CRITICAL ASPECTS IN THE DEVELOPMENT OF A CURVED FAST RAMPED SUPERCONDUCTING DIPOLE FOR FAIR SIS300 SYNCHROTRON

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Abstract

The FAIR facility, under development at GSI, includes a large synchrotron for heavy ions acceleration: the SIS300, so called for having a magnetic rigidity of 300 Tm. The dipoles of this synchrotron shall be pulsed at the rate of 1 T/s up to 4.5 T maximum field in a bore of 100 mm. The magnets have a magnetic length ranging from 3.94m to 7.89 m with a cos-theta configuration. The coils with have the particular characteristic to be curved (the sagitta is 114 mm for the long dipoles). Design activities, coupled with conductor R&D and model coil construction, are under way for developing a curved fast-cycled superconducting dipole, suitable for operations of the SIS300. The main goal is the construction, before the end of 2009, of a prototype magnet, including cold mass, fully integrated into a horizontal cryostat. An important intermediate milestone is the industrial feasibility assessment of the winding technology developed for a curve cos-theta dipole, through the construction of cured curved magnet poles, actually under way. The paper covers the critical aspects of this development, with particular emphasis on the constructive problems.

INTRODUCTION

This paper deals with R&D activities in progress at Italian Institute for Nuclear Physics aimed at developing the high field rapidly-cycling super-conducting dipoles needed for SIS300 [1]. In order to have the maximum possible acceptance at a minimum field volume, a curved design with a radius of 66.67 m was proposed for the bending dipoles by FAIR team. 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 is curved with a sagitta of 114 mm for long dipoles), and they are fast ramped. 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 to 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 prototype of the short dipole ready in the summer of 2009. 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.

BASIC DESIGN CONCEPTS

Table 1 shows the main characteristics of the model coil. The basic assumption for the design was that the coil should be wound curved, because in this way one can avoid the problem of spring back effects during all manufacturing stages and coil operation.

At an initial stage the choice of a curved winding led the design to a layout based on a single layer coil mechanically supported only by the collars. This basic choice was due to the envisaged manufacturing difficulties related to the mechanical coupling between two curved layers or between a curved collared coil and a curved yoke. 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.

Table 1: Characteristics of the model coil

Nominal Field (T) :	4.5
Ramp rate (T/s)	1
Radius of magnet curvature (m)	66,67
Magnetic Length (m)	3.784
Bending angle (deg)	3 1/3
Coil aperture (mm)	100
Max operating temperature (K)	4.7

