Plan and status of the review on the past experience with Nb_3Sn dipoles

D. Schoerling

7th of November 2016, Annual EuroCirCol meeting

Mandate

- Within the FCC technology companion programme at CERN a review is requested
- First paragraph from the recommendations of the EuroCirCol review:

> "There has been an impressive amount of design work carried out over a relatively short period of time. The Committee did note the **lack of reference** to previous efforts and identification of new ideas versus what might be considered extensions of earlier work. We encourage continued integration and collaboration with other high field magnet programs. Doing so would add considerable value to the program and accelerate progress toward the Collaboration's goal."

- Report on recommended follow-up R&D: Gap analysis
- The review report shall be a useful tool to understand how to best design high-field dipole magnets

Scope of reviews under preparation

- A first report shall describe objectively all SMC and RMC magnets, which have been so far built and tested. The description shall be performed in great detail including the design, the production process and the test results to fully document the performed work and make it better accessible. Currently, Rafal Ortwein is reviewing the work done in 927 and Hugo Bajas/Jose Vicente Lorenzo Gomez the powering test results. This work could be published as CERN Yellow Report.

- A second review report shall treat all lines of Nb_3Sn dipole magnets for High-Energy Colliders, which have been developed at BNL, CERN, LNBL, Fermilab and Twente in the past and review the technology development dedicated to high-field superconducting magnets. This work shall conclude with the formulation of the main open R&D topics to go beyond the current state-of-the-art. Sasha Zlobin and Daniel Schoerling intend to set-up a structure and form a team for the review before the end of this year. This review could be published as a book.

SMC/RMC production and test report

- This report summarizes in great detail (~1000 pages) the design, manufacturing and test results of the SMC/RMC program (SMC #1, #2, #3a, #3b, #4, #5, 11T #1, #2, #3, #4, #4 C201, #4 C202 (without test); RMC Fresca 101, 201, 102, 202, QXF 201, QXF 202 (without test)
- It is the first time that all available information and the large amount of test data is coherently and comprehensively analysed and presented.
- The report does not intend to provide an analysis, what the best practice is to build a Nb_3Sn superconducting dipole. However, it provides a comprehensive overview of the technologies developed within the frame of the SMC/RMC program!

Schedule

- Copyediting1 (DS): Ready until end of February 2016 -> Authors should submit first version before the end of the year.
- Copyediting2 (DS): Ready until end of March 2017
- Copyediting3 (UK): Ready until May 2017
- Expert review of final draft: Ready July 2017 for next EuroCirCol review
- Proofreading (UK): August 2017
- Publication: August/September 2017

SMC/RMC table of contents

Contents

Powering test results will be added in the relevant section

SMC/RMC test results, list of figures

Main parameters of magnet
- Inductance measurement
- RRR measurement
- AC loss measurements (integrated power over full cycle vs ramp rate and maximum current)

Training
- I_q vs. number of quench
- I_q vs temperature (1.9 K and 4.2 K)
- I_q vs. strain/transverse peak stress over different SMC coils (few data)
- I_q vs ramp rate dI/dt

Quench studies
- Histogram of quench location (head/straight/mid-plane)
- MIITS vs. I_q
- *T vs.* MIITs [*T* calculated from (1) MIITs (adiabatic), (2) Cu resistivity through voltage measurement (non-adiabatic), and (3) energy dissipation in the magnet integrating the product $V_r \times I$ (adiabatic)]
- R_{mag} after quench vs. time (with and without quench heaters)
- E_{diss} (dissipated in He) and E_{extr} (in dump resistor) and E_{stored} vs I^2_q (with and without natural quench)
- Transversal & longitudinal quench velocity v_q vs. $J_{Non\text{-}Cu}$
- Time constant t = $L/(R_{dump} + R_{mag}) = -I(t)/(dI/dt)$ vs t
- (Detection time – Trigger time) vs I/Ic for different RMCs (quench heater efficiency)
- (Quench start time – Time when threshold is reached) vs. I/Ic

Instabilities
- Histogram of the number of flux jumps vs. RRR (different plots for RRP and PIT)
- Histogram of the amplitude of flux jumps vs I/Ic
- Bar chart with number of precursors vs. number of quench

Review of the Nb_3Sn accelerator magnet design and technologies

Editors: Schoerling, Zlobin

1. Introduction
   1. Historical overview (1960s-1980s)
   2. Nb_3Sn strand and cable progress (Intro, PIT & RRP)
2. Review of Nb3Sn accelerator magnet R&D programs
   1. Early demonstrators
      1. MSUT
      2. D20
   2. Nb3Sn magnet designs and technologies
      1. Block-type dipole
         1. LBNL HD + SM
         2. TAMU
         3. CERN FRESCA2 + SMC/RMC
      2. Common coil dipole
         1. LBNL RD
         2. BNL
         3. FNAL HFDC + HFDB
      3. Cos-theta dipole
         1. FNAL HFDA + mirrors HFDM
         2. FNAL/CERN MBH + mirrors + SMC/RMC
3. Summary – editors
   1. Strand and cable, insulation
   2. Coil design, materials, technologies (winding, splicing, grading, insulation, impregnation, heat treatment)
   3. Mechanical structures, materials
   4. Performance
   5. Potential for cost optimization
   6. Open issues
4. References

Total: 68-89p + Photos + refs

Detailed content of sections:

- Project goal, timeline, approach
- Magnet design choice
- Conductor choice and parameters
- Magnetic design and analysis
- Mechanical structure and analysis
- Quench protection approach
- Magnet technology details, new features, materials, technology development and results
- Magnet performance (quench performance, field quality, magnet protection parameters, etc.)
- Summary, achievements, lessons learned and open issues

Conclusion & Schedule

- The information of SMC/RMC is gathered, but at the moment only partially well dressed and editing is still required to make the report consistent and non-redundant.
- The SMC/RMC production and test report will be extremely detailed and comprehensive (~1000 pages).
- The review on the past dipole development lines shall be written by the leading experts and review the development of the Nb_3Sn dipole magnets and the main relevant technology developments
- The review shall conclude with the formulation of the main open R&D topics to go beyond the current state-of-the-art
- This review will be very useful for our work towards demonstrators and shall be the base for identifying the key R&D topics (for example insulation, impregnation, etc.)

EuroCirCol

CERN

FCC
hh ee he