STEAM at the MT26 conference

16 October 2019

Emmanuele Ravaioli
on behalf of the STEAM team
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Title</th>
<th>Type</th>
<th>Software</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Douglas M. Araujo</td>
<td>CERN</td>
<td>Preliminary Design of HEPdipo, a Nb3Sn Large Aperture Dipole Magnet for Cable and Insert Coil testing</td>
<td>Poster</td>
<td>LEDET</td>
<td>Yes</td>
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<tr>
<td>Daniel Davis</td>
<td>LBNL</td>
<td>Performance, diagnostic, and quench measurements of a dipole composed of two racetrack coils wound with high temperature superconducting Bi-2212 Rutherford cable</td>
<td>Oral</td>
<td>LEDET</td>
<td>Yes</td>
</tr>
<tr>
<td>Helene Felice</td>
<td>CEA</td>
<td>Advances in Nb3Sn Superconducting Accelerator Magnets</td>
<td>Plenary</td>
<td>LEDET</td>
<td>Yes</td>
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<tr>
<td>Alexandre M. Louzguiti</td>
<td>CERN</td>
<td>Design of radiation hard spare units for the orbit corrector dipoles of LHC</td>
<td>Poster</td>
<td>LEDET</td>
<td>Yes</td>
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<tr>
<td>Vittorio Marinozzi</td>
<td>FNAL</td>
<td>Analysis of the heater-to-coil insulation in MQXF coils</td>
<td>Poster</td>
<td>LEDET</td>
<td>Yes</td>
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<tr>
<td>Samuele Mariotto</td>
<td>INFN</td>
<td>Fabrication and results of the first Round Coil Superferric Magnet at LASA</td>
<td>Poster</td>
<td>COSIM</td>
<td>No → Yes</td>
</tr>
<tr>
<td>Matthias Mentink</td>
<td>CERN</td>
<td>Protection Studies of the HL-LHC circuits with the STEAM Simulation Framework</td>
<td>Poster</td>
<td>BBQ, COSIM, LEDET, ProteCCT, SIGMA</td>
<td>Yes</td>
</tr>
<tr>
<td>Matthias Mentink</td>
<td>CERN</td>
<td>Quench simulations versus experimental observations on the HL-LHC MCBRD canted-cosine-theta short models and prototype magnets</td>
<td>Oral</td>
<td>BBQ, ProteCCT</td>
<td>Yes</td>
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<tr>
<td>Emmanuele Ravaioli</td>
<td>CERN</td>
<td>Quench protection of the 16 T Nb3Sn ERMC and RMM magnets</td>
<td>Oral</td>
<td>LEDET</td>
<td>Yes</td>
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<tr>
<td>Andrew Twin</td>
<td>Oxford Instruments</td>
<td>Use of Silicon Carbide Varistors For Quench Protection of Superconducting Magnets in Cryogenic Environments</td>
<td>Oral</td>
<td>ProteCCT</td>
<td>Yes</td>
</tr>
</tbody>
</table>
STEAM at MT26 conference – New contacts and future users

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rod Bateman</td>
<td>Tokamak Energy</td>
<td>Quench protection of HTS magnets</td>
</tr>
<tr>
<td>Marco Breschi</td>
<td>University of Bologna</td>
<td>Magnet transient simulations; University training</td>
</tr>
<tr>
<td>Arnaud Foussat</td>
<td>CERN</td>
<td>Quench protection studies</td>
</tr>
<tr>
<td>Piyush Joshi</td>
<td>BNL</td>
<td>Support during magnet testing</td>
</tr>
<tr>
<td>Andrew Twin</td>
<td>Oxford Instruments</td>
<td>Quench protection studies</td>
</tr>
</tbody>
</table>
Magnetic and Mechanical 3-D Modelling of a 15 T Large Aperture Dipole Magnet

- Douglas M. Araujo (CERN)
- 16 October 2019

**MAGNETIC DESIGN**
- Peak field on coils: 1 T
- Homogeneity of 1% over 1 m length
- Margin of 10% at 4.2 K
- RFK write technology
- Rectangular aperture of 100 x 100 mm
- Double layer impregnated coils
- Block-type magnet with stainless-steel coils
- Shaded and key pre-load system
- Energy Extraction quench protection system
- Magnet for the SPC-EPFL test facility