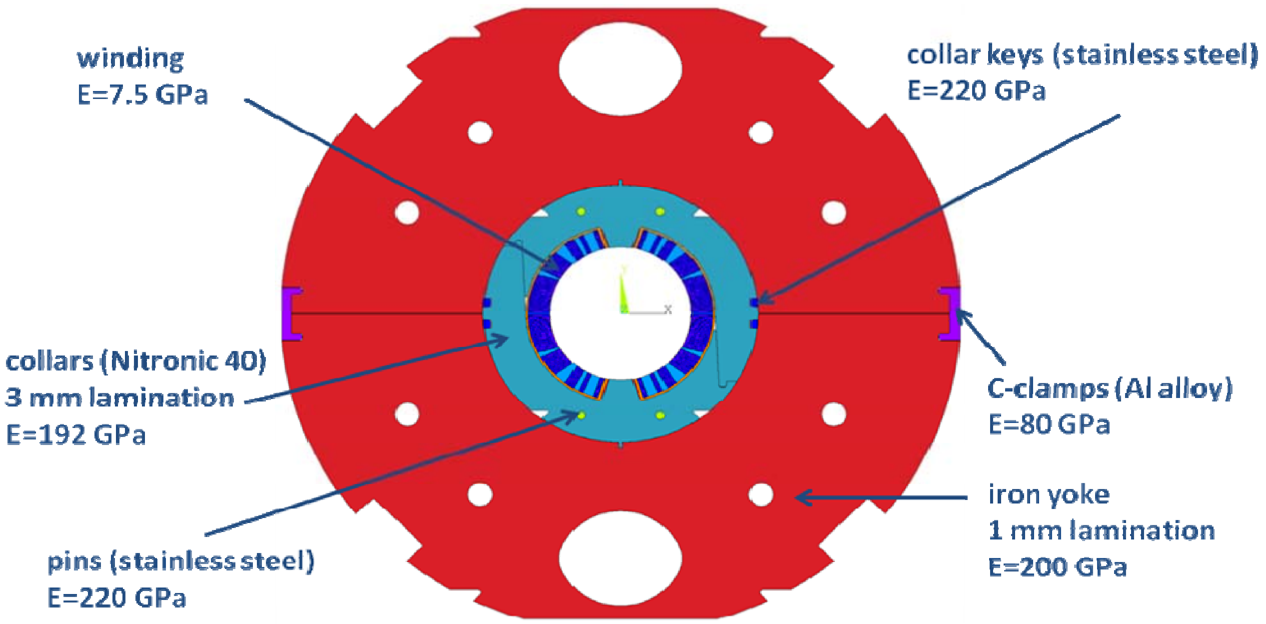

Figure 1: Cross section of the cold mass with some details of mechanical properties

On this basis a 5 block lay-out was chosen. The mechanical strength is provided by a 30 mm thick collar in high strength austenitic steel (Nitronic 40). The winding is pre-stressed up to 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, while the main parameters of conductor and winding are summarised in Table 2 and Table 3. Fig. 2 shows how the cold mass could appear once completed while Fig. 3 shows a detail of the coil end.

The conductor under development [2,3] is based on a cored Rutherford cable with 36 strands (similar to the LHC outer layer), whose main characteristics are shown in Table II. This conductor is characterized by having several components sized for low ac losses. In particular the cable is cored using a thin (25 µm) stainless steel foil (AISI 316L) for increasing the inter-strand electrical resistance, so minimizing the coupling currents.

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
Cable characteristics :	
Number of strands	36
Width (mm)	15.1
Thickness: Thin/Thick edges (mm)	1.362/ 1.598
Core material/thickness (µm)	AISI 316 L/ 25
Critical Current @5T , 4.22K	>18540 A

