Fabrication of 10 Meters Superconducting Twin Dipole Prototype Magnets, for the LHC Project, at Ansaldo

R. Marabotto, A. Martini
ANSALDO GIE
Via N. Lorenzi 8, I-16152 Genova, Italy

Abstract

In the magnets development phase for LHC project, CERN and INFN awarded to Ansaldo the complete construction of three superconducting 10 m long twin dipole prototypes. In order to set up tooling and construction techniques, one 10 m long twin collared dummy coils and several complete short models were made and tested at room and liquid nitrogen temperature. This paper reports the status of the superconducting prototypes manufacturing at Ansaldo.
A description of the development activities on models and their results is reported.

1. INTRODUCTION

In the R&D program for the main bending magnets, a few European firms were involved in the manufacturing of 10 m long superconducting dipoles.

The Italian 'Istituto Nazionale di Fisica Nucleare', awarded Ansaldo with the construction of two complete S.C. prototypes, a dummy collared coils 10 m long and as main contractor, the supply of the two cryostats.

A third S.C. prototype has to be manufactured under CERN contract.

Up to now Ansaldo has delivered to CERN the first two prototypes of the seven commissioned to the European firms, the first one has been successfully tested up to 9 T showing the soundness of the design and manufacturing, the second one is ready to be tested and the last one is in the final assembly phase.

In order to meet all the design technical specifications, Ansaldo has been involved in an intensive program for the development and optimisation of the manufacturing techniques.

The main activities developed in the course of the prototype manufacturing can be summarised as follow:

- technique for long half shell fabrication
- assembly of the shrinking cylinder
- electrical connections

Starting from the experience matured during the fabrication of the dummy collared coils and the previous S.C. dipole models, several optimisations were applied to make faster and more reliable the manufacturing.

2. PROTOTYPES MANUFACTURING

The fabrication of the superconducting dipoles has been preceded by a dummy full scale active part manufacturing. (three main elements form the active part: cured coils, ground insulation and collars).

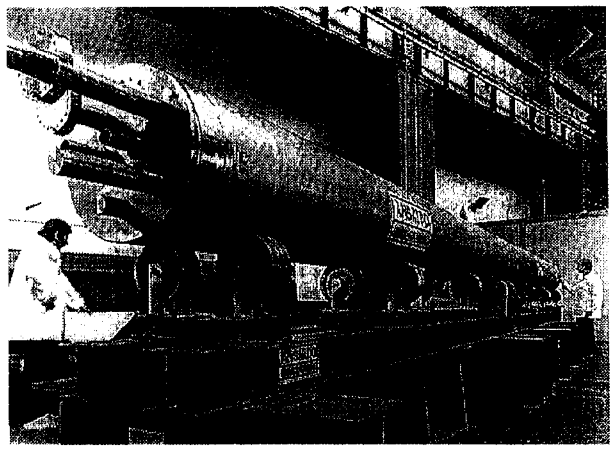

Figure 1. LHC_MBP 2 cold mass.

The components for the dummy were the same used in the S.C. prototypes but copper conductors instead of S.C. ones.

This first activity allowed to set up winding, collaring techniques and improve the end spacers shape.

On the collared coils were performed dimensional tests at room temperature and electrical tests at room and liquid nitrogen temperature; the results have shown the technical feasibility of certain critical operations, like manufacturing of very precise polymerised coils and mainly, the collaring of a magnet 10 m long using a very tight coupling tolerances.
For the fabrication we had to provide special tooling [1]: C.N.C. winding machine, high precision moulds and mandrels for the winding and curing operations, a 10 m long press for automatic curing cycle and able to produce an axial force of 10 MN/m for the collaring.

Taking into account the important experience collected in the fabrication of the dummy, we started with the manufacturing of the S.C. dipoles, during this stage were optimised, from the first to the last dipole, several activities.

2.1 Coils

Winding and curing are now well consolidated activities. Now it is possible to get good repeatability regarding the dimensional and mechanical characteristics. Special care has been taken in the fabrication of the coil ends, both for the turn insulation and the conductors positioning.

We have noticed that very little modifications on the conductor dimensions require an important change in tooling or turn insulation system, so that to get very precise and uniform cured coils a particular attention has to be paid in the choice of the dimensional cable and electrical insulation tolerances.

The coil ends impregnation using charged epoxy resin [2], has been an easy and efficient way to solve the dimensional and mechanical problems and represents a useful solution for manufacturing model or prototype magnets.