**CABLE AND MAGNET PARAMETERS**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire diameter (in mm)</td>
<td>0.012</td>
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<tr>
<td>Current density (A/mm²)</td>
<td>4.200</td>
</tr>
<tr>
<td>Critical current (A)</td>
<td>18400</td>
</tr>
<tr>
<td>Critical current density 12 T</td>
<td>3000</td>
</tr>
<tr>
<td>Critical current density 15 T</td>
<td>3000</td>
</tr>
<tr>
<td>C, in kJ/m²/mm²</td>
<td>2525</td>
</tr>
<tr>
<td>T C, in K</td>
<td>16</td>
</tr>
<tr>
<td>R C, in T</td>
<td>28.8</td>
</tr>
<tr>
<td>Number of wires per cable</td>
<td>44</td>
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<tr>
<td>Bare cable thickness (in mm)</td>
<td>0.08</td>
</tr>
<tr>
<td>Number of turns per layer (quadrant)</td>
<td>32</td>
</tr>
<tr>
<td>Operating current (A)</td>
<td>34.4</td>
</tr>
<tr>
<td>Total stored magnetic energy (kJ)</td>
<td>12.7</td>
</tr>
<tr>
<td>Operating temperature T, in K</td>
<td>4.2</td>
</tr>
</tbody>
</table>

**MECHANICAL DESIGN**
- Von Mises Stress in MPa: 150 MPa
- Peak stress on the structural parts in MPa: 160 MPa
- After processing:
  - Average contact pressure in MPa: 35.8

**QUENCH PROTECTION ANALYSIS**
- Quench propagation performed using STEAM-LEDIT: https://espace.cern.ch/steam

- Peak tension of 105 MPa
- Peak pressure of 35 MPa

**STEAM at the MT26 conference – E. Ravaioli – 16 October 2019**
LBL-CLIQ Demonstration on RC7n8 Common Coil Dipole at 77 K

- First CLIQ testing of a Bi-2212 dipole. Ready for liquid helium quench testing.
- LEDET simulation matches reasonably with measurement.
  - Rapid decay due to dynamic inductance replicated
Simulating Control of CLIQ Heat Deposition with Mid-Taps: 
Coil Field and Quench Margin
Alexandre M. Louzguiti (CERN)

Design of radiation hard sparse units for the orbit corrector dipoles of LHC

Context

Due to the HL-LHC upgrade, the Nb-Ti orbit corrector dipoles (MC2C and MC38) will receive significantly increased gamma radiation doses, i.e. up to 20 MGy over the HL-LHC lifetime. These magnets, essential to the LHC operation, were not designed to withstand such doses; we have thus started a gamma radiation campaign to determine their radiation hardness.

In addition, since the available spares magnets are limited in number and not radiation resistant, we have also designed radiation hard versions of the present MC2C and MC38 magnets.

Magnet components and insulation systems

Gamma radiation hardness of present magnets

Radioactive contamination by injection

Gamma radiation hardness: magnetic shielding

Quench simulation

Quench simulation

Conclusion

We have presented the results of a radiation test campaign on MC2C and candidate materials for spares for MC2C and MC38 magnets. We have started a water radiation campaign to determine the gamma doses that these magnets can safely absorb to anticipate the number of units that will need to be replaced. In parallel, we have designed radiation hard spare versions of the MC2C and MC38 magnets involving technology modifications (magnets, yokes, supports) with respect to their original designs.

In addition, we have performed simulations, mechanical and quench protection studies that have confirmed the viability of these designs in the same technological environment than the present MC2C and MC38 magnets installed in LHC.
Analysis of the heater-to-coil insulation in MQXF coils

Vittorio Marinozzi (FNAL)

In the framework of the MTF26 project, the general LHC code superconducting magnets will be calculated with more performance gain. The project collaborates with the LHC and DT groups in the field of the magnetic performance. One of the main technological challenges for the high-field magnets is the optimization of the electrical and mechanical performances of the insulation system. A detailed study of the performance and optimization of the insulation system is required to be associated with efficient ways to improve the electrical and mechanical properties of the magnet in order to reduce the impact of loss on the coil. This paper presents the results of the analysis of the insulation system in MQXF coils. The results show that the insulation system in MQXF coils is optimized to achieve the desired performance.
I. INTRODUCTION

