reached in all tests (some detraining quenches)
  - Up to 19 kA (highest current reached so far)
Test results
MQXFS1

• Then...
  • Increase of axial pre-load (MQXFS1c)
  • $I_{ult}$ reached at 1.9 K and 4.2 K (some detraining and loss of memory)
Test results
MQXFS1

- Then…
  - Stainless steel shell welding (MQXFS1d)
  - Process demonstrated, limited pre-load increase at warm and no pre-load increase at cold
Test results
MQXFS3

- 2nd generation coils, RRP 108/127, 132/196, 144/169
- MQXFS3a
  - Degradation in end region of coil 7, bypassed at high ramp rates
- Then increase axial (MQXFS3b)
  - Better, but similar behavior
Test results
MQXFS3

- Then
  - Change of coil and increase azimuthal (MQXFS3c)
  - $I_{ult}$ only at high ramp-rate $\rightarrow$ limited by “old” coil (106)
- Interpretation: degradation triggering self-field instability
Test results
MQXFS3

- MQXFS3a assembled with pole key to collar interference
  - Major damage in pole key

![Graph showing pole key and no pole key stresses](image)

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Test results
MQXFS5

- 2\textsuperscript{nd} generation coils, PIT 192
  - “Nominal” pre-load
  - $I_{ult}$ reached, both at 1.9 K and 4.5 K, with full memory
  - Change of slope during training
Test results
MQXFS4

- 2nd generation coils, RRP 108/127
  - “Nominal” pre-load
  - $I_{ult}$ reached, both at 1.9 K and 4.5 K, with full memory
  - Fastest training

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Test results
MQXFS4

- Then…
  - Insertion of cold bore and beam screen
    - Validation of process
  - No effect on magnet performance
MQXFAP1

- 1\textsuperscript{st} generation coils, 4.0 m, RRP 108/127, 132/169, 144/169
- 3 thermal cycles for problems in cryogenic system
- $I_{\text{nom}}$ reached, training stopped because of a short to ground caused by previous double-short QH to coil
MQXFAP1

• Short was caused by a series of events
  • Coil 5 impregnation was poor in the short area:
    • Increased possibility of helium trapped after cold test
  • Between quench 1 and 2, magnet hi-potted with high voltage (2.5 kV) at 293 K, after helium exposure
• Design weakness is excluded
MQXFAP2

- 2nd generation coils, 4.2 m, RRP 108/127
- Same pre-load as MQXFAP1
- Test in progress
Comparison/conclusions

• All short models and MQXAP1 reached $I_{nom}$
• 3 short models reached $I_{ult}$
  • MQXFS3 only at high ramp-rate and MQXFAP1 stopped by electrical short
• MQXFS4 fastest training (6 quenches to 85% of $I_{ss}$)
Quench protection

- Inner layer quench heaters abandoned
  - Issue of delamination not solved
- Protection with outer layer QH and CLIQ
Next steps

• Assembly of MQXFBP1

• Assembly of MQXFS6: PIT with bundle
Appendix
Conductor and cable

- Two final strands
  - RRP 108/127 (MQXFA/B)
  - PIT 192 with bundle barrier (MQXFB)
- Also used
  - 132/169 and PIT without bundle barrier
- So, $I_{nom}$ correspond to
  - 77% of $I_{ss}$ for RRP
  - 79% of $I_{ss}$ for PIT
- And $I_{ult}$ $\rightarrow$ 84-86%
- 1st and 2nd gen. cables
  - From 0.55° to 0.40° keystone angle

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Field quality