R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300

P.Fabbricatore INFN-Genova

P.Fabbricatore¹, F. Alessandria², G. Bellomo², S. Farinon¹, U. Gambardella³, J.Kaugerts⁴, R.Marabotto⁵, H.Müller⁴, R.Musenich¹, G.Moritz⁴, D. Pergolesi¹, M.Sorbi² and G. Volpini²

(¹) INFN-Genova, Italy
(²) INFN-LASA and Milan University, Physics Department, Italy
(³) INFN-Laboratori di Frascati, Italy
(⁴) GSI-FAIR, Germany
(⁵) ASG-Superconductors (former Ansaldo), Genova, Italy,
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300

P. Fabbricatore INFN-Genova

The facility **FAIR** including the synchrotrons **SIS100** and **SIS300**
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300

P. Fabbricatore INFN-Genova

48 long dipoles – Magnetic length 7.89 m
12 short dipoles – Magnetic length 3.94 m

SIS 300 arc cryostat stacked on top of SIS 100

Courtesy Jan Patrick Meier
We are working at the development of a design for these magnets. The achievement of this target is passing through a R&D activity (*DiSCo_RaP*) aimed to the construction of a model of the short dipole.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal field</td>
<td>4.5 T</td>
</tr>
<tr>
<td>Ramp rate</td>
<td>1.0 T/s</td>
</tr>
<tr>
<td>Radius of curvature</td>
<td>66.67 m</td>
</tr>
<tr>
<td>Magnetic length</td>
<td>3.784 m</td>
</tr>
<tr>
<td>Bending angle</td>
<td>3 1/3 deg.</td>
</tr>
<tr>
<td>Coil aperture diameter</td>
<td>100 mm</td>
</tr>
<tr>
<td>Max operating temperature of LHe</td>
<td>4.7 K</td>
</tr>
<tr>
<td>Current sharing temperature</td>
<td>5.7 K</td>
</tr>
<tr>
<td>Operating conditions (fraction of I_c on the load line)</td>
<td>69%</td>
</tr>
<tr>
<td>Field quality at radius R=35 mm</td>
<td>2 (in 10^{-4} units)</td>
</tr>
</tbody>
</table>
Criticities of SIS300 dipoles ➔ Demand for R&D

1) AC losses
2) Field quality
3) Manufacturing
4) Large number of magnetic cycles
1) AC losses

Ac losses in the superconducting cable

1.1) Hysteretic losses in the superconductor
1.2) Coupling losses in the strand multifilamentary structure
1.3) Losses due to coupling currents between strands

Losses in the iron (Irreversible Magnetization, Eddy currents)

Eddy currents in the metallic structure

The heat generated shall be removed by the cooling system. We can have two unwanted cases:

1) Due to the limited heat transfer capability of cooling system the coil could quench
2) The thermal load to cooling system is high → High operation costs
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300
P. Fabbricatore INFN-Genova

<table>
<thead>
<tr>
<th>Aperture (mm)</th>
<th>B (T)</th>
<th>dB/dt (T/s)</th>
<th>Q (W/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC</td>
<td>53</td>
<td>8.34</td>
<td>0.0075</td>
</tr>
<tr>
<td>RHIC</td>
<td>80</td>
<td>3.5</td>
<td>0.07</td>
</tr>
<tr>
<td>SIS300</td>
<td>100</td>
<td>4.5</td>
<td>1</td>
</tr>
</tbody>
</table>

- Development of a low loss superconducting cable
- Maximization of the heat flow to the coolant
- Minimization of eddy currents
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300

P. Fabbricatore INFN-Genova

Contribution to ac losses (ramping) 34.4 W (9 W/m)

