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

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Abstract

One of the basic components of the FAIR facility, under development at GSI, is the synchrotron SIS300 (300 Tm rigidity). In order to reach the required high intensities of proton and heavy ions beams, the magnets of this synchrotron have to be pulsed from the injection magnetic field of 1.5 T up to 4.5 T maximum field at the rate of 1 T/s. These 7.8 m long, cos-teta shaped coils with a 100 mm bore have the particular characteristic to be curved (the sagitta is 114 mm). All these aspects demand for a challenging R&D, aimed at the development of a low loss conductor and at a suitable winding technology for curved coil. Further design issues are related to the optimization of stress distribution involving materials able to hold 10^7 cycles and to the maximization of the heat transfer to coolant (supercritical helium). At the present time, design activities are going on with the aim to design, construct and test a 3.8 m long prototype within 2010. In order to achieve this objective, several intermediate milestones are included in the R&D program. One of the most challenging is the industrial development of a method for winding a curved cos-teta dipole with the required geometrical accuracy.

INTRODUCTION

In the framework of a large international collaboration it is planned to construct a Facility for Anti-proton and Ion Research (FAIR) [1], to be integrated in the existing GSI accelerator complex in Darmstadt. The new facility will provide high intensity primary and secondary beams of ions and antiprotons for experiments in nuclear, atomic and plasma physics.

A central role of the FAIR facility is played by the synchrotrons SIS100 and SIS300 (the number in the name is related to the magnetic rigidity expressed in Tm). In order to reach the required high intensities, the magnets of the synchrotrons have to be rapidly pulsed at a high repetition frequency. The required dipole ramp rate is 4 T/s for SIS100 at about 1 Hz and 1 T/s for SIS300, with a duty cycle of 50%.

This paper deals with R&D activities aimed at developing the high field rapidly-cycling super-conducting dipoles needed for SIS300. The designers of SIS300 stressed the importance to have the maximum acceptance at the minimum field volume. Consequently, a curved design with a radius of 66.67 m was proposed. The present lattice design includes 48 long dipoles with magnetic length 7.89 m and 12 short dipoles with magnetic length 3.94 m. The coils have two main features: they are curved (the corresponding sagitta is 114 mm for long dipoles), and they are fast ramped (for a superconducting magnet). Both these characteristics demanded for a challenging R&D, aimed at the development of the required low loss conductor, a robust design with respect fatigue issues and a suitable winding technology.

The Italian National Institute of Nuclear Physics (INFN) proposed to perform this R&D in a larger framework aimed at construct a model magnet. A project, called DISCORAP ("Dipoli SuperCOnduttori RApidamente Pulsati"), started in 2006 according a specific INFN-FAIR Memorandum of Understanding signed by both institutions in December 2006. The aim is to have a complete cold mass model of the short dipole ready in the summer of 2009 [2]. After a preliminary test of the cold mass in a vertical cryostat, it will be integrated in a horizontal cryostat for a test campaign at GSI.

COIL LAYOUT

Table 1 shows the main characteristics of the model coil. The starting assumption for the design was that the coil should be curved since the winding, because: 1) This solutions allows defining a curved geometry of the coil with no residual stresses; 2) Once cured, the coil can be handled in simple and safe way for the following manufacturing operations (collaring, insertion in the iron yoke, …).

A different solution, involving the bending of a straight coil, has to face the problem of the spring back effect during all manufacturing stages and coil operation. The unpredictability of a mechanically loaded curved coil led us to reject this option.

At an initial stage the choice of a curved winding naturally oriented, on the design side, to a single layer coil mechanically supported only by the collars. This basic choice was based on the reason that the mechanical coupling between two curved layers or between a curved collared coil and a curved yoke appeared to be critical operations, which could be afforded only once the simplest curved layout (single collared layer) had been deeply investigated.

Table 1: Characteristics of the Model Coil

Nominal Field (T) :	4.5
Ramp rate (T/s)	1
Radius of magnet geometrical curvature (m)	66 1/6
Magnetic Length (m)	3.784
Bending angle (deg)	3 1/3
Coil aperture (mm)	100
Max operating temperature (K)	4.7

Nevertheless later on we realized that the iron yoke must have a role in limiting the mechanical deformations of the collared coil. If not, we could have fatigue failures in some locations of the collar. This point remarks the difference between small and large number of magnetic cycles. In our case the magnet shall be cycled 10 million times. These cycling operations will depress the mechanical properties of the materials. This should be taken into account both at design level (minimizing the stress variation during cycle) and at material choice level, by selecting fatigue resistant materials.

