CONCEPTUAL SPECIFICATION

COLD MASS OF THE 11 T DIPOLE FOR THE DISPERSION SUPPRESSOR REGIONS OF LHC

[LHC-MBH]

WP11

Equipment/system description

The 11 T dipole will replace some of the main dipoles in the dispersion suppressor regions of LHC. This will allow creating space for additional collimators to cope with beam intensities that are larger than nominal, such as in the High Luminosity LHC (HL LHC) Project.

The cold mass of the 11 T dipole comprises two apertures with coils of about 5.5-m length. Two cold masses of the 11 T dipole will produce an integrated field of 119 Tm at 11.85 kA, which corresponds to the bending strength of the LHC main dipole. The 11 T dipole will be connected in series with the LHC main dipoles.

Version	**LHC sectors concerned**	**CDD Drawings root names (drawing storage):**
Baseline	S12, S23, S67, S78, possibly S81, S45, and S56	LHCMBH__----

TRACEABILITY

Project Engineer in charge of the equipment	**WP Leader in charge of the equipment**
H. Prin, F. Savary	F. Savary

Committee/Verification Role	**Decision**	**Date**
PLC-HLTC/ Performance and technical parameters	Rejected/Accepted	2014-09-02
Configuration-Integration / Configuraration, installation and interface parameters	Rejected/Accepted	20YY-MM-DD
TC / Cost and schedule	Rejected/Accepted	20YY-MM-DD
Final decision by PL	Rejected/Accepted/Accepted pending (integration studies, …)	20YY-MM-DD

Distribution: HL-TC

Rev. No.	***Date***	***Description of Changes*** *(major changes only, minor changes in EDMS)*
0.1	2014-08-26	Draft

1 CONCEPTUAL DESCRIPTION

1.1 Scope

The 11 T dipole will replace some of the main dipoles in the dispersion suppressor regions of LHC.

The cold mass of the 11 T dipole comprises two apertures with coils of about 5.5 m length assembled in separate collars. Two cold masses of the 11 T dipole will produce an integrated field of 119 Tm at 11.85 kA, which corresponds to the bending strength of the LHC main dipole. The 11 T dipole will be connected in series with the LHC main dipoles.

The cross-section of the 11 T dipole cold mass is shown in Fig.1. In this figure, the bus bars, the heat exchanger pipe, the N-line, the support pads, and the cold bore tubes are not shown.

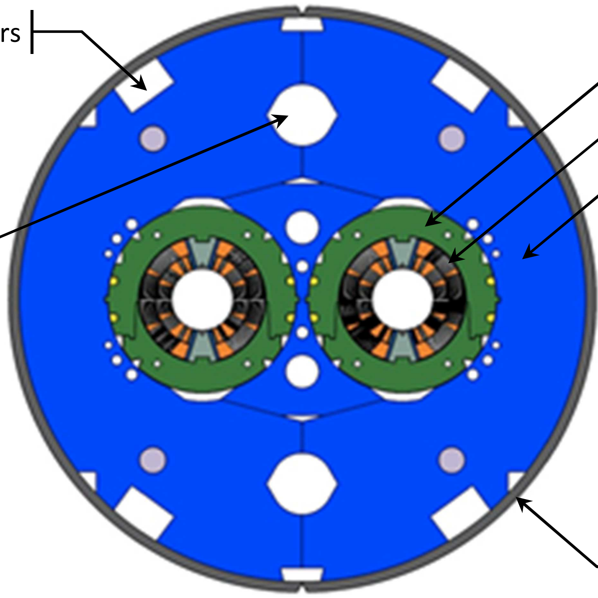

Fig.1: Simplified view of the cross-section of the 11 T dipole cold mass assembly.

1.2 Benefit or objective for the HL-LHC machine performance

The 11 T dipole will allow creating space in the dispersion suppressor regions of LHC to install additional collimators, which are needed to cope with beam intensities that are larger than nominal, such as in the High Luminosity LHC (HL LHC) Project [1].

1.3 Equipment performance objectives

The 11 T dipole will provide an integrated field of 119 Tm at 11.85 kA, which is the nominal operation current of the LHC main dipoles; this corresponds to a nominal magnetic flux density of 11.25 T at the center of the bore, which shall be obtained with a margin of ~20% on the magnet load line [2].

The geometric field quality will be optimized to keep the low-order field errors below 10-4 unit.