<table>
<thead>
<tr>
<th>Component</th>
<th>Contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hysteresis</td>
<td>36.5 %</td>
</tr>
<tr>
<td>Coupling Strand</td>
<td>10.7 %</td>
</tr>
<tr>
<td>Interstrand Ra+Rc</td>
<td>5.9 %</td>
</tr>
<tr>
<td>Total conductor</td>
<td>(53.1 %)</td>
</tr>
<tr>
<td>Collars + Yoke eddy</td>
<td>4.0 %</td>
</tr>
<tr>
<td>Yoke magn</td>
<td>16.2 %</td>
</tr>
<tr>
<td>Beam pipe</td>
<td>12.2 %</td>
</tr>
<tr>
<td>Collar-Keys-Pins</td>
<td>8.7 %</td>
</tr>
<tr>
<td>Yoke-Keys-Pins</td>
<td>5.8 %</td>
</tr>
</tbody>
</table>
Ac losses in the superconducting cable: a summary of conductor requirement and critical R&D

1) Hysteretic losses in the superconductor

$$Q \propto a B_e J_c$$

Critical R&D for reducing filament dimensions (3.5 - 2.5 μm)

2) Coupling losses in the strand multifilamentary structure

$$Q_e \propto \frac{B^2_{e \text{ peak}} l_p^2}{\rho_{et} T}$$

Critical R&D for optimizing interfilament resistivity and minimizing twist pitch

3) Coupling losses between strands

$$Q_c \propto \frac{B^2_{e \text{ peak}} l_{p \text{ Ruth.}}}{R_c T}$$

$$Q_a \propto \frac{B^2_{e \text{ peak}} l_{p \text{ Ruth.}}}{R_a T}$$

Critical R&D for reducing/optimizing crossover interstand resistance and adjacent resistance. Minimize twist pitch
Ac losses in the superconducting cable: a summary of conductor requirement and critical R&D

1) Hysteretic losses in the superconductor

\[ Q \propto a B_e J_c \]  
Critical R&D for reducing filament dimensions (3.5 - 2.5 μm)

2) Coupling losses in the strand multifilamentary structure

\[ Q_e \propto \frac{B_{e \text{peak}}^2 I_p^2}{\rho_{et} T} \]  
Critical R&D for optimizing interfilament resistivity and minimizing twist pitch

3) Coupling losses between strands

\[ Q_c \propto \frac{B_{e \text{peak}}^2 I_{p\text{Ruth.}}}{R_c T} \]  
Critical R&D for reducing/optimizing crossover interstand resistance and adjacent resistance. Minimize twist pitch

\[ Q_a \propto \frac{B_{e \text{peak}}^2 I_{p\text{Ruth.}}}{R_a T} \]
Ac losses in the superconducting cable: a summary of conductor requirement and critical R&D

1) Hysteretic losses in the superconductor

\[ \mathbf{Q} \propto a \mathbf{B}_e \mathbf{J}_c \]

Critical R&D for reducing filament dimensions (3.5 - 2.5 μm)

2) Coupling losses in the strand multifilamentary structure

\[ \mathbf{Q}_e \propto \frac{\mathbf{B}_{e \text{ peak}}^2 \mathbf{I}_p^2}{\rho_{et} T} \]

Critical R&D for optimizing interfilament resistivity and minimizing twist pitch

3) Coupling losses between strands

\[ \mathbf{Q}_c \propto \frac{\mathbf{B}_{e \text{ peak}}^2 \mathbf{I}_{p \text{Ruth.}}}{\mathbf{R}_c T} \]

Critical R&D for reducing/optimizing crossover interstand resistance and adjacent resistance. Minimize twist pitch

\[ \mathbf{Q}_a \propto \frac{\mathbf{B}_{e \text{ peak}}^2 \mathbf{I}_{p \text{Ruth.}}}{\mathbf{R}_a T} \]
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300
P.Fabbricatore INFN-Genova

