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1370117	**0.1**	**DRAFT**

REFERENCE : LHC-MBH-ES-0002

CONCEPTUAL SPECIFICATION

2-M LONG MODEL PROGRAMME FOR THE 11 T DIPOLE PROJECT

[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.

A joint R&D programme started in October 2010 between FNAL and CERN with the goal of developing the necessary technology for the fabrication of a 5.5 m long two-in-one aperture Nb_3Sn dipole prototype suitable for installation in the LHC. During the first years, most of the construction work was carried out at FNAL.

Prior to work on the design and fabrication of full-length prototypes and magnets for LHC, a model programme was settled at CERN based on the technology developed at Fermilab in the US. This programme started effectively in the middle of 2011.

The CERN model programme comprises the fabrication of 10 models of 2-m length in two configurations: a single aperture structure, and a two-in-one aperture structure, in order to obtain a faster return on experience on both the manufacturing process and the performance with the single aperture models before the collared coils are recovered to be assembled in two-in-one aperture models.

Version	**LHC sectors concerned**	**CDD Drawings root names (drawing storage):**
Baseline	None	LHCMBHSP for single aperture models LHCMBHDP for two-in-one aperture models

TRACEABILITY

Project Engineer in charge of the equipment	**WP Leader in charge of the equipment**
D. Smekens	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	2014-08-28	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. It has 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 cross-section of the 11 T dipole models scope of this specification is shown in Fig.1.

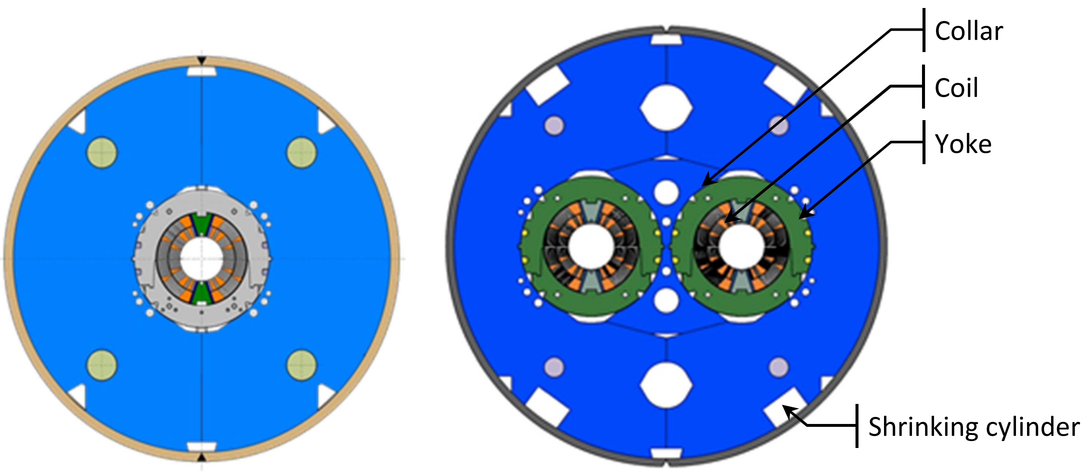

Fig.1: Cross-section of the 11 T dipole model, single aperture (left) and two-in-one aperture (right).

A joint R&D programme started in October 2010 between Fermilab and CERN with the goal of developing the necessary technology for the fabrication of a 5.5 m long two-in-one aperture Nb_3Sn dipole prototype suitable for installation in the LHC. During the first years, the construction of the models and the performance tests were carried out at FNAL.

Prior to work on the design and fabrication of full-length prototypes and magnets for LHC, a model programme was settled at CERN on the basis of the technology developed at FNAL. This programme started effectively in the middle of 2011.

The CERN model programme comprises the fabrication of 10 models of 2 m length in two configurations: a single aperture structure, and a two-in-one aperture structure, in order to obtain a faster return on experience on both the manufacturing process and the performance with the single aperture models before the collared coils are recovered to be assembled and tested in two-in-one aperture models.

1.2 Benefit or objective for the HL-LHC project and for CERN

The model programme will allow setting up at CERN the necessary infrastructure, and developing know-how, for the construction of high field magnets made of Nb_3Sn conductor.

The model programme will allow setting up at CERN the necessary infrastructure, and developing know-how, for the construction of high field magnets made of Nb_3Sn conductor. It is a mandatory step prior to designing and fabricating full length magnets and it is a major step towards the development of high field magnets for future accelerators.

The CERN model programme for the 11 T dipole is defined in Table I.

