Mechanical analysis and assembly of MQYYM: a 90 mm NbTi quadrupole magnet option for HL-LHC


J. C. PEREZ, S. FERRADAS TROITIÑO, A. FOUSSAT, E. TODESCO, S. EMAMI NAINI, M. GUINCHARD (CERN)
THE MQYY QUADRUPOLE OPTION IN HL-LHC

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>MQY</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Aperture diameter</td>
<td>70 mm</td>
<td>90 mm</td>
</tr>
<tr>
<td>Inter beam distance</td>
<td>194 mm</td>
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</tr>
<tr>
<td>Magnetic length</td>
<td>3,4 m</td>
<td>3,67 m</td>
</tr>
<tr>
<td>Gradient</td>
<td>160 T/m</td>
<td>120 T/m</td>
</tr>
<tr>
<td>Current</td>
<td>3610 A</td>
<td>4590 A</td>
</tr>
<tr>
<td>Peak field at nominal current</td>
<td>6,1 T</td>
<td>6,4 T</td>
</tr>
<tr>
<td>Load line margin</td>
<td>23%</td>
<td>23%</td>
</tr>
<tr>
<td>Temperature</td>
<td>4,5 K</td>
<td>1,9 K</td>
</tr>
<tr>
<td>Mechanical structure</td>
<td>Self supported collars</td>
<td></td>
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OVERVIEW OF MQYY ACTIVITY

- Single aperture short model of 1.320 m long
- Operating current: 4550 A (23% margin)
- NbTi cable with kapton insulation
- Yoke outer diameter 360 mm

2 full length prototypes

PHASE 1
- Concept design

PHASE 2
- Engineering design

PHASE 3
- MQYYP Manufacturing
PRE-STRESS REQUIREMENTS

### Design Material Properties

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[1] J. Lucas et al., Internal report on MQMC2 coil rigidity measurements

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PRE-STRESS REQUIREMENTS

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PRE-STRESS REQUIREMENTS

![Cast3M model](image)

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**Pre-stress requirements**

**Design material properties**

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PRE-STRESS REQUIREMENTS

**Design Material Properties**

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- **Coil thermal contraction**: 5 mm/m

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**Azimuthal stress after collaring:**

- **60 MPa** for a minimum compression of **10 MPa** on the pole during energization at ultimate current
- **Lower than 150 MPa** to not damage the insulation [3]

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MQYYM WINDING

- 10 Coils have been wound at CEA
- 4 coils for magnet assembly and 2 spares have been identified after electrical tests

First layer winding and polymerisation

Second layer winding and polymerisation

High pressure during polymerisation leading to the apparition of shear plane crack in G10
- 10 Coils have been wound at CEA
- 4 coils for magnet assembly and 2 spares have been identified after electrical tests

High pressure during polymerisation leading to the apparition of shear plane crack in G10

Grooves for Vtaps wires
Check the coils size to adjust the coils preload after collaring (at CERN)

General Procedure [6][7]:
- Define the coil nominal size (using the stainless steel dummy coils)
- Press the coil on the E modulus press until the nominal coil size

MQYYM MECHANICAL CHARACTERISATION OF THE COILS

Coil 1 (reference coil)

Average stress (MPa)

Displacement (mm)

Coil 1 inner layer

Coil 1 outer layer

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MQYYM MECHANICAL CHARACTERISATION OF THE COILS

Corrected curves

Initial collar cavity size (ie dummy coil size)

Average stress (MPa)

Displacement (mm)
Nominal collar cavity size (ie dummy coil size)

Preload would be:
≈150 MPa outer
≈120 MPa inner
Preload would be:
≈160 MPa outer
≈130 MPa inner
MQYYM MECHANICAL CHARACTERISATION OF THE COILS

![Diagram showing stress-strain relationship for coils.](image)

- **Average stress (MPa)**
- **Displacement (mm)**

- **2:1**
- **3203 004 x8**
- **3203 002 x8**

- **-0.15 mm de-shimming**

Legend:
- Green line: Coil 1 inner layer
- Red line: Coil 1 outer layer
- Purple line: Collar cavity target
- Orange line: Real collar cavity (tolerances + rigidity)

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MQYYM MECHANICAL CHARACTERISATION OF THE COILS

Target preload
≈120 MPa outer
≈90 MPa inner
Requires -0,15 mm

Minimum preload
60 MPa

-0,8 -0,7 -0,6 -0,5 -0,4 -0,3 -0,2 -0,1 0 0,1 0,2
Displacement (mm)

-140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140
Average stress (MPa)

Coil 1 inner layer
Coil 1 outer layer
Collar cavity target
Real collar cavity (tolerances + rigidity)
MQYYM MECHANICAL CHARACTERISATION OF THE COILS

Coil 3,8,9 bigger

Coil 2 smaller

Average stress (MPa)

Average displacement (mm)

Displacement (mm)

Coil 1 inner layer
Collar cavity target

Coil 1 outer layer
Real collar cavity (tolerances + rigidity)