Technological development and innovation is underpinning magnets for particle accelerators require new solutions in magnets’ design and use of HTS materials. A main weapon for the construction of superconducting high field solenoids is proposed here. Such advanced magnet design is proved to be a potential candidate for future solenoids in superconductors using only single layers of superconductors. A step forward is achieved by the design of a magnet with a maximum field at the pole face of 11 T, which is obtained by a new kind of winding: a non-superconducting solenoid (NCS) placed in the central part of the magnet, while the superconducting winding is placed in the pole faces. This innovative method is demonstrated to be effective for the suppression of stray fields, while achieving a field of 11 T at the pole faces. The NCS winding is designed to minimize the magnetic field in the central part of the magnet, thus reducing the stray field. The superconducting winding is then placed around the NCS winding, increasing the field at the pole faces. This approach allows for a significant improvement in the magnetic field distribution and a reduction in the magnetic field in the central part of the magnet. The presented design is a step forward in the development of magnets for particle accelerators, as it demonstrates the potential of using non-superconducting materials in the central part of the magnet to achieve high field strengths at the pole faces.
Introduction

- High-Luminosity Large Hadron Collider Upgrade: CERN Upgrade to achieve ten times higher luminosity
- Circuits powering ten different superconducting magnet types, with often more than one variant per magnet type
- Within STEAM project: Extensive simulation effort, cross-checked against experimental observations where possible, toward understanding the transient behavior of the HL-LHC circuits and their components, and to ensure their proper protection

Inner triplet circuit

- Lattice triplet in the MAD-X lattice generator (LATT1)
- Inner triplet circuit (HC1) in the steering-magnet model (LSM1)
- Effects of DC and AC on the beam (Note: AC is black; DC is red)
- Additional quadrupole magnets, protected with energy extraction (QO)
- Initial voltage development after a quench (QO)
- Discharge behavior of the magnets (QO)
- Twin Aperture Orbit Correctors: Protection against energy extraction and quench back
- Definition of energy extractor characteristics for proper protection
- Initial voltage development after a quench (QO)
- Discharge behavior of the magnets (QO)

Main dipole circuit + 11 T cryo-assembly

- Complete dipole circuit with 11 T cryo-assembly and term circuits
- Magnets of different types: superconducting (HL-LHC), hybrid (HC1), and warm (warm magnets, high-temperature superconductors)
- Simulation of transient behavior of the circuit current limits + hardware (HC1)
- Simulation of the peak voltage to ground and resulting hotspot temperatures for different energy extraction values (quench stopper, warm magnets)

Hollow Electron Lens

- Hollow Electron Lens: 16 circuits powering superconducting magnets, protected with energy extraction
- For different energy extraction values, simulation of the resulting hotspot temperatures and voltages to ground (QO)

Superconducting busbars

- Quench simulations of the various superconducting busbar models
- Consideration of quench stoppers, local cooling conditions, expansion loops, etc.
- Initial voltage development, quench propagation velocity, effect of compositions, resulting hotspot temperature (QO)

Summary

- Extensive simulation effort to understand the transient behavior of the HL-LHC circuits (HL-LHC Work Package 7)
- Simulation tools developed for this purpose: Co-simulation, LEDET, SIGMA, BBQ, ProtocCC, amongst others
- Purpose: To ensure proper protection and introduce adjustments to the circuits as needed, to contribute to the success of the HL-LHC upgrade
- These studies were made possible through collaboration within the CERN Technology department and with the external collaborators. We thank everyone for their support.
Simulation versus experimental observations (1/2)

- **Extensive** measurement campaign by SM18 personnel
- Comparison of simulation to experimental observations for: Different magnetic lengths, energy extractor types, helium bath temperatures, operating currents
- No free parameters except global constants $f\text{LoopFactor} = 2.0$, $\text{addedHeCpFrac} = 0.6\%$
Andrew Twin presented Matthias’ simulations of transients in CCT magnets performed with ProteCCT.
Helene Felice (at her plenary talk)

Modeling quench behavior (some examples)

**LEDET**: Lumped-Element Dynamic Electro-Thermal

- Quench simulation including coupling losses
- Allows CLIQ parametrization
- Valid for stand alone magnets
- Validation with MQXFAP1

*Courtesy of E. Ravaioli*

[Graphs and data](https://espace.cern.ch/steam/)

**ANSYS® User defined elements**

- Modeling magnetization of the conductor due to coupling currents
- Combining all the effects into a single coupled simulation with B and T dependant properties

*Courtesy of L. Brouwer* [https://usmdp.lbl.gov/scpack-code/](https://usmdp.lbl.gov/scpack-code/)

**ANSYS® 3D thermal stress**

*Ongoing study 3D modeling AUP/HL-LHC cross-check ongoing*

*Courtesy of J. Ferradas Troitino*
Congratulations to Lorenzo!

IEEE CSC Graduate Study Fellowship in Applied Superconductivity

https://ieeecsc.org/awards/ieee-csc-graduate-study-fellowship-applied-superconductivity