On these bases a 5 block lay-out was chosen. The winding is mechanically supported by a 30 mm thick collar in high strength austenitic steel and it is pre-stressed at 70 MPa at room temperature. The iron lamination is mechanically coupled to the collared coil in a way to give no further pre-stress but to limit the deformation during magnetic energization. Fig. 1 shows the cross section of the cold mass.

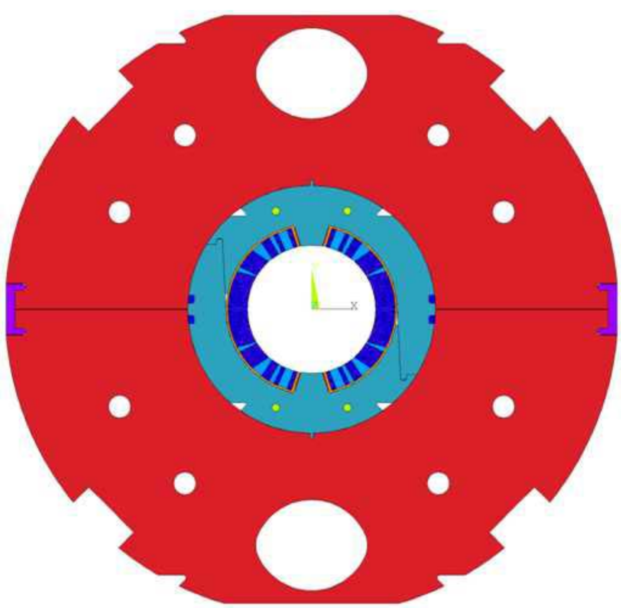

Figure 1: Cross section of the cold mass. The 5-blocks winding is in blue, the collars are in light blue and the iron lamination in red. The two halves of the iron are closed through Al alloy clamps.

The conductor under development is based on a cored Rutherford cable with 36 strands (similar to the LHC dipole outer layer), whose main characteristics are shown in Table 2. This conductor is characterized by having several components sized for low ac losses: 1) The filaments are fine (down to 2.5 µm) for minimizing the hysteretic losses; 2) The part of the matrix surrounding the filaments is made of CuMn, for the electromagnetic decoupling of the filaments and for increasing the transverse resistivity and, consequently, the coupling losses; 3) The cable is cored using a thin stainless steel foil (25 µm) for cutting down the inter-strand coupling currents.

This latter characteristic makes the conductor stiffer than a standard Rutherford cable, causing more difficult winding operations. For this reason we considered crucial the performing of an industrial R&D aimed at developing the winding techniques of a cored cable for a curved coil.

Table 3 shows the main characteristics of the winding. Fig.2 shows more details of cold mass ends with the end spacers and the electrical exits.

Table 2: Characteristics of the Conductor

Strand characteristics :	
Filament diameter (µm)	2.5 to 3.5
Strand Diameter (mm)	0.825
Twist Pitch (mm)	5-7
Cable characteristics :	
Number of strands	36
Width (mm)	15.1
Thickness: Thin/Thick edges (mm)	1.362/ 1.598
Core material/thickness (µm)	AISI 304/ 25
Critical Current @5T , 4.22K	>18540 A

Table 3: Characteristics of the Winding

Block number	5
Turn number/quadrant	34 (17+9+4+2+2)
Operating current (A)	8920
Yoke inner radius (mm)	96.85
Yoke outer radius (mm)	240.00
Peak field on conductor (with self field) (T)	4.90
B_{peak} / B_o	1.09
Working point on load line	69%
Current sharing temperature (K)	5.69