Conductor under construction at Luvata Fornaci di Barga

<table>
<thead>
<tr>
<th>Wire</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter after surface coating</td>
<td>0.825 ± 0.003 mm</td>
<td></td>
</tr>
<tr>
<td>Filament twist pitch</td>
<td>5 +0.5 -0 mm</td>
<td></td>
</tr>
<tr>
<td>Effective Filament Diameter for 1st Generation wire</td>
<td>3.5 μm</td>
<td></td>
</tr>
<tr>
<td>Effective Filament Diameter for 2nd Generation wire</td>
<td>2.5 μm</td>
<td></td>
</tr>
<tr>
<td>Interfilament matrix material</td>
<td>Cu-0.5 wt% Mn</td>
<td></td>
</tr>
<tr>
<td>Filament twist direction</td>
<td>right handed screw (clockwise)</td>
<td></td>
</tr>
<tr>
<td>Ic @ 5 T, 4.22 K</td>
<td>&gt; 541 A</td>
<td></td>
</tr>
<tr>
<td>n-index @ 5 T, 4.22 K</td>
<td>&gt; 30</td>
<td></td>
</tr>
<tr>
<td>Stabilization matrix</td>
<td>Pure Cu</td>
<td></td>
</tr>
<tr>
<td>Strand transverse resistivity at 4.22 K</td>
<td>0.4 + 0.09 B [T]</td>
<td>nΩ·m</td>
</tr>
<tr>
<td>Cu+CuMn:NbTi ratio (α ratio)</td>
<td>&gt;1.5</td>
<td></td>
</tr>
<tr>
<td>α ratio tolerance</td>
<td>± 0.1</td>
<td></td>
</tr>
<tr>
<td>Surface coating material</td>
<td>Staybrite (Sn-5 wt% Ag)</td>
<td></td>
</tr>
<tr>
<td>Surface coating thickness d</td>
<td>0.5 μm</td>
<td></td>
</tr>
</tbody>
</table>

30 to 40 thous. NbTi filaments in CuMn matrix s/d ~0.15
Cable made of 36 strands with a core (thin sheath in SS 316L)
2) Field Quality

At present, the field quality seems under control from design point of view and looks much less critical than other aspects.

Total variation of sextupole and decapole field harmonics during the ramp up (dBo/dt=1 T/s), due to persistent currents, eddy currents in conductor and paramagnetism of copper-manganese matrix.
3) Manufacturing difficulties

The need of a low loss conductor imposes the use of a cored cable, stiffer than a simple Rutherford cable, so making the winding harder.

We think that the coil should be wound curved. This solution allows defining without uncertainty the geometrical dimensions of a curved stress-free coil (no spring back effects).

→ Development of the winding technologies for curved poles with cored cable. This activity is under progress in ASG-Superconductors. At present, we have many evidences that a suitable manufacturing methodology can be obtained.
A special winding machine has been developed at ASG-Superconductors. Successful winding tests done first with LHC outer layer conductor …
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300

P. Fabbricatore INFN-Genova
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300

P. Fabbricatore INFN-Genova
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300

P. Fabbricatore INFN-Genova

.. and later with a dummy cored conductor
3) Fatigue load

The magnets shall be cycled 10 million times, consequently the design shall be optimised in view of severe fatigue loads. Radiation effects may even weaken the material with respect to mechanical and electrical strength.

→ Mechanical design optimization to be checked through experimental results on the model
3) Fatigue load

The magnets shall be cycled 10 million times, consequently the design shall be optimised in view of severe fatigue loads. Radiation effects may even weaken the material with respect to mechanical and electrical strength.

→ Mechanical design optimization to be checked through experimental results on the model
The design of the model is close to be finalised (Summer 2008)
R&D ACTIVITIES AIMED AT DEVELOPING A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300
P.Fabbricatore INFN-Genova
Conclusions

Low loss cable, heat removal, fatigue, methods for manufacturing a curved winding are the main problems we are facing with the R&D activity DiSCoRaP.

Design, winding test and conductor development are going on with the final target of a model coil in its horizontal cryostat ready by end of next year.

A winding technology for curved poles with cored cable was developed.