To avoid any deformation of the beam closed orbit, the transfer function of the 11 T dipole shall be identical to that of the main dipole. However, this is not possible in the entire current range because the 11 T dipole is stronger at lower currents (it has more turns) and the transfer function is reduced at higher current (due to more saturation). This can be mitigated by adding dedicated trim power converter. In absence of trim current, the resulting orbit distorsion could be mitigated by means of the standard orbit correctors in the LHC lattice. However, a fully validated solution is not available at the moment, including machine protection, reliability, and availbility (for example, the operation of LHC would be compromised in case of failure of an orbit corrector). The correction of the transfer function with a trim circuit is the preferred option as it would allow simpler and more tranparent operation [3].

Unlike the LHC main dipole, which is curved in the horintal plane, the 11 T dipole will be straight because of the brittleness of Nb_3Sn after reaction. Also, it will be equipped with the same cold bore tube and beam screen as the present curved dipole to facilitate integration. To mitigate the corresponding reduction of mechanical aperture, the two cold masses of a cryo-assembly will be assembled with an angle of 2.55 mrad relative to each other, and shifted by 0.8 mm towards the center of the LHC.

TECHNICAL ANNEXES

2 PRELIMINARY TECHNICAL PARAMETERS

2.1 Equipment Technical parameters

Table 1: Equipment parameters

Characteristics	Unit	Value
Aperture	mm	60
Number of apertures	-	2
Distance between apertures @ RT/1.9 K	mm	194.52/194
Cold mass outer diameter	mm	580
Magnetic length	m	5.307
Bore field @ nominal current	T	11.23
Peak field @ nominal current	T	11.6
Nominal operation current	kA	11.85
Operating temperature	K	1.9
Loadline margin	(%)	19
Minimum strand I_c without self-field correction (12 T, 4.222 K)	A/mm^2	438
Stored energy per meter @ $I_{nom.}$	MJ/m	0.9663
Differential inductance per meter @ $I_{nom.}$	mH/m	11.97
Superconductor	-	Nb_3Sn
Strand diameter	mm	0.7
Cu to Non-Cu ratio	-	1.15
RRR, after reaction		>100
Superconductor current density at 12 T, 1.9 K	A/mm^2	2750
Number of strands per cable		40
Cable bare width before reaction	mm	14.7
Cable bare mid thickness before reaction	mm	1.25
Keystone angle	degree	0.79
Cable insulation thickness per side azimuthal, before/after reaction	mm	0.155/0.110
Number of layers	-	2
Number of turns (inner/outer layer)	-	56 (22/34)
Cable unit length for the two layers (no layer jump splice)	m	650
Coil physical length (Roxie)	m	5.415
Magnet physical length (active part)	m	5.799
Magnet physical length (cold mass)	m	6.252
Cold mass weight	t	~ 8
Heat exchanger hole diameter	mm	60
Heat exchanger distance from centre	mm	xxx
F_x per quadrant @ $I_{nom.}$	MN/m	3.15 [tbc]

F_y per quadrant @ $I_{nom.}$	MN/m	-1.59 [tbc]
F_z per aperture @ $I_{nom.}$	kN	430 [tbc]
Cold bore inner diameter/thickness	mm	50*/1.5*
Gap cold bore to coil	mm	3**
Fringe field on the cryostat outer surface	mT	xxx

* Assuming the current cold bore tube is used.

** Assuming the current cold bore tube and ground insulation are used.

2.2 Operational parameters and conditions

The magnet will operate at 1.9 K in superfluid helium up to a nominal current of 11.85 kA.

The magnet will be protected with quench heaters and a by-pass diode operating at cold, integrated to the cold mass assembly. In the current stage of the development, it is foreseen to use one diode stack for the two 11 T dipole cold masses of a complete cryo-assembly. This needs to be validated.

2.3 Technical and Installation services required

Table 2: Technical services

Domain	Requirement
Electricity & Power	13 kA for the main circuit 300 A for the trim circuit [tbc] 600 A for the spools (integrated sextupoles, and octupoles/decapoles, where needed)
Cooling & Ventilation	-
Cryogenics	Cooling power per magnet to be defined (xx W operational plus 50% margin) 1.9 K cooling through heat exchangers
Control and alarms	-
Vacuum	Insulation vacuum in the cryostat
Instrumentation	Voltage taps for quench detection, temperature sensors

Table 3: Installation services

Domain	Requirement
Civil Engineering	-
Handling	The 11 T dipole cold mass shall be handled and transported with care in order not to damage the coils at any moment throughout the manufacturing process, including its integration with the cryostat and the installation in the tunnel. The most critical phase is after the reaction and before the impregnation of the coils. See also the conceptual specification of the cryo-assembly.
Alignment	Cold mass alignment in the cryostat within 0.1 mm (TBC) and 1 mrad (TBC)

2.4 Reliability, availability, maintainability

The 11 T dipole being connected in series with the main dipoles, it needs to be able reaching the nominal field in a reasonable number of quenches, and to have sufficient stability in order not to limit the overall perfomance of an entire sector of LHC.