2.2 Ground insulation

Although the dielectric reliability is quite good (discharge tests on the dummy coils have shown a high safety margin) the application of the polyimide layers around the assembled coils has taken a good deal of time.

On each prototype was improved the lay-out and the techniques but up to now, we were not able to reduce in significant way the time needed for manufacturing.

From the industrial production point of view, this experience suggests to find a faster way to do the assembly, and this could represent an important matter for the next developments.

2.3 Quench heaters

In order to simplify the fabrication, all the stainless steel strips were electrically connected far from the coils.

With the present configuration (thin stainless steel strips glued onto a polyimide film) we have found some difficulties in their handling during the assembly on the coils.

2.4 Collaring

Nowadays the collaring of a 'twin structure' using three 10 m long calibrated pins [2] can be done without technical problems and respecting the economy of an industrial production.

The analysis of the measurements collected for all the collared coils has shown: good agreement between dimensional measurements and the design requirements, good dielectric behaviour of insulation system both at room and liquid nitrogen temperature.

2.5 Final assembly

The cold mass assembly was not a crucial operation even if the clearances among the components are very tight.

Thanks to the to the optimisation made in our shops: the two 316 LN stainless steel 10 m long half shells had to be joined together by simultaneous longitudinal welding in order to ensure a well-defined azimutal stress on them and in the same time, a uniform gap (at room temperature) between the half yokes after the longitudinal welding completion.

The observances of these design requirements [3] were reached by aluminium spacers placed between the half yokes.

This solution, as shown in figure 2, has represented the main improvement with respect to the standard design.

An effective assembly of the shrinking cylinder by welding of two half shells seems to be strongly correlated to their geometrical characteristics (circularity, surface condition, straightens) so we have taken into account several solutions to get precise half shells.

The half shells for the first prototype have been obtained by longitudinal cutting of a 10 m stainless steel tube, machined with great accuracy on the inner diameter. For the second and third prototypes, the long half shells were made by precise 2 m long half shells joined together by but to but welding.

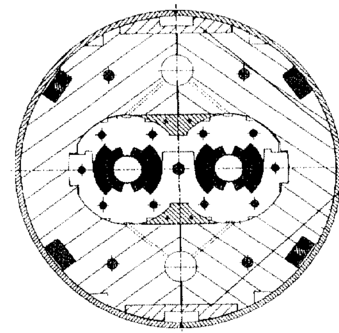

Figure 2. Ansaldo cold mass cross section.

2.6 Electrical connections

A complete model of the external electrical connections, between dipoles and dipoles to bus bars, was developed.

From the manufacturing point of view we did not find any problem even if the lay-out should be improved (for an industrial production) in order to make faster and easier these operations.

2.7 Completion of the cold mass

Beam tubes, heat exchanger, fillers were mounted and the cold mass have been closed by covers welded on the two ends. Reinforcement rings have been used to limit the deformations due to the welding shrinking (longitudinal and circular) near by the two ends of the shrinking cylinder.

The cold mass supports have been modified to give more flexibility in their positioning.

3. DEVELOPMENT ACTIVITIES

The correct assembly of the shrinking cylinder around the half yokes has represented the most critical point in the manufacturing of these prototypes.

An intensive work on short models has been necessary to find out the correct way to guarantee the design requirements.

The past experience on MTA1 S.C. model convinced us that a shrinking cylinder obtained by welding of two stainless steel half shells cannot assure, acting only on the control of the welding parameters, a uniform gap between half yokes along a 10 m dipole.

Starting from these considerations we have explored some possibilities to limit the welding effect.

3.1 Steel spacers as welding shrinkage restraint element

In order to reduce the shrinking effect, first we thought to substitute the half yokes clamps with steel spacers able to maintain the right gap between half yokes during the longitudinal welding.

Then the spacers have to be extracted by hydraulic system placed in the heat exchanger housing.

The model, 1 meter long, has pointed out some practical weak points, mainly due to the high pressure needed to extract the spacers. That meant possibility of leaks and low reliability in operation for a full scale magnet.

