State of the Construction of the Two INFN Full Length Superconducting Dipole Prototype Magnets for the Large Hadron Collider (LHC)

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Abstract

A collaboration was set up between CERN (European Organization for Nuclear Research) and INFN (the Italian "Istituto Nazionale di Fisica Nucleare") to build two full scale (10 meter long) twin-aperture superconducting dipole prototypes for the LHC. The construction of these two magnets is financed by INFN who also has taken care of the development and procurement of the necessary superconducting cables and of the magnet cryostats.

The collaboration has permitted CERN to start tackling the delicate phase of full length magnet development in advance with respect of its self-financed program.

The paper describes the development of tooling and manufacture of the prototypes, which is, at present, under way. A description of the state of advancement of the work is given, as well as indications on the delivery program.

Emphasis is put on the main fabrication aspects, on the capability to obtain in practice the design requirements, on the technical problems encountered during manufacture and on the adopted solutions.

1 INTRODUCTION

The construction of the LHC requires main dipoles whose specifications—field level, field quality, reduced operating temperature, etc.— are very demanding and a substantial upgrade of the magnet technique is required. For this reason in these years an intense R&D program on very high field dipoles for the LHC has been launched by CERN in collaboration with many scientific Institutions and industries in Europe.

The first step was the construction of several short, 1 m long, twin models which were tested in 1991 [1]. Meanwhile the development design for the scaling up to full length was going on somewhat anticipating the short model tests.

In this frame INFN, the Italian Institute for nuclear research, has financed the construction of two dipoles by ANSALDO, Genoa. This includes the development of the special tools required for the dipole construction like the winding machine and a big press for collaring and shrinking cylinder welding.

The obvious reason for such a program, which started in 1989 and has a cost of about LIT 5 milliards (including superconducting cables [2] and 1.8 K cryostats), is to involve industry in this prototype phase, recognizing the advantage of having an "on line" feedback to the design from the manufacturer. This should give a substantial benefit to the project schedule because the technology transfer to the industry takes place in this initial phase.

2 FROM 1 TO 10 METERS: DESIGN AND FABRICATION ASPECTS

2.1 Design

The full length dipole prototype is a natural evolution of the previous 1 m long MTA1 magnets. The superconducting cable are of the same type as those used in MTA1, with the same conductor distribution in the coils [1]. The structure surrounding the coils has been improved by including in the final design results of more detailed finite-element magneto-structural calculations [3] as well as indications coming from manufacture and test results of MTA1. The structure is designed to withstand e.m. forces whose horizontal components acting on each aperture are of the order of 5 MN per meter of magnet length.

The main modification can be resumed as follows:

1. the Al collars, made out of high strength alloy (type 2014-T6), have been reshaped, whilst conserving the principle of one collar for two aperture. Locking is obtained by means of pinning rods.

2. The "male" collar has now three "arms" while the "female" one is a simple spacer.

3. The " shoulders" (the areas where contact between collars and the iron yoke occur) have been redesigned with a curved shape so as to privilege contact close to the horizontal axis of the magnet at 1.8 K.

4. The central wedge of the collars has been prolonged towards the centre of the aperture in order to improve the support of the first conductor of the inner layer.

5. The iron yoke lamination is 10 mm larger in diameter than in MTA1, which represents an improvement both from the magnetic and the structural point of view.

6. The areas in contact with the collar shoulder have been reshaped, with a radius of curvature, different from the one imposed to the collar shoulder, which should allow having the wanted contact conditions at the operating temperature.

7. The yoke lamination contour have been modified in the central parts so as to avoid contact with the collars except in the regions where contact is wanted.

In addition to the above-mentioned modifications made on the main part of the magnet cross-section, a substantial redesign of the magnet ends has been carried out with the aim of obtaining a simpler and more effective design.

An up to date cross section of the magnet is shown in Fig. 1.

