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Status of the Cold Mass of the Short Straight Section for the LHC

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Abstract

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***Abstract* — In the framework of the LHC (Large Hadron Collider) R&D program, CERN and CEA-Saclay have collaborated to develop and construct two quadrupole magnet prototypes which have been successfully cold-tested. This collaboration has been extended as part of French special contribution to the LHC project. The previous design has been adapted to meet the new LHC parameters and two new cold masses are being constructed. This paper describes the new cold masses, their assembly process and the foreseen organization for the industrial production of about 470 units.**

I. Introduction

As part of the magnet R&D program for the Large Hadron Collider (LHC), a collaboration was started in 1989 between CERN and CEA-Saclay in France leading to the development, fabrication and testing of two prototype quadrupole magnets. One of these two prototypes has been integrated into a Short Straight Section (SSS) unit of the CERN's test string in operation since 1994 [1].

Following the approval of the LHC project and within the framework of the French participation to the LHC, a new collaboration between CERN, CEA-Saclay and CNRS in Orsay, France, has been concluded. While the CEA is in charge of the cold masses of the SSS, the CNRS has been entrusted with their cryostating. The SSS units are fully described in [2].

Although the overall guidelines of their design have not been changed, the parameters and the configuration of the cold masses have been adjusted in order to meet the present requirements of the LHC. In addition, some improvements or corrections have been included in the design. It is therefore necessary to build new prototypes to validate the new design.

The cold mass assembly now includes correction magnets. Considering security, cost of special tooling and feasibility, its mounting will be done mainly in the vertical position with the cold mass supported on one end [3].

The design of the quadrupole coil is now finished but the study of the whole cold mass is continuing. First tooling and components, especially for coil winding and curing, have already been ordered, so that the fabrication should start before end of 1997. The cold test of the two new cold mass prototypes at Saclay is planned to be performed in autumn 1998. The mounting in the cryostat, made by CNRS in collaboration with CERN will then precede the intensive tests in CERN in a new test string.

The production series of 470 units, by European industry, should start in 1999 and be finished mid 2004. The transfer of technology will be started during the prototype fabrication at Saclay in 1998.

II. Description of the Cold Masses

A. *Modifications due to changes in the LHC Machine parameters*

The design of the first two prototypes was based on LHC parameters as of 1990. Since that time, the quadrupole gradient has been reduced from 252 T/m to 223 T/m in order to follow the decrease of the dipole field from 10 T to 8.3 T.

The classical B-stage insulation has been abandoned in favour of an all polyimide insulation which allows the superfluid helium to penetrate the cable insulation. The helium provides additional enthalpy and has the advantage of very high thermal conductivity.

To provide more space in the RF cavities region, the distance between both aperture axes has been changed from 180 to 194 mm at liquid helium temperature.

Magnetic measurements performed on the already constructed second prototype [3] have shown that, as expected from calculations, a current imbalance of up to 3 kA (nominal current for 252 T/m is 15 kA) appears to have no measurable effect on the multipole coefficients. This allows powering of the two collared coils independently and permits suppression of the foreseen tuning quadrupole magnets.

The cold mass of the earlier short straight section consisted of two parts. One was the main twin aperture magnet with its stiffening inertia tube and the other was all the correction elements, mounted in a separate inertia tube. The two halves were aligned and joined together, both mechanically and electrically, to form the complete cold mass of the prototype short straight section. In the new design, the quadrupole is centered longitudinally, correction magnets are installed on both sides and there is a single thick inertia tube.

The cold masses built with the new design must conform to the final requirements of the LHC machine. This implies that interfaces must be studied with particular attention, not only those of the short straight section but also those with other magnets and to general environment.

B. Improvements

Tests performed on the two first prototypes [4],[5[,[6] showed that some design improvements could be made.