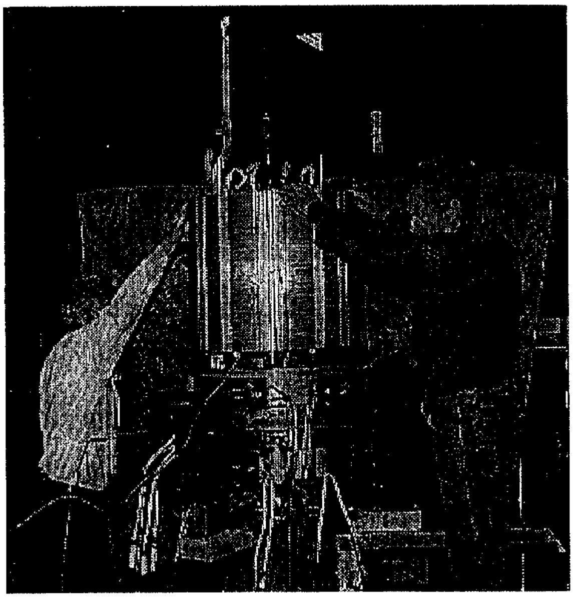

Figure 4. Assembly of the shrinking fit cylinder

3.1.2 Shrink fit technique

In this technique a heated stainless steel cylinder is placed around the half yokes, due to the steel contraction during its cool down, this method is able to shrink the half yokes without any welding.
The inner diameter of the cylinder can be machined with very high accuracy so that its contraction can be achieved with good precision.

A half meter model has been manufactured, the assembly operations were rather simple, see figure 4, and we got good dimensional results.

In parallel we also made a study to verify the feasibility of this technique on a full scale dipole.
The results have been positive from the manufacturing point of view, but not for what regard a fast acquisition of the tooling and for its application on curved dipole.

3.3 Aluminium spacers as welding shrinkage restraint element

This third method, shown in figure 2, solves the main disadvantage due to the spacers extraction after welding.
In fact thanks to the high thermal contraction of the aluminium alloy, it allows to leave the spacer inside the magnets. To demonstrate the behaviour of such technique we had to manufacture and test several short models.

Before manufacturing the LHC_MBP1 prototype, two models were tested.
During the longitudinal welding and the two thermal cycles performed from room and liquid nitrogen temperature, the dimensions of gap between half yokes and the stresses on the shrinking cylinder were monitored.
The results have shown in both models good agreement with the design requirements and good repeatability at room and liquid nitrogen temperature, we have also noticed that during the thermal cycles is also possible to recover misalignments between the two gaps. Taking into account the positive results we decided to follow this way for the prototypes manufacturing.

A third model was done to improve the quality of the longitudinal welding, in fact the longitudinal weldings on the long dipole have to be 100 % X ray inspected according to ASME code for pressure vessels.

A second step has been introduced to improve the speed and reliability of the longitudinal welding.
A different methodology has been applied, the first welding passes have been done by hand and the completion using automatic welding machine. To set up this new technique was necessary to do other two short models.

In such way we had the possibility to define the correct welding procedure in order to guarantee the reliability in the welding quality (respecting ASME code) along 10 m.
We have used with profit this experience on the second prototype LHC_MBP2 reducing the time for execution control and reparation.

Now the assembly of the shrinking cylinder is a well-defined operation, the next goal is to reduce again time for this activity, increase the margin of reliability and improve the quality of the welding from the metallurgical point of view, in other words find a solution as near as possible to the industrial one.

For these reasons we made some optimisation with respect to the LHC_MBP2 welding procedure using a fully automatic longitudinal welding.

Two short models have been done modifying step by step some geometrical characteristics, collecting interesting information on the shrinking behaviour and its control.

The last prototype will be assembled using these parameters.

4. CONCLUSIONS

The manufacturing of the long prototypes has required a relevant effort in order to find manufacturing methods able to meet all the design specifications.

An effective cooperation among Ansaldo, CERN and INFN has allowed to solve the most crucial points, getting three prototypes fully satisfying the design specification both from the manufacturing and design point of view as the successfully tests on the first prototypes have confirmed.

5. REFERENCES

[1] E. Acerbi, M.Bona, D.Leroy, R.Perin, L.Rossi, "State of the construction of the two INFN full length superconducting dipole prototype magnets for the Large Hadron Collider (LHC)", Proc. of III EPAC, Berlin, Germany, March 1992, p. 1420.

[2] E. Acerbi, M.Bona, D.Leroy, R.Perin, L.Rossi, "Development and fabrication of the first 10 m long supercunducting dipole prototype for the LHC", Proc. of MT-13 Conference, Victoria B.C., September 1993.

[3] M. Bona, D. Perini, "Finite-element structural analysis of 10 m long dipole prototype magnet for the LHC", IEEE Trans. Magn., vol.28, January 1992, p. 385.