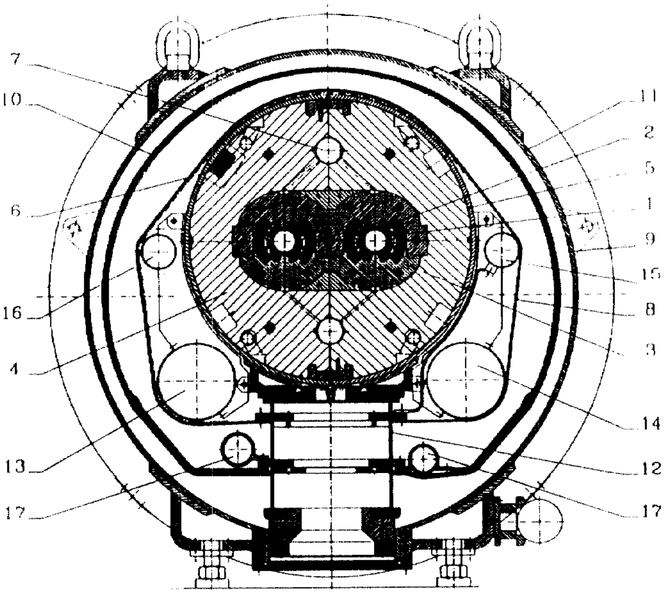

Figure 1: The dipole cross section

2.2 Fabrication

The main problems to be tackled from the point of view of fabrication are resumed by the need of producing a magnet, 10 m long with a precision of the order of few tens of μm, in the very tight foreseen planning.

Great dimensional precision is required for the elements to be used in the magnets. Strict controls have been imposed on the insulated superconducting cables to guarantee the respect of the tolerances. The collars and the iron yoke laminations are produced by fine blanking. This solution, in addition to be obviously cheaper than the electro-erosion, is also better from the point of view of precision and reproducibility in the production.

Due to the difficulties, to simulate the main operations before undertaking them on the superconducting magnets, a dummy prototype is being made with copper conductors.

2.3 Tools

Fews of the tools already used for the INFN production of the HERA dipoles, like the press for the coil moulding and curing and the press for the yoke laminations stacking, have been reconverted with some modifications.

The winding machine is somewhat different from that used for the HERA dipoles, allows a maximum tensile load on the cable of 1 kN and is carefully left-right balanced with a leading motor on both side of the winding.

The press for collaring, see Fig. 2, was designed according a new concept. It is divided into 0.8 m long sections which can be independently pressed up to a maximum force per unit length of 10 MN/m. This feature should facilitate the collaring operation allowing a very precise pinning of the collars which must assure the proper prestress on the coils.

The big press for collaring will allow also a proper welding of the shrinking cylinder, operation difficult to be executed with careful control of the vertical gap between the two halves of the iron yoke which is one of the novel and most important feature of the LHC dipoles [4].

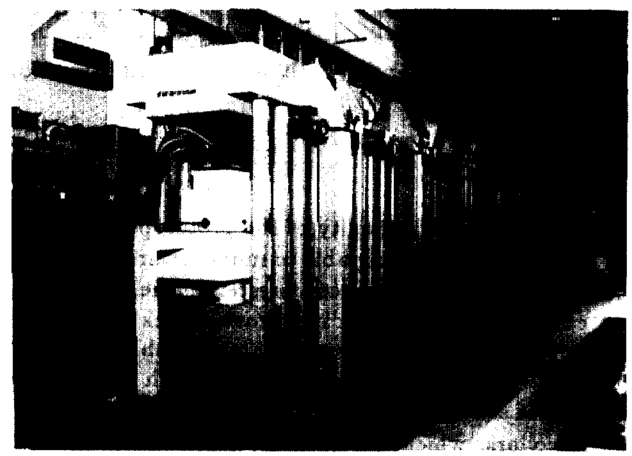

Figure 2: photograph of the 10 MN/m press for collaring.

3 DIPOLE CONSTRUCTION

3.1 Insulation

The insulation is slightly different from the solution adopted in the 1 m long models, having an additional half overlapped layer of 12.5 μm thick Kapton^{TM} tape. This configuration ensures better insulation quality.

