Recent Activities on Pulsed Magnets

presented by L. Bottura

CARE-05 General Meeting
CERN, November 23rd-25th, 2005
Overview

- **Ongoing R&D for FAIR at GSI**
  - Design optimization, prototyping and test work on SIS-100 model (2 T, 4 T/s, 2 s, 200 x 10^6 cycles)
  - Test and analysis of a model for SIS-200 (4 T, 1 T/s, 24 s, 1 x 10^6 cycles)
  - Design work on SIS-300 (6 T, 1 T/s, 24 s, 1 x 10^6 cycles)

- **Pulsed Magnet Working Group** see [http://pmwg.web.cern.ch/pmwg/](http://pmwg.web.cern.ch/pmwg/)
  - Informal working group with 25 participants, 5 institutions collaborating in CARE-HHH-AMT
  - Foster exchange of information and steer R&D on superconducting pulsed magnets for accelerators (LHC & FAIR)
  - 2 meetings on design issues (strand, cable, magnet)

- **ECOMAG-05**
  - Workshop on pulsed superconducting magnets for accelerators
  - October 26th-28th, 2005 in Frascati (I)
Aims

- Define a set of magnet design parameters for the development of pulsed superconducting magnets for accelerators (this is one of the main objectives of HHH-AMT)
- Review the state-of-the-art of design and manufacturing capability
- Specify performance requirements and define R&D needs

Workshop jointly hosted and sponsored by ENEA and INFN Frascati

Organizing committee:

- L. Bottura (CERN), A. Della Corte (ENEA), P. Fabbricatore (INFN), U. Gambardella (INFN), G. Moritz (GSI), W. Scandale (CERN), D. Tommasini (CERN)
A Workshop!

- Three working groups
  - Wires and Cables (WG-1) J. Kaugerts (GSI)
  - Low losses pulsed magnets (WG-2), E. Salpietro (EFDA-CSU)
  - Heat transfer, quench protection and magnetic measurements (WG-3), A. Siemko (CERN)
- Invited talks from specialists in the field
  - D. Leroy (CERN) - Low-Loss Wires
  - P. Bruzzone (EPFL-CRPP) - Low-Loss Cables
  - J. Minervini (MIT-PFC) - Pulsed and AC Magnets
  - B. Baudouy (CEA-Saclay) - Cryogenic Heat Transfer
- Contributions from industry
- Summary and round table session
Superconducting Pulsed Accelerator Magnets

2 T, 4 T/s SIS-100 prototype

Heat load to helium, 1.4 m dipole
2 T, 4 T/s, 1 Hz
\[ Q_{\text{total}} = 38 \text{ W} \]
\[ Q_{\text{iron}} = 29 \text{ W} \]
\[ Q_{\text{coil}} = 9 \text{ W} \]

4 quenches to short sample limit
Continuous operation at 2 T/s
3 cycles at 4 T/s to 4 T
AC loss within a factor 2 of calculation

Characterization
Industrial production issues

Heat load optimization
Long-term mechanical stability
### Magnet Design Parameters for FAIR SIS-100 and SIS-300

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SIS-100</th>
<th>SIS-300</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak field [T]</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Good field region [mm]</td>
<td>HxV = 130x60</td>
<td>Φ = 80</td>
</tr>
<tr>
<td>Magnet length [m]</td>
<td>2.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Number of dipoles</td>
<td>108</td>
<td>108</td>
</tr>
<tr>
<td>Field quality [10^{-4}]</td>
<td>± 6</td>
<td>± 2</td>
</tr>
<tr>
<td>dB/dT [T/s]</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Duration of a cycle [seconds]</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td>Number of cycles (20 years) [-]</td>
<td>200 x 10^6</td>
<td>1 x 10^6</td>
</tr>
<tr>
<td>Radiation load [W/m]</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Average refrigeration power [W/m]</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
# Magnet Design Parameters for the Upgrade of LHC Injectors

