PULSED MAGNETS WITH CURVED SHAPE FOR FAIR

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Abstract

The Italian Institute of Nuclear Physics (INFN) is performing a R&D activity aimed at the construction of a model magnet for FAIR SIS300 dipole, which due the fast cycling operation (1 T/s) and the need to have a curved shape with a radius of 66.67 m, appears to be a very challenging task. The aim is to have a complete cold mass model of the short dipole ready in 2009 and the complete magnet in 2010. An important milestone has been recently achieved, with the successfully completion of the winding test aimed at assessing the developed winding technology for curved cosθ dipoles involving a cored Rutherford cable.

INTRODUCTION

In the framework of the Facility for Anti-proton and Ion Research (FAIR) [1] an important role is played by the synchrotron SIS300 which will accelerate intense heavy ion beams at high energy (e.g 2 10^9 per second U^{92+} up to 34 GeV/u). In order to reach the required high intensities, the magnets of the synchrotron have to be rapidly pulsed at a high repetition frequency. The required dipole ramp rate is 1 T/s with a duty cycle of 50%.

For having the maximum acceptance at the minimum field volume, a curved design with a radius of 66.67 m was proposed for the main dipoles. 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 sagitta is 114 mm for long dipoles and 28 mm for the short ones. Both the high ramp rate and the geometrical curvature demanded a challenging R&D, aimed at the development of the required low loss conductor, a robust design with respect to fatigue issues and a suitable winding technology.

The Italian National Institute of Nuclear Physics (INFN) is performing this R&D in a larger framework aimed at the construction of a model magnet. A project, called DISCORAP (acronym for "Dipoli SuperCOnduttori RApidamente Pulsati") is under way.

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A specific INFN-FAIR Memorandum of Understanding was signed by both institutions in December 2006 and the activities were performed in three INFN sections (Frascati, Genova and Milano-LASA) and in ASG Superconductors (this latter under INFN contract).

The aim is to have a complete cold mass model of the short dipole ready in the 2009 [2]. After a preliminary test of the cold mass in a vertical cryostat in 2010, it will be integrated into a horizontal cryostat for a test series at GSI/FAIR

COIL CHARACTERISTICS

Table 1 shows the main characteristics of the model coil. This model represents a test bench in view of the construction of the real fast cycled curved sc dipole magnet for SIS300. If the constructive technologies and the technical solutions adopted for the model are successfully, the next step will be the realization of prototypes, preliminary to the mass production. However also if the model is neither a magnet to be installed in the SIS300 nor a prototype magnet, it contains most of the features and the characteristics of the SIS300 short dipoles.

The starting assumption for the design was that the coil should be wound curved, because:

1) This solution allows defining a curved geometry of the coil with no residual stresses;

2) Once cured, the coil can be handled in a simple and safe way for the following manufacturing operations (collaring, insertion in the iron yoke, …).

Since the initial design stage, in order to simplify the construction, we chose a single layer coil, mechanically supported mainly by the collars and partially by the iron yoke. This lay-out, fully acceptable from a design point of view, allows focusing the problematic of the construction on the crucial aspects related to the coil curvature and the peculiarity of the cored cable.

As result of these basic choices and after a dedicated magnetic design activity, a 5 block lay-out was chosen.

The winding is mechanically supported by a 30 mm thick collar of high strength austenitic steel with very low magnetic permeability.

The iron lamination is mechanically coupled to the collared coil in a way to give no further coil pre-stress but to limit the collared coil deformation during magnetic energization.

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

This approach is finalised to increase the strength in view of the fatigue load (the magnet shall be operated for 10^7 cycles).

Fig. 1 shows a picture of the cold mass under design. Table 2 and Table 3 summarize the main characteristics of conductor and winding.

The conductor under development is based on a cored Rutherford cable with 36 strands (similar to the LHC dipole outer layer).

Among the several features aimed to minimize ac losses, the cable presents a very peculiar characteristic: it is cored using a thin stainless steel foil (25 μm) for cutting down the inter-strand coupling currents, which would cause very high ac losses.

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

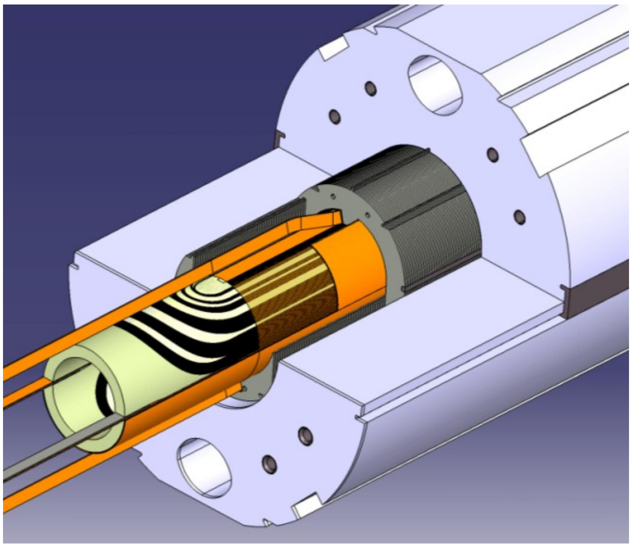

Figure 1: View of the cold mass under design with a detail of the coil end with electrical terminations. The winding is naturally curved. The collars and the iron laminations are assembled in a way to follow the coil curvature. The longitudinal stiffness ids provided by the outer shall in stainless steel (not shown here)

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

INDUSTRIAL R&D

The design of the model coil went in parallel with the industrial R&D activities aimed at demonstrating the construction feasibility of curved collared winding. This activity was carried out at ASG Superconductors in Genova, under an INFN contract. A special winding machine was developed for winding the cored Rutherford cable on a curved mandrel (see Fig. 2).

An important milestone was recently achieved, with the successfully completion of two complete poles (winding and curing) of the desired geometrical quality, proving the soundness of the developed winding technology (see Figs. 3 and 4).

The conductor used for these winding tests is not yet the low loss conductor under development (it is now under construction at Luvata in Pori (F) and available in the spring 2009), but a trial winding cored cable obtained by cabling the LHC dipole wire (the one for outer layer) with a stainless steel insert (See Fig. 5).

The two poles will be assembled in a way to form a complete dummy coil, which can be used for collaring tests.

Fig. 2: Winding operation with a dummy conductor. The geometrical curvature is clearly appreciable.

Fig.3: Two complete poles, after curing,

Fig.4: Details of one coil end.

Fig.5: The trial winding conductor used for the winding tests. In between the strands one can see the thin stainless steel core used for depressing the inter-strand coupling currents.

FUTURE ACTIVITIES

The next step of the R&D is devoted to the construction activities of the model magnet. Our plan is to have the cold mass finished by the 2009, ready for preliminary cold tests soon afterwards and a complete cold tested under real operating conditions at GSI approximately in 2010. For this latter test the magnet shall be integrated into a horizontal cryostat presently under design.

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