MAGNETS FOR THE PHASE I LHC UPGRADE[*]

P. Fessia

Abstract

The scope of the LHC Upgrade Phase I is to make possible the focusing of the beams to a β*=0.25 m in IP1 and IP5, and provide reliable operation of the LHC at a luminosity of 2 10^{34} cm^{-2} s^{-1}. Presently the time-line of the project foresees the installation of the equipment in the tunnel during the LHC shut-down of 2012 in order to be operational for physics run 2013. This document tries to review the requirements of the project in term of magnets, the related choices and status and frame of the development.

INTRODUCTION

The LHC experiments are presently installed in points 1, 2, 5 and 8 around the circumference of the machine. On the left and on the right of each point the experimental insertions provide the final focussing of the beams before their collision. The two high luminosity experiments ATLAS and CMS are installed in point 1 and point 5 respectively. In the frame of the LHC Upgrade Phase I it is planned to change the magnetic elements of the 4 insertions around these 2 points; this is valid both for the low-β quadrupoles and for the correctors. The present configuration starting from the IP is the following:

1) Q1: it is the 1st low-β quadrupole. It is MQXA [1] type; it has been designed and produced by KEK (Japan). A dipole corrector is integrated in this unit (MCBX).
2) Q2: this unit is made of 2 MQXB type quadrupoles [2]. They have been designed and produced by Fermilab (U.S.A.); it also integrates a dipole corrector (MCBX).
3) Q3: this unit is equal to the Q1 for what concerns the low-β quadrupole. It integrates a MCBXA, a dipole corrector also equipped with sextupole and dodecapole correctors, a skew quadrupole corrector and a sextupole corrector.
4) DFBX: this is a dedicated cryogenic feed box. The unit feeds the elements from Q1 to Q3 with the required cryogenic supply and it integrates the current leads required to power the quadrupole and the corrector magnets.
5) D1: separation dipole.

The four quadrupole magnets are based on superconducting technology and their working temperature is 1.9 K. The aperture diameter is 70 mm and the gradient 215 T/m. The D1 is a normal conducting dipole.

BOUNDARY CONDITIONS

The following hypotheses have to be taken as basis of the new magnets design and of their integration:

1) The interfaces between the LHC and the experiments remain unchanged at ± 19 m respect to the interaction point
2) The cooling capacity of the cryogenic system and other main infrastructure elements shall remain unchanged.
3) The new quadrupole shall make use of the LHC dipole superconducting cable. See Table 1 [3].

Table 1: SC cable characteristics

	Inner layer	Outer Layer
Number of strands	28	36
Mid-thickness	1.9±0.006 mm	1.48±0.006 mm
Width	15.10 mm	15.10 mm
Critical current I_c 10 T, 1.9 K 9 T, 1.9 K	>13750 A	>12960 A
dI_c/dB	>4800 [A/T]	>3650 [A/T]

4) The new magnets shall be compatible with the present tunnel geometry, no civil engineering work is foreseen
5) The technologies, materials and tooling to be employed shall be derived as much as possible from the recent development for the LHC in order to minimise the project budget and limit the development time and risk.

The use of known technologies and solutions brings also to profit from existing tooling. In particular a large workshop able to build and repair the 15 m long LHC Main Dipole is being installed at CERN providing a very valuable infrastructure that should used for the assembly of the new low-β quadrupoles. The design of this magnet should be, where possible, compatible with this existing assembly line. With the same logic the use of the existing reserve in low carbon steel for the iron yoke laminations and the use of the available low permeability austenitic steel strip for the collars would allow mitigating the financial exposure and reduce the supply time.

LAY-OUT

The new lay-out would foresee to have the 4 quadrupoles separated in 4 independent units each one cryostated separately. In addition the correctors would be installed in a separate cold mass equipped with its own cryostat. This solution has the advantage, respect to the present one, to detangle the production of the quadrupole units from the corrector availability; it provides more

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[*]This project has received funding from the European Community's Seventh Framework Programme (FP7/2007-2013) under the Grant Agreement nº 212114

flexibility and it separates the 12 KA bus bars, necessary to feed the quadrupoles, from the 600 A bus bars necessary for the correctors. The 4 quadrupoles units are called Q1, Q2a, Q2b, Q3 and the corrector cold mass Corrector Package. The cryogenic feed box would be substitute by a technical module being the terminal for a superconducting link. This will provide the electrical feeding from a remote installed feed box equipped with the necessary current leads.