+/- 50µm

-0.15 mm de-shimming

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MQYYM MECHANICAL CHARACTERISATION OF THE COILS

Coil 3, 8, 9 bigger
Coil 2 smaller

Coils 3, 8, 9
-0.1 mm de-shimming
-0.2 mm de-shimming

Average stress (MPa)
Average displacement (mm)

Displacement (mm)

Coil 1 inner layer
Coil 1 outer layer
Collar cavity after 0.1 mm deshimming
Collar cavity target
Collar cavity after 0.2 mm deshimming
Real collar cavity (tOLERANCES + rigidity)
Preload will be:
≈120 MPa outer
≈90 MPa inner
Requires -0.1 mm for coil 2 and for -0.2 for other coils
No shimming in the ends

Initial position (@3MPa) and final position (@110MPa) along the coil 1

- Displacement (mm)
- Position of the measurement along the Coil1 (mm)
- Initial position @3MPa
- Final position @110MPa
MQYYM ASSEMBLY

- Assembly made at CERN
- Positionning of the protection heaters and instrumentation of the trace
MQYYM ASSEMBLY

- Assembly made at CERN
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- Ground plane insulation forming and mounting
Assemby made at CERN
- Positionning of the protection heaters and instrumentation of the trace
- Ground plane insulation forming and mounting
- Collaring shoe and protection shim positioning
- Mounting of the collars
- **Bi-axial gauges** used at two locations
- **Cut out** in the instrumented collars to remove the $\sigma_r$
- Misalignment of the collars over the coil ends
- Bigger forces used on the jacks over the coil ends
MQYYM COLLARING AND INSTRUMENTATION

- Massaging + Insertion of the keys at 70%
- Factor 2 between the strain read in the collars and the one expected due to the lack of collar nose

Stress in the collars measured by the strain gages

Collars mounting | 150 kN on the main jacks | Insertion of the keys at 70% | Removal of collaring forces | Creep after 2 days | Desassembly

- Inner layer
- Outer layer

σ₀ in Pa
- 7.76E+09
- 6.68E+09
- 5.92E+09
- 4.99E+09
- 4.07E+09
- 3.15E+09
- 2.23E+09
- 1.31E+09
- 3.85E+08
- 5.36E+08

Instrumented collars

0.6 mm Protection shim

~230 MPa on measured collar

120 MPa in coil

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MQYMM COLLARING AND INSTRUMENTATION

- Massaging + Insertion of the keys at 70%
- Factor 2 between the strain read in the collars and the one expected due to the lack of collar nose

Stress in the coil (2 time less than the stress measured in the collar)
- Massaging + Insertion of the keys at 70%
- Factor 2 between the strain read in the collars and the one expected due to the lack of collar nose
Electrical tests after the collaring at 70%: Turn to turn short circuit detected => decision to decollar
- Short disappears after decollaring of the LE
- Location of the short circuit suspected to be between the pole turn and turn 2
- Crack starts observed in coils
NEXT ASSEMBLY STEPS AND TEST

Mandrel removal & flanges assembly

Longitudinal preload apply with instrumented bullets

3D model in progress for the definition of the axial preload

Axial displacement (mm)
NEXT ASSEMBLY STEPS AND TEST

Mandrel removal & flanges assembly

Longitudinal preload apply with instrumented bullets

Yoking

Axial displacement (mm)

3D model in progress for the definition of the axial preload

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NEXT ASSEMBLY STEPS AND TEST

Mandrel removal & flanges assembly

Yoking

Connection box

Longitudinal prelaod apply with instrumented bullets

Connection box mock-up made at CEA

Axial displacement (mm)

3D model in progress for the definition of the axial preload

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NEXT ASSEMBLY STEPS AND TEST

- Mandrel removal & flanges assembly
- Longitudinal preload apply with instrumented bullets
- Connection box mock-up made at CEA
- Axial displacement (mm)
- 3D model in progress for the definition of the axial preload
- Test at CEA Saclay
- 1.9K test in saturated bath

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One 4 meter long practice coil has been wound by Sigmaphi and by Elytt Energy
The mechanical structure mock-up program is in the final phase
IN SUMMARY

- Due to turn-to-turn short in the first MQYYM assembly a **new assembly is foreseen in October 2019**
- Based on coils mechanical measurement and strain gages measurement of the first MQYYM collaring, **target pre-load should be achieved**
- A cold test is scheduled this winter at CEA

- **Two 4 meter long practice coil** have been wound within QUACO: One by Sigmaphi and one by Elytt Energy
- **2 full length prototypes are expected** to be delivered in fall 2020 at CEA for cold tests
ELECTRICAL ISSUE

- Electrical tests after the collaring at 70% (Resistance and capacitance discharge)
- Turn to turn short circuit detected => decision to decollar

Coil 3 exhibits
- a change of R of about 9 mΩ in the inner layer (2%)
- a change of L of about 2/8 % at 100 Hz/1kHz wrt other coils