LARP LONG NB3SN QUADRUPOLE*

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Abstract

A major milestone for the LHC Accelerator Research Program (LARP) is the test, by the end of 2009, of two 4m-long quadrupole magnets (LQ) wound with Nb_3Sn conductor. The goal of these magnets is to be a proof of principle that Nb_3Sn is a viable technology for a possible LHC luminosity upgrade.

INTRODUCTION

The LARP Long Quadrupole (LQ) is going to be the first 4m long Nb_3Sn quadrupole magnet ever built. With an aperture of 90 mm, and a gradient of 200 T/m, the LQ is a "Proof of Principle" magnet aiming at demonstrating that Nb_3Sn technology is mature for use in high energy particle accelerators. The LQ is thus a fundamental step toward the LARP goal of developing Nb_3Sn quadrupole prototypes for the LHC (Large Hadron Collider) [1] interaction regions for a possible luminosity upgrade.

The Long Quadrupole R&D builds upon other LARP tasks (such as the Technological Quadrupoles (TQ) [2,3], and the Long Racetrack [4]), and upon tasks performed by other programs (such as the Long Mirror under development at Fermilab [5]). A preliminary description of coil design and fabrication process was presented in [6]. The quench protection was presented in [7]. The present plan includes the fabrication of three LQ models by early 2010

MAGNETIC DESIGN

Two support structures (collar-based and shell-based) are under consideration using the same coils. The magnet parameters are presented in Table 1 for both structures at critical current values of 2400 and 2800 A/mm^2 (at 4.2 K, 12 T). The shell-based structure has slightly higher gradients (+4%) than the collar-based structure because the iron is closer to the coils.

The cable has 27 strands with 0.7 mm diameter. Cable width and mid-thickness are 10.08 mm and 1.26 mm respectively. The strand is RRP (Restack-Rod-Process) by OST (Oxford Superconducting Technology). A design with 54 Nb_3Sn sub-elements (54/61) will be used for the first set of coils. Use of RRP strands with larger number of sub-elements is under consideration for the third LQ.

Table 1: LQ Magnet Parameters

Parameter	**Unit**	**Collar-based LQ**		**Shell-based LQ**	
Critical current density at 4.2 K, 12 T	A/mm^2	2400	2800	2400	2800
N of layers		2			
N of turns		136			
Coil area (Cu + nonCu)	cm^2	29.3			
4.2 K temperature					
Quench gradient	T/m	221	231	233	243
Quench current	kA	13.3	14	13.4	14
Peak field in the body at quench	T	11.5	13	11.9	12.4
Peak field in the end at quench	T	12	12.5	11.4	12.4
Inductance at quench	mH/m	4.6	4.6	4.9	4.9
Stored energy at quench	kJ/m	406	443	439	479
1.9 K temperature					
Quench gradient	T/m	238	249	251	262
Quench current	kA	14.4	15.1	14.5	15.2
Peak field in the body at quench	T	12.4	13	12.9	13.4
Peak field in the end at quench	T	12.9	13.5	12.4	13.4
Stored energy at quench	kJ/m	472	516	512	559

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MECHANICAL DESIGN

Three mechanical designs (referred to also as support structures) have been developed for the Long Quadrupole. Two of them are based on the LARP TQ magnets. The collar-based LQ (Fig. 1) is a straightforward scale-up of the TQC magnet. The only new features are: (i) the skin will be welded (the latest TQC model used a bolted skin); (ii) possible introduction of coil alignment features.

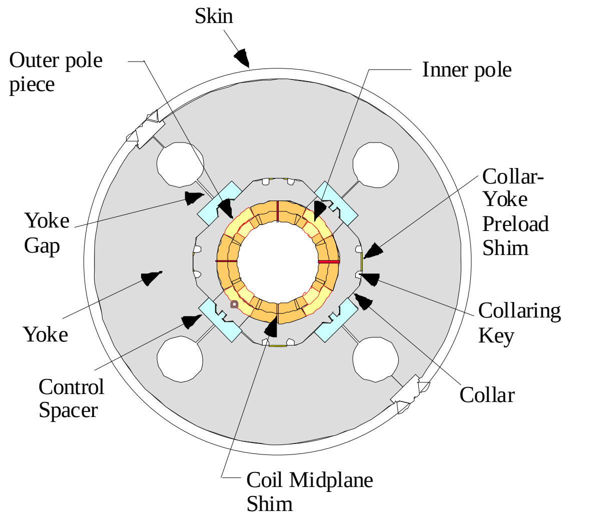

Figure 1: Collar-based LQ

The shell-based LQ (Fig. 2) is based on the TQS with some improvements: (i) optimized pads in order to reduce peak stress in the outer layer; (ii) slightly thinner aluminum shell, (iii) stainless steel rods for end pre-stress; (iv) new features for pre-assembly of the 4m structure before coil insertion (use of "masters", segmented pads and shell).

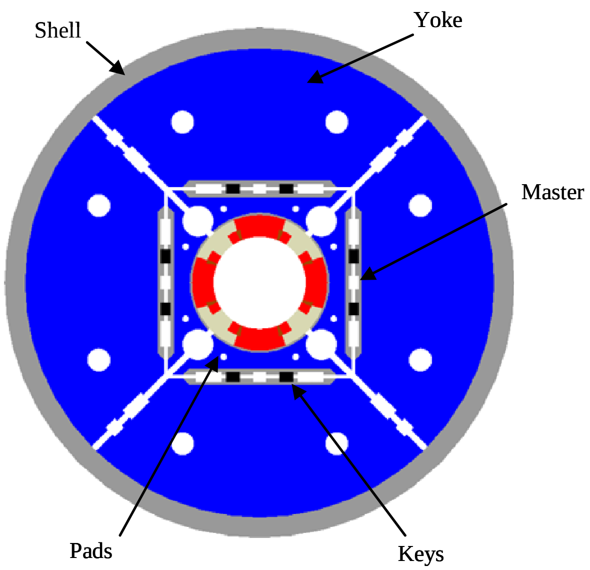

Figure 2: Shell-based LQ

The third design ("Hybrid design") combines some of the best features of the TQ designs (collars for coil assembly and alignment, and use of bladders for controlled application of pre-stress). Time and budget constrains didn't allow the development of short models using this design. Therefore it cannot be considered for the Long Quadrupole.

Further details about these designs can be found in [7].

PLANS

The fabrication and test plan is based on the unique advantages of each structure developed during the TQ R&D. The shell-based structure reached with TQS02 a gradient 10% higher than the LQ target (200 T/m) and has a very short magnet assembly and disassembly time. These features are very attractive for the first LQ model (LQ01), which aims exclusively at the target gradient and where LQ coils will be tested for the first time (possibly requiring to change some of them after the first test).

The collar-based structure provides more accelerator magnet features (such as coil alignment), which are very attractive for subsequent LQ models.

The TQ R&D has also shown that coils previously tested in a shell-based structure can be successfully retested in a collar-based structure.

The main steps of the plan are:

- First model (LQ01) with shell-based structure. Goal: to achieve LQ target gradient with a structure allowing quick exchange of coils.
- Second model (LQ02) with collar-based structure, reusing LQ01 coils. Goal: to demonstrate more accelerator magnet features with long Nb_3Sn coils, allowing significant savings by reusing LQ01 coils.
- Third model (LQ03) with structure depending on previous results. Goal: to demonstrate reproducibility of best performing LQ model, and to allow improvements by possible use of improved conductor.

By developing both structures (shell- and collar-based) this plan provides the highest probability of success within the short timeframe. It also allows building a large and unique set of expertise and experimental data for the design of prototypes for the LHC IR upgrade.

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