TABLE I
MODEL PROGRAM AT CERN

Identification	Single / Two-in-One	Type of cable
MBHSM101 (single coil)	1-in-1	Cu – RRP 108/127
MBHSP101	1-in-1	RRP 108/127
MBHSP102	1-in-1	RRP 132/169
MBHSP103	1-in-1	PIT120
MBHDP101	2-in-1	RRP 108/127 – RRP 132/169
MBHDP102	2-in-1	RRP 108/127 – PIT120
MBHSP104	1-in-1	RRP 132/169
MBHDP103	2-in-1	RRP 132/169 – RRP 132/169
MBHSP105	1-in-1	PIT120
MBHDP104	2-in-1	PIT120 – PIT120

Except for MBHSM101 for which the table indicates the type of cable for Coil 1 and for Coil 2, the table indicates the type of cable for both coils in case of a single aperture model (SP), and the type of cable for Aperture 1 and for Aperture 2 in case of a two-in-one aperture model (DP).

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 11.23 T at the center of the bore, which shall be obtained with a margin of ~20% on the magnet load line [1].

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

The goals of the CERN model programme are listed below.

1. Develop further the technology currently available at FNAL;
2. Test two variants of conductor made from different manufacturing routes, namely RRP and PIT;
3. Understand better the quench behavior and field field quality of Nb_3Sn magnets;
4. Study solutions to critical problems or processes like the magnet protection, the fabrication of quench heaters, the reaction treatment, and the coil impregnation.

TECHNICAL ANNEXES

2 PRELIMINARY TECHNICAL PARAMETERS

2.1 Equipment Technical parameters

Table 1: Equipment parameters

Characteristics	Unit	Single	Two-in-One
Aperture	mm	60	
Number of apertures	-	1	2
Number of layers per coil	-	2	
Number of turns (inner/outer layer)	-	56 (22/34)	
Cable unit length for two layers (no layer jump splice)	m	220	
Distance between apertures @ RT/1.9 K	mm	-	194.52/194
Magnetic length	m	1.692	
Coil physical length (Roxie)	m	1.807	
Magnet physical length	m	2.239	
Yoke outer diameter	mm	510	550
Shell thickness	mm	12	15
Cold mass weight	t	3.56	xxx
Bore field @ nominal current	T	11.23	11.23
Peak field @ nominal current	T	11.6	11.6
Nominal operation current	kA	11.85	
Operating temperature	K	1.9	
Loadline margin	(%)	20	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	xxx	0.9663
Differential inductance per meter @ $I_{nom.}$	mH/m	xxx	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	

2.2 Operational parameters and conditions

The models will be tested at 4.3 K and 1.9 K up to their short sample limit in order to study the quench performance, the quench heater performance (e.g. quench heater delays), and the field quality.

2.3 Technical and Installation services required

Table 2: Technical services

Domain	Requirement
Electricity & Power	Power supply up to 16 kA at 4.3 K and 1.9 K
Cooling & Ventilation	-
Cryogenics	Vertical cryostat operating at 4.3 K and 1.9 K equipped with instrumentation feed throughs and connectors for both electrical and mechanical instrumentation
Control and alarms	-
Vacuum	-
Instrumentation	Voltage taps for quench detection, temperature sensors, …
Specific measurements	Warm/Cold magnetic measurements Mechanical instrumentation

Table 3: Installation services

Domain	Requirement
Civil Engineering	-
Handling	Yes, lifting girders and transport frames
Alignment	-

2.4 Reliability, availability, maintainability

Non applicable

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 [2]. The 11 T dipole will be designed for 5 MGy.

2.6 List of units to be installed and spares policy

None of the 2-m long models will be installed in the LHC machine

3 PRELIMINARY CONFIGURATION AND INSTALLATION CONSTRAINTS

3.1 Longitudinal range

Non applicable

3.2 Volume

Non applicable

3.3 Installation/Dismantling

Non applicable

4 PRELIMINARY INTERFACE PARAMETERS

4.1 Interfaces with equipment

Interfaces need to be defined with the test bench in SM18.

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)

5 COST & SCHEDULE

5.1 Cost evaluation

Cost estimate: tbd

5.2 Preliminary schedule

Table 5: Preliminary schedule

Model	2014	2015	2016
MBHSM101 (single coil)			
MBHSP101 (RRP 108/127)			
MBHSP102 (RRP 132/169)			
MBHSP103 (PIT 120)			
MBHDP101 (SP101 + SP102)			
MBHDP102 (SP101 + SP103)			
MBHSP104 (RRP 132/169)			
MBHDP103 (SP102 + SP104)			
MBHSP105 (PIT 120)			
MBHDP104 (SP103 + SP105)			

An average duration of 7 months is counted for the fabrication and testing of the single aperture models, and 5 months for the two-in-one. This plan is certainly optimistic, and we may foresee right away that the schedule could slip till mid-2016. Moreover, an additional coil needs to be inserted between SP102 and SP103 for a specific impregnation trial.

6 TECHNICAL REFERENCE DOCUMENTS

[1] M. Karppinen et al., "Design of 11 T Twin-Aperture Nb3Sn Dipole Demonstrator Magnet for LHC Upgrades", CERN-ATS-2013-025

[2] 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