3.2 Winding

Winding is a delicate operation for this magnets, since the stiffness of the inner and outer cable is quite high. The small radii of curvature at the first turns in the coil ends, coupled to the cable stiffness, require a very strict control of the winding parameters. Moreover, since the cable is unsoldered, it has the tendency to bulge when leaving the curved part to the next straight part. All the above mentioned elements obliged the manufacturer to shape the G11 end spacers according to the actual configuration of the cable in the curved areas rather than to the theoretical configuration.

In Fig. 3 the winding of the first 10 m long superconducting coil is shown.

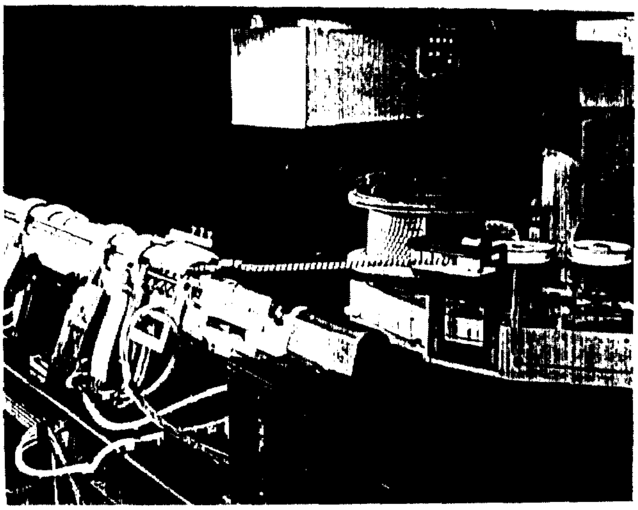

Figure 3: Winding an LHC 10 m long coil at Ansaldo.

3.3 Components

The main technical difficulty of the prototype magnet for the LHC consists in being able to manufacture the magnet with the very strict tolerances foreseen in the design. This fact calls for an accurate dimensional check of the parts to be used in the magnet and of the assembly procedure. The coils have to be wound and cured with tolerances of few tens of μm over 10 m of length.

The collars, which have tolerances of the order of 20 μm , have to be placed around the coils, pressed such as to transmit average azimuthal stresses in the coils up to 80 MPa and then pinned together with a clearance in pinning operation of about 50÷100 μm over 10 m length.

Tens of μm precision is also required for the alignment of the iron yoke halves and the subsequent welding of the half-shrinking cylinders under the press. The final result after welding is closely related to the state of pre-stress which is imparted to the yoke and the rest of the structure. It is therefore very important to be able to control such a result with precision. Ansaldo and CERN have jointly undertaken a development program on models to set up the optimal alignment, pressing and welding procedure such as to control the weld shrinkage and to be able to reproduce it in the magnet.

4 PROGRESS STATUS

The up to date status is the following:

- four copper coils have been wound for a dummy dipole. Their collaring is in preparation, the layer to layer connections and ground insulation are almost completed;
- collaring of the dummy coils will start in April;
- one inner layer and one outer layer superconducting coils have been wound. We expect to finish the coils for the first dipole by mid April;
- collaring of the first superconducting dipole will take place in May;
- the active part (coils + collars + iron yoke + shrinking cylinder) will be ready by the end of October;
- the cold mass will be completed with the end cover flanges by the end of November;
- we expect to have the first dipole in its 1.8 K cryostat ready to be tested at CERN in early 1993.

5 CONCLUSIONS

The construction of the LHC dipole prototypes is a complex matter since it has to be carried out in such a way that the strict design requirements in terms of tolerances are reproduced in practice. Moreover, since the manufacture is spread over a relatively long period of time, flexibility is required in order to be able to implement in the magnets design solutions developed during the first stage of construction and likely to represent an improvement of the behaviour of the final magnets. For these reasons a strict and continuous interaction between manufacturer and CERN-INFN is one of the most important points for the success of these pilot prototypes.

6 ACKNOLEDGEMENTS

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