HEAT DEPOSITION

The experimental insertions, due their proximity to the interaction point, are submitted to an important heat deposition due to the collision debris. Extensive studies [4] on the subject are being carried out with the aim to insure safe operation of the magnets and to indentify, if necessary, corrective actions. The aim is to guarantee that

1) In the superconducting cable the quench limit of 4.3 mW/cm^3 is not exceeded
2) The installed cryogenic capacity of 400 W at 1.9 K is enough to guarantee the functioning of the magnets

The main results of the work show that

- The most exposed magnet would be the Q2a
- In this magnet the limit of 4.3 mW/cm^3 would be exceeded if no actions is taken
- Extra shielding is necessary and a 1st shielding of stainless steel in Q1 of 13 mm thickness is enough to bring the deposition on Q2a below the limit

Table 2 reports the repartition of the loads among the different components.

Table 2: Heat loads in the low-β quadrupoles

Item	**Q1[W]**	**Q2a[W]**	**Q2b[W]**	**Q3[W]**
Beam screen	14	5	10	14
Shielding	56	-	-	-
Cold Bore	7	6	12	16
SC cable on mid plane	17	11	23	25
Collars	21	10	18	25
Iron yoke	24	10	15	22

The average linear power densities in each magnet varies from 5.4 W/m in the Q2a till the 11.2 W/m in the Q3

MAGNETS

The low-β quadrupole

As previously stated these magnets will use the LHC Main Dipole superconducting cable for the conductor distribution; a two layers cosθ solution is at the moment the preferred option. These magnets would provide a gradient between 130 T/m and 110 T/m in the possible aperture range from 110 mm to 130 mm with a total quadrupole magnetic length for each insertion between 36 m and 38 m [5,6]. A possible conductor distribution for a 120 mm aperture is shown in Fig.1. This solution would provide an operational gradient of 152 T/m at short sample and 121.5 T/m at the operating current.

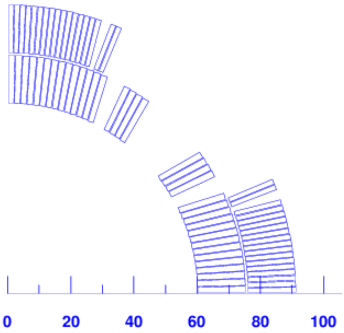

Figure 1: Tentative conductor distribution for a 120mm aperture.

In order to improve the heat transfer from the cable to the super fluid helium new possible insulation schemes are being studied. The aim is using the well known polyimide tapes in different topology to increase the channels between the helium bath and the cable core. A presently studied solution [7] foresees the application of a 3 layer system where the intermediate one has the function to create an open helium path between the cable edges and the rest of the conductor (see Fig.2).

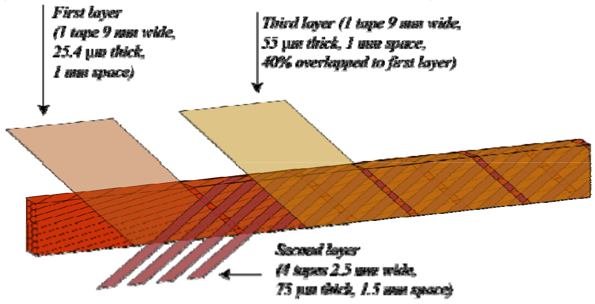

Figure 2: Proposed insulation system.