Both magnets needed a few quenches to reach the nominal gradient and, even if, for both prototypes, one aperture never quenched, the low safety margin along the load line, at 12 %, was considered to be too small. The reduced gradient and the use of the same superconducting cable as the one used for the second layer of the main LHC arc dipoles leads to a safety margin of 20 % which is considered sufficient.

One quadrupole coil in the first prototype was equipped with specially designed strain gauge collars which measured the strain on the pole piece of the collar. The prestress at the coil reduced to zero before reaching the nominal current, however without leading the magnet to quench. This resulted from mechanical properties (Young modulus and thermal contraction coefficient) of the coils being different from the expected ones and from polyimide creeping which was not taken into account at the design time. Mechanical tests are being performed to better quantify the mechanical behaviors of the coils.

The quench heaters exhibited some spread in efficiency: the time for the magnet to quench after heating only one heater varied from 42 to 88 ms. The quench heaters were made of a stainless steel sheet (30 μm thick, 12.9 mm width) glued manually onto polyimide foils. It has been decided to improve the fabrication of this component and tests for industrial fabrication using "printed circuit" technology are in course.

The field harmonics measured on the second prototype exhibit a linear variation as a function of current. This variation has been explained by the fact that the stainless steel collars are slightly magnetic. The magnetic permeability, which was specified to be less than 1.02, was measured to decrease from 1.02 to 1.01 as the magnetic field is increased from 1 to 5 T. Computations made with these variation produce results in good agreement with observation. To avoid this phenomena in the future, the stainless steel magnetic permeability is now specified to be less than 1.005.

C. The new prototypes: description and assembly

The main parameters of the new quadrupole design are summarized in table 1 and a view of the cold mass is shown in figure 1. The major principles behind the main quadrupole design are described in [7].

The main LHC arc quadrupole magnet consists of a pair of collared coil assemblies, mechanically supported by stainless steel collars, surrounded by a common low carbon steel yoke. Each quadrupole coil consists of four double layer winding (or pole), wound with an insulated superconducting cable of so-called Rutherford type.

TABLE 1
LHC Main Quadrupole Parameters

Nominal temperature	1.9	K
Nominal gradient	223	T/m
Margin on load line	19.7	%
Nominal current	11870	A
Number of turns per pole	24	
Magnetic length	3.1	m
Beam separation distance (cold)	194	mm
Inner coil aperture diameter (warm)	56	mm
Outer coil diameter	118.6	mm
Outer yoke diameter	452	mm
Collar material	Stainless steel	
Yoke length including end plates	3250	mm
Inertia tube overall length	5355	mm
Total mass when fully assembled	~6.3	tons

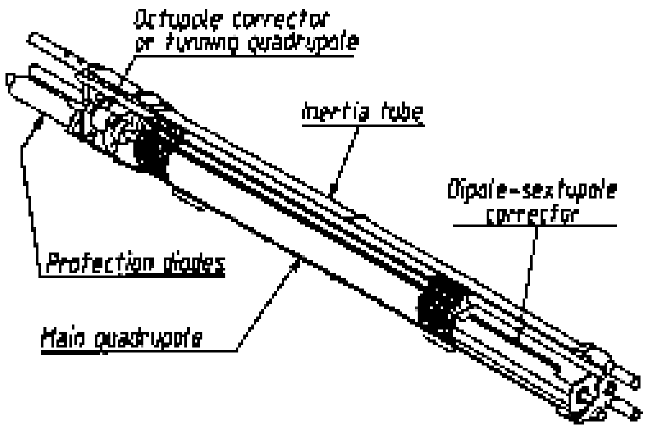

Fig 1. Global view of the cold mass

The cold mass of a short straight section consists of a 5.35 m long austenitic stainless steel tube, the inertia tube, which houses a twin-aperture main quadrupole with a yoke of 3.25 m and two pairs of different auxiliary magnets located at each end of the quadrupole. Combined dipole-sextupole corrector units are located at one end, whilst either two small octupoles or two tuning quadrupoles are mounted at the other end.