Like the main dipoles, the 11 T dipole shall be reasonably easily replaceable.

2.5 Radiation resistance

The 11 T dipole will inevitably see shower from the collimator. The worst case is at the moment with ion operation at IP2 for which the peak dose in the coils is estimated around 1 MGy [4]. The 11 T dipole cold mass will be designed for 5 MGy.

2.6 List of units to be installed and spares policy

Two full-length prototypes will be fabricated to validate the design, the overall performance in nominal operation conditions (to be checked on horizontal test benches in SM18), and the different interfaces with the neighbour systems. These prototypes may be used as spares if they conform fully to the technical requirements.

The units to be installed are listed here after.

For LS2, around IP2, 4 units to replace 2 main dipoles MB.A10L2 and MB.A10R2

For LS3, around IP7, 8 units to replace 4 main dipoles MB.B8L7, MB.B10L7, MB.B8R7, and MB.B10R7

For LS3 to be confirmed, around IP1 and IP5, up to a maximum of 16 units to replace 8 main dipoles, location to be defined.

3 PRELIMINARY CONFIGURATION AND INSTALLATION CONSTRAINTS

3.1 Longitudinal range

See conceptual specification for the cryoassembly.

3.2 Volume

The 11 T dipole cold mass has an outer diameter of 580 mm, except on the side of the collimator where the diameter of the end cover needs to be enlarged to 750 mm. The length of the cold mass assembly is 6.252 m, from the datum plane “C” to the datum plane “L”. Overall, the volume occupied by the cold mass assembly is of the order of 1.65 m^3.

3.3 Installation/Dismantling

The position of the main dipoles that have to be removed from the tunnel and replaced by the 11 T dipole cryo-assembly is given in section 2.6.

The 11 T dipole cold mass will be designed with standard features at its ends that will face the existing magnets in the tunnel to facilitate its installation and connection to the existing equipment, e.g. M-flanges and bellows, preparation of the bus bar extremities in view of the splicing, end flanges on the X/V lines, …

4 PRELIMINARY INTERFACE PARAMETERS

4.1 Interfaces with equipment

To be defined

4.2 Electrical interfaces

Table 4: Circuits to be generated

New circuit description	Circuit LHC code name (if known)	Approx. current rating (if known)	Approx. voltage rating (if known)
Trim circuit		300 A [tbc]	

5 COST & SCHEDULE

5.1 Cost evaluation

Cost estimate: tbd

5.2 Preliminary schedule

Table 5: Preliminary schedule

Phase	2014		2015		2016		2017		2018		2019		2020		2021		2022		2023	
Conceptual design	■																			
Engineering design (Prototype)		■	■																	
Procurement of components		■	■	■																
Fabrication			■	■	■															
Integration in cryostat + testing					■	■														
Engineering design (Final for LS2)				■	■															
Procurement of components					■	■														
Fabrication							■	■	■											
Integration in cryostat + testing									■	■	■									
Engineering design (Final for LS3)								■	■	■	■									
Invitation to tender / contract										■	■	■								
Contract execution / delivery													■	■	■	■	■	■		
Integration in cryostat + testing																	■	■	■	■

6 TECHNICAL REFERENCE DOCUMENTS

[1] L. Rossi, "LHC Upgrade Plans: Options and Strategy", IPAC2011
[2] M. Karppinen et al., "Design of 11 T Twin-Aperture Nb3Sn Dipole Demonstrator Magnet for LHC Upgrades", CERN-ATS-2013-025
[3] F. Savary et al., "Status of the 11 T Nb3Sn Dipole Project for the LHC"
[4] Private communication A. Lechner 8 Aug. 2014, and G. Steel et al., "Limits on collimator settings and reach in β*", LHC Collimation Review 2013

7 APPROVAL PROCESS COMMENTS FOR VERSION X.0 OF THE CONCEPTUAL SPECIFICATION

7.1 PLC-HLTC / Performance and technical parameters Verification

Comments or references to approval notes. In case of rejection detailed reasoning

7.2 Configuration-Integration / Configuraration, installation and interface parameters Verification

Comments or references to approval notes. In case of rejection detailed reasoning

7.3 TC / Cost and schedule Verification

Comments or references to approval notes. In case of rejection detailed reasoning

7.4 Final decision by PL

Comments or references to approval notes. In case of rejection detailed reasoning