Concerning the mechanical structure the present favored solution uses self supporting austenitic steel collars. A structure with 2 keys per quadrant has been selected with an angle between mid-plane and the keys of 15°, this solution provides the best compromise between the repartition of the forces between the 2 keys (best solution 2 keys near the mid-plane) and the stiffening effect that the keys have on the structure when they are moved a part. Fixing as design parameter the maximum allowable radial movement of the coil on the mid-plane, it is possible to find the corresponding collar thickness. It has been decided to limit this movement to less than 60 µm; this brings to a collar thickness of 39 mm for 130 mm aperture magnet and to 36 mm for a 120 mm aperture. Fig. 3 shows the Von Misses distribution of the stresses in the collar for a 120 mm aperture case [8].

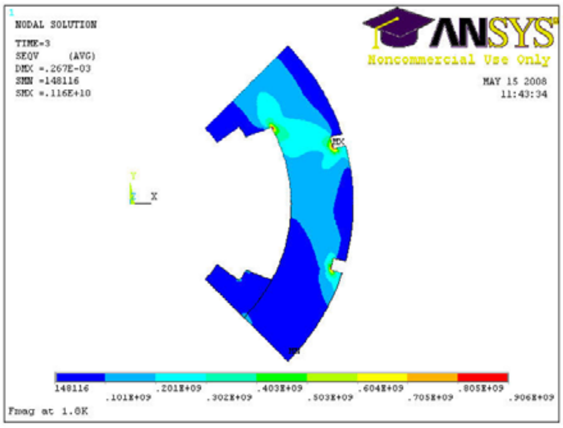

Figure 3: Von Misses stress distribution in a collar for a 120 mm aperture, at short sample condition.

Correctors

At the moment the following correctors are deemed necessary and are under development:

1) A dipole corrector with an integrated strength of 6 Tm and an estimated central field of about 3T. Two units would be necessary: one for the horizontal and one for the vertical plane
2) A skew quadruple with an integrated strength of 20 T and gradient of 40 T/m
3) A sextupole corrector with an integrated strength of 0.01 T at r=17 mm

The studies are at the moment addressing the possibility to upscale the design of the present correctors installed in the LHC.

COLLABORATIVE FRAME

The LHC Upgrade Phase I is not only a CERN approved construction project but it is at the centre of more general collaboration efforts. Various high value agreements have been or are being established that are instrumental for the final success of the project:

SLHC-PP

The Preparatory Phase of the Large Hadron Collider upgrade (SLHC-PP) is a project co-funded by the European Union in its 7th Framework Programme, CERN and 16 European research institutes and universities.

SLHC-PP comprises coordinating, support and technical activities. Among the other Work-Package N.6 groups 5 institutes with the aim to develop the prototypes necessary to proof the feasibility of the magnets necessary for the LHC upgrade phase I. These institutes are

- CERN: European Organization for Nuclear Research, Switzerland
- CEA-Saclay: Commissariat à l’Energie Atomique, France
- CIEMAT: Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain
- CNRS-IN2P3: Centre National de Recherche Scientifique, France
- STFC: Science and Technology Facilities Council, United Kingdom

CERN and CEA will be involved in the design and fabrication of the low-β quadrupole model and prototype, STFC and CIEMAT will develop the models and prototypes of two types of correctors, CNRS-IN2P3 will be the main actor in the development of the prototype cryostat for the new quadrupole.

Special contributions

Two special contributions are being discussed and finalised:

- An exceptional contribution from of France to CERN: CEA and CNRS would take care of the supply of key components for the series production of the low-β quadrupoles and of the correctors
- A contribution from the US laboratories for the supply of the new D1 superconducting separation dipoles.

CONCLUSIONS

The LHC upgrade of phase I requires the design of at least 4 types of different magnets, among them a very demanding large aperture quadrupole. In total it is foreseen to build 20 quadrupoles including spares. Other 20 units are the needed correctors. The design studies have started and they have not put in evidence show stoppers for the project. It is a major construction work and the first step to guarantee that the LHC will remain a scientific instrument at the frontier satisfying the requirement of the community of the high energy physics. Several collaborations are being set to guarantee the successful completion of the project.

ACKNOWLEDGMENTS

The author wish to thank all the people member of the LIUWG (LHC Insertions Upgrade Working Group) and the collaborators from the participating institutes.

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