Status of the Activity for the Construction of the HL-LHC Superconducting High Order Corrector Magnets at LASA-Milan

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Mon-Mo-Or1
Scope

- The INFN-LASA follows the design, construction and test of the 5 prototypes of the high order (HO) corrector magnets for the interaction regions of HL-HiLUMI.
- This activity is founded by INFN (Magix “activity”), and with an agreement CERN contributes for about 50%.
Magnet zoo (prototypes)

Sextupole
OD=320 mm
Completed & successfully tested

Octupole
OD=320 mm
Completed & successfully tested

Decapole
OD=320 mm
Completed & in test phase

Dodecapole
OD=320 mm
Ordering phase

Skew quad
OD=460 mm
Ordering phase

Physical length:
- 90-120 mm from 6-pole to 10-pole
- 430 mm 12-pole normal
- 840 mm 4-pole skew

Conductor type: NbTi
Peak field on cond.: 2-3 T
Operating current: 105-180 A
Margin on load line: 50-60%

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The design is based on superferric configurations.
Large bore aperture (150 mm)
Nb–Ti coils operating in a static superfluid He bath at 1.9 K.
Large margin on load line (about 60%, corresp. to $\Delta T \approx 4.5$ K).
- The detailed 3D design of all magnets completed, to fulfill the requirements

<table>
<thead>
<tr>
<th>Magnet order</th>
<th>Type</th>
<th>Integr. field at r=50 mm</th>
<th>Magnetic Length</th>
<th>Coil Peak Field</th>
<th>Magnetic stored energy</th>
<th>Operating Current</th>
<th>Turn per coils</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrupole</td>
<td>S</td>
<td>1.016</td>
<td>0.671 m</td>
<td>3.53 T</td>
<td>36 kJ</td>
<td>182 A</td>
<td>754</td>
</tr>
<tr>
<td>Sextupole</td>
<td>N,S</td>
<td>0.064</td>
<td>0.140 m</td>
<td>2.14 T</td>
<td>1.2 kJ</td>
<td>132* A</td>
<td>216*</td>
</tr>
<tr>
<td>Octupole</td>
<td>N,S</td>
<td>0.046</td>
<td>0.099 m</td>
<td>2.06 T</td>
<td>1.1 kJ</td>
<td>105 A</td>
<td>228</td>
</tr>
<tr>
<td>Decapole</td>
<td>N,S</td>
<td>0.026</td>
<td>0.097 m</td>
<td>1.73 T</td>
<td>0.5 kJ</td>
<td>105 A</td>
<td>228</td>
</tr>
<tr>
<td>Dodecapole</td>
<td>N</td>
<td>0.086</td>
<td>0.471 m</td>
<td>1.44 T</td>
<td>7.8 kJ</td>
<td>105 A</td>
<td>432</td>
</tr>
<tr>
<td>Dodecapole</td>
<td>S</td>
<td>0.017</td>
<td>0.089 m</td>
<td>1.44 T</td>
<td>~0.9 kJ</td>
<td>105 A</td>
<td>~172</td>
</tr>
</tbody>
</table>

* Value of the sextupole prototype, to be scaled for the series production.
The scope was:
- $T_{\text{max}} < 250$ K (for safety reason)
- $\Delta V_{\text{max}} < 300$ V (to limit the magnet test at room temp. to 2 kV)

The protection study has been executed with the code QLASA

Comparison between calculation and prototype tests validate the results.
Quench Protection II

- Study has been performed to avoid dump resistor for energy extraction (to simplify the circuit)
- Results: all magnets fulfill the requirements except the Quadrupole

Max voltage & hot spot temperature without dump resistor

<table>
<thead>
<tr>
<th></th>
<th>4-pole</th>
<th>6-pole</th>
<th>8-pole</th>
<th>10-pole</th>
<th>12-pole-N</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-max (V)</td>
<td>633</td>
<td>135</td>
<td>70</td>
<td>36</td>
<td>251</td>
</tr>
<tr>
<td>T-max (K)</td>
<td>132</td>
<td>164</td>
<td>131</td>
<td>122</td>
<td>147</td>
</tr>
</tbody>
</table>

- With a $R_{\text{dump}} = 1.5 \, \Omega$ (grounded in the middle), the Quadrupole V-max goes to 287 V
Prototyping I

• The prototyping of 6-pole, 8-pole and 10-pole has followed the same procedure:
  
  – Winding & Impregnating the S.C. coils at LASA
  
  – Test of single coil in LHe (to validate coil construction)
  
  – Ordering of the mechanical components of the magnets
  – Assembling of the components & coils at LASA
  – Quality Assurance tests
  – Powering test of the magnet in LHe and He-II
Different solutions tested and validated in the magnets.

Insulating materials compliant with the design radiation dose of 25 MGy

Casing and ground insulation in Duratron (PEI, 30% glass fiber)

Solution full in BTS2 (resin S2 laminate) or hybrid BTS2/Duratron
Prototyping III
Mechanics

- The iron laminations have been precisely machined by wire electro-erosion, with tolerance of +/-0.03 mm

The external alignments grooves allows to align the laminations with an external rectified tool

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Prototyping IV
Electrical Connections

• The soldering of coil & voltage taps connections is performed on Cu tracks on 2 separate Arlon disks.
Prototyping V

- Three of the five magnets have been completed

6-pole
Completed
Tested

8-pole
Completed
Tested

10-pole
Completed
To be tested

12-pole & 4-pole
Assigned to industry

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12-pole and 4-pole have larger dimensions
Coils cannot be built at LASA
Construction has been assigned to industry after a tender
Completion in 2018
Powering Test

- The magnet is inserted in a vertical cryostat for test in LHe and He II (2.2 K)

- **Scope of tests:**
  - To reach nominal and ultimate current (108% of nominal) and stay for 1 h
  - Verify limiting current (@ 4.2 K)
  - Verify memory on training after thermal cycle

- 6-pole tested in Feb. 2016: excellent results already reported last year (97% of s.s.l.)

- 8-pole tested in May 2017

- 10-pole test in Sept. 2017

- 12-pole and 4-pole in 2018
• Reached required performance with 3 quenches
• Proved to have stable operation at ultimate current (108% of nominal) and at 150% of nominal.
• Slow training towards short sample and reached 90% of s.s.l. after ~20 quenches.
Conclusions

- The prototyping of the 5 high order corrector magnets of HL-LHC is ongoing at INFN-LASA (Milan).
- The first prototype, the sextupole, was completed and tested in 2016.
- The octupole, completed and tested in 2017: it reached required performance.
- The decapole is completed and powering test is in progress.
- No substantial issues have been identified in magnet constructions.
- The dodecapole and skew-quadrupole construction has been assigned to industry.
- The completion and test of the magnets is expected in May 2018 (dodecapole) and in September 2018 (skew-quadrupole).
To Giovanni Volpini (1963-2016), who initiated, worked and leaded this activity at LASA & CERN