<table>
<thead>
<tr>
<th></th>
<th>PS⁺</th>
<th>SPS⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak field [T]</td>
<td>3</td>
<td>4.5</td>
</tr>
<tr>
<td>Good field region [mm]</td>
<td>HxV = 130x80</td>
<td>Φ = 80</td>
</tr>
<tr>
<td>Magnet length [m]</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Number of dipoles</td>
<td>100</td>
<td>750</td>
</tr>
<tr>
<td>Field quality [10⁻⁴]</td>
<td>± 4</td>
<td>± 2</td>
</tr>
<tr>
<td>dB/dT [T/s]</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Duration of a cycle [seconds]</td>
<td>3.6</td>
<td>12</td>
</tr>
<tr>
<td>Number of cycles (20 years) [-]</td>
<td>60 x 10⁶</td>
<td>1 x 10⁶</td>
</tr>
<tr>
<td>Radiation load [W/m]</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Average refrigeration power [W/m]</td>
<td>20</td>
<td>10</td>
</tr>
</tbody>
</table>
Magnet Design Options: from 2 T to 6 T

- Efficient use of conductor
- Good field quality
- 3.5 T for PS$^+$
- Internally cooled cables
- Controlled heat transfer
- Optimised cross section
- Operating margin
- 3 T for PS$^+$
- 2 T for SIS-100
- 6 T for SIS-300
- 6 T for SIS-300
Comments on the Magnet Design Options

- All magnet families have difficulties and challenges
  - *Balance* of conductor margins, losses, heat removal
  - *Field quality* in ramped conditions
  - *Large dynamic range* (a factor 30 in energy for the PS+)
  - *Magnet protection* during quench
  - Pulsed SC joints
  - *Fatigue* (several 1…100 MCycles)
  - Radiation (1…10 MGy)
  - Measurement and test issues
- All factors can be addressed and seem to be in reach of present technology, possibly with *optimized industrial process* (strand, cable)

**Can we build and measure these magnets?** YES
Networking Results - 1

- More than 70 participants (initial plan on 30 to 50)
- 17 laboratories and universities
  - Bochvar Institute, CEA, CERN, CIEMAT(*), EFDA-CSU(*), ENEA(*), EPFL-CRPP(*), FzK(*), GSI, IHEP, INFN-Frascati, INFN-Genova, INFN-Milano, JINR, KEK, MIT(*), Ohio State
  - (*) fusion/energy laboratories
- 7 major European industries:
Networking Results - 2

- Cross-breeding among laboratories (HEP and Fusion research in particular) on the topic of pulsed superconducting magnets
- Industry involved from the start of the brainstorming, bringing focused and relevant experience in this technology
- Very positive response!

We have identified a general interest in the community of clients and producers
Follow-up

- The material discussed is collected and will be posted on the www site of the Workshop
- The design coordinators will maintain momentum on the issues identified
- Reconvene in 6 months to verify progress

Special session at WAMDO
April 3-7 2006
CERN (Archamps)
Strand R&D Targets

D = 0.5 ... 0.8 mm
Jc > 2500 ... 3300 A/mm²
D_{eff} = 3.5 ... 5 µm

D = 0.8 mm
Jc > 2700 A/mm²
D_{eff} = 2.5 µm

D = 0.5 ... 0.8 mm
Jc > 2000 A/mm²
D_{eff} = 1 µm
Small Filament R&D - 1

- About 50% of the loss is generated by hysteresis in the filaments
- Simply reducing the filament size does not work

12000 monocores (1.5 mm wide)!

filament distortion near the copper!
Small Filament R&D - 2

Modified double stack
3.3 μm
In preparation

Hex single stack
Better geometry control
Small Filament R&D - 3

CuNi barriers
$D_{\text{eff}} = 5.2 \, \mu m$

CuNi to reduce coupling

CuMn matrix

CuMn to reduce proximity