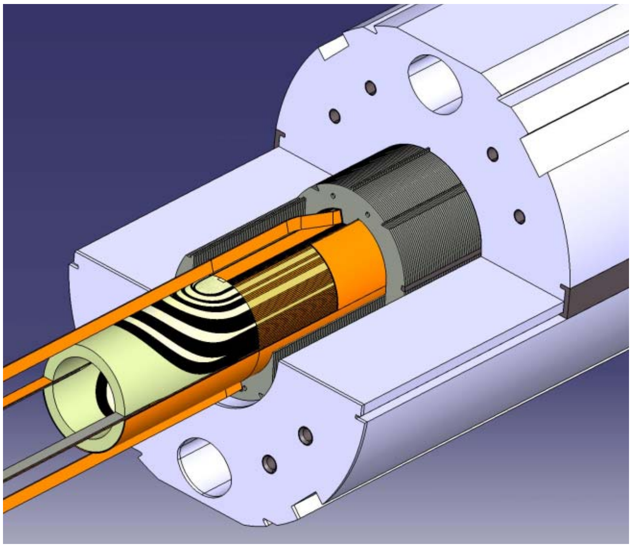

Figure 2: Details of the under design coil end.

INDUSTRIAL R&D

The design of the model coil is going on in parallel with crucial industrial R&D activities aiming at demonstrating the constructive feasibility of curved collared winding. This activity is under way at ASG Superconductors in Genova under an INFN contract. A special winding machine has been developed for being able to wind a Rutherford cable on a curved mandrel. An important milestone has been recently achieved with the successfully completion of the winding test aimed at assessing the developed winding technology. Fig.3 shows the winding operation of a curved coil and Fig.4 a detail of the coil end. The conductor used for these winding tests is not yet the low loss conductor under development (available at the end of 2008) but a dummy cored conductor obtained by cabling the LHC dipole wire (the one for outer layer) with a stainless steel insert (See Fig. 5).

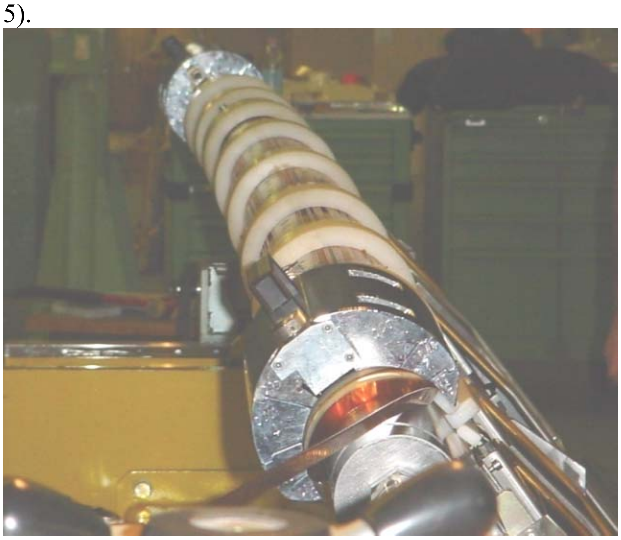

Figure 3: Winding operation with a dummy conductor. The geometrical curvature is clearly appreciable.

Figure 4: Winding test. Detail of the coil end with G11 spacers.

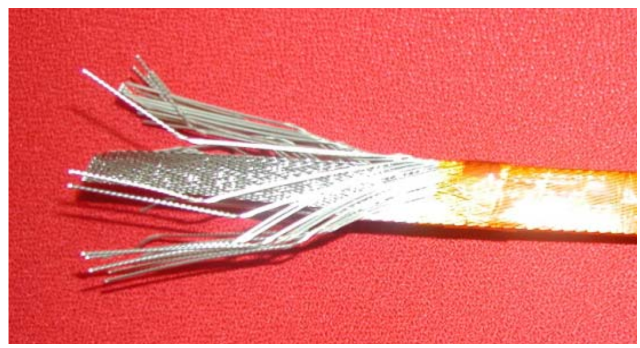

Figure 5: The dummy conductor used for the winding tests. In between the strands it is visible the thin stainless steel core used for depressing the inter-strand coupling currents.

FUTURE ACTIVITIES

The next step of the R&D is the construction of two cured poles with a dummy conductor within July 2008. Soon after the construction activities of the model magnet will start. Our plan is to have the cold mass finished within the summer 2009, ready for preliminary cold tests soon after and a completely cold tested in real operating conditions at GSI approximately in 2010. For this latter test the magnet shall be integrated into a horizontal cryostat presently under design.

REFERENCES

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