Six high current busbars for the main dipole and quadrupole magnets and a number of auxiliary magnet busbars pass through each cold mass.

A container with a pair of safety diodes for quench protection is attached to the cold mass. Voltage taps are wired at various locations on the magnets winding, busbars and diodes, for monitoring and quench protection purposes. Temperature, helium pressure and level sensors are also present.

The inertia tube is at the same time a stiff support for the magnets and a helium pressure (20 bars) vessel. It is sealed by end covers fitted with pipes which provide the passage for the helium flow and the busbars to the adjacent magnet units.

The manufacture of a quadrupole includes the electrical insulation of the cable with polyimide tapes, the very high precision winding and curing, the electrical and mechanical measurements of the windings, the assembly of ground insulation and quench heaters, the installation of ancillary equipment and the collaring with well defined prestress.

After electrically connecting the poles, the collared coil assemblies will undergo electrical, dimensional and magnetic measurements at room temperature.

The laminated low-carbon steel yoke is then built around a pair of collared coil assemblies, the wiring for the voltage taps and quench heaters is carried out and the complete quadrupole magnet again undergoes electrical and dimensional measurements.

The octupole correction magnets are positioned on a base unit, the main quadrupole assembly is then positioned on top of them and the combined dipole-sextupoles are installed on top of the quadrupole. The busbars, the instrumentation and its wiring are put in place and the inertia tube is lowered around this assembly. The centering and blockage of the magnets inside the inertia tube is provided by a serie of longitudinal keys very precisely positioned with regard to the mechanical axis of the tube. These operations are made in a vertical position to avoid that the effect of gravity disturbing the perfect centering of the magnets: the magnetic axes have to be aligned with the mechanical axes with a precision of 0.1 mm.

The final assembly of the cold mass also includes the welding of prefabricated end-covers to the inertia tube, the insertion of cold bore tubes as well as the mounting of the container with the safety diodes. The final testing will include electrical and magnetic measurements and a high pressure test at superfluid helium temperature.

III. Industrial production

After the completion and the test of the two new cold mass prototypes, industrial production should start. A market survey was launched in July 1997 to select, before end of 1997, firms to which the call for tender will be sent. Selected firms will be allowed to assist at the critical stages on the ongoing prototype fabrication at CEA-Saclay during 1998.

The call for tender is planned to be sent out at the beginning of 1999, in order to have the contract placed at the end of the same year. To avoid risk of failure and to achieve a good production rate, it is foreseen to have two firms or joint ventures in charge of the fabrication of the cold masses.

CEA-Saclay will transmit a fully detailed technical documentation and will send the persons who built the prototypes to the firms in order that they transmit their knowledge of technology. The technical documentation will contain the description and the drawings of the tooling and components, detailed assembly procedures and a set of control and test procedures.

CEA-Saclay will also be in charge of the follow-up of pre-series and series fabrication. For this purpose, CEA-Saclay's people will also be present at the firms. However, firms will be fully responsible of the supply of tooling and components and of their fabrication.

Some material (super-conducting cable, polyimide insulating tapes and sheets, auxiliary magnets, diode assemblies, steel, ...) will be supplied by CERN from within large contracts placed for LHC components which are aimed at achieving cost reduction due to quantity and a distribution of contracts over CERN's member states. For some of these components, CERN may entrust the responsibility of the contractors for the control over delivery and quality.

IV. Conclusion

CEA-Saclay, in collaboration with CERN, has designed, fabricated and successfully tested two cold mass prototypes for the short straight sections of the LHC. The design is being updated and improved and two new prototypes of a new generation will be constructed and tested in 1998.

After completion of these two prototypes, the industrial production of 470 units can start. CEA-Saclay will actively participate in the technology transfer and quadrupole follow-up of industrial fabrication.

The end of the fabrication of all the quadrupole cold masses is planned for mid-2004. This should satisfy the demand for the first physics run in the second half of 2005.

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