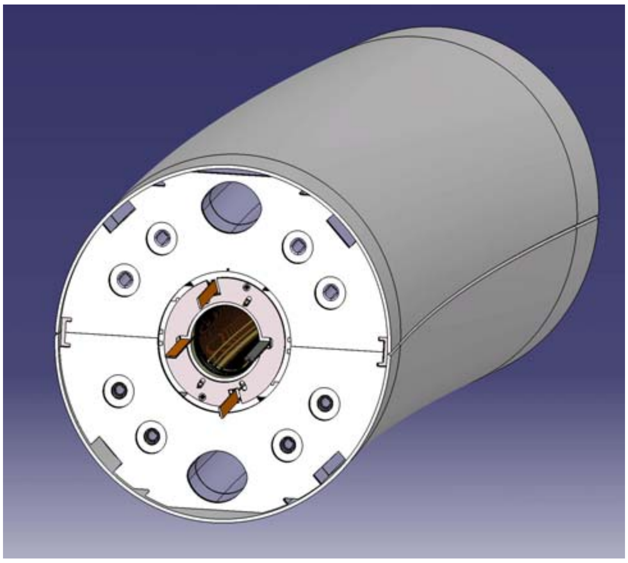

Fig. 2: Artistic view of the cold mass

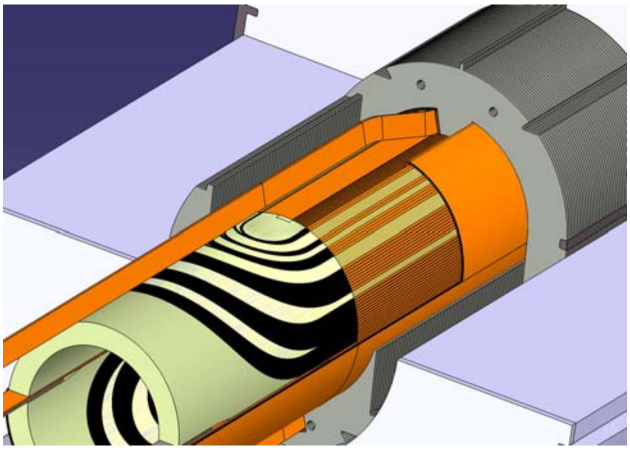

Fig. 3 A detail of the coil end

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

WINDING TECHNOLOGY

The need to have a SS core inside the cable makes the conductor stiffer than a standard Rutherford cable, causing much more difficult winding operations. For this reason we considered crucial to develop the winding techniques of a cored cable for a curved coil at an industrial level.

This activity is presently under way at ASG Superconductors in Genova, Italy, under an INFN contract. The winding tests are done using both the LHC dipole outer layer cable and a trial winding conductor made of 36 wires, used in the LHC dipole outer layers, cabled around a SS core (See fig.4). A special winding machine has been developed for winding 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. 5 shows the winding operation of a curved coil and Fig. 6 a detail of the coil end.

The next step of the R&D is the construction of two cured poles with a trial conductor by July 2008. Soon afterwards. The construction activities of the model magnet will start. Our plan is to have the cold mass finished by the summer 2009

Fig.4. The “dummy” conductor used for the winding tests.

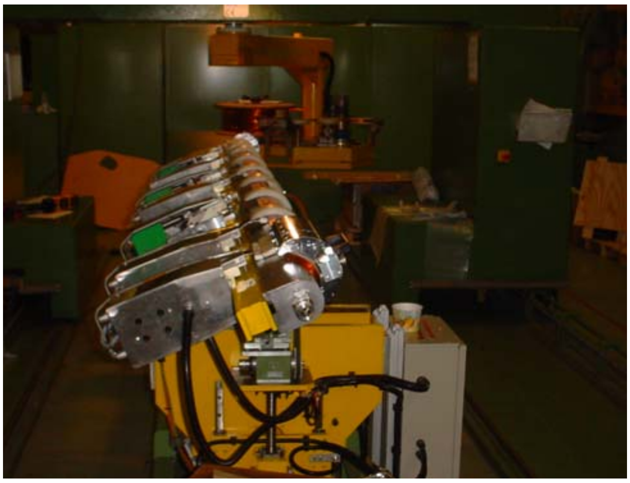

Figure 5: Winding operations with dummy cable

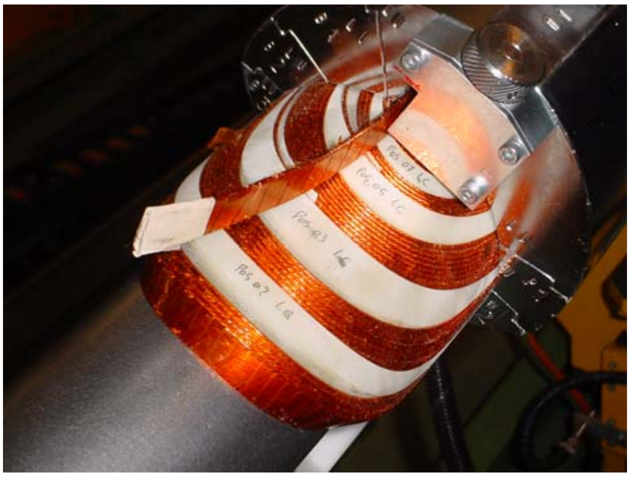

Figure 6: Detail of the coil end (the one with electrical exits)

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