MECHANICAL DESIGN OF AN ALTERNATE STRUCTURE FOR LARP NB3SN QUADRUPOLE MAGNETS FOR LHC*

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Abstract

An alternative structure for the 120 mm Nb3Sn quadrupole magnet is presently under development for use in the upgrade for LHC at CERN. The design aims to build existing technology developed in LARP with the LQ and HQ magnets and to further optimize the features required for operation in the accelerator. The structure includes features for maintaining mechanical alignment of the coils to achieve the required field quality. It also includes a helium containment vessel and provisions for cooling with 1.9 K helium. The development effort includes the assembly of a six inch model to verify required coil load is achieved. Status of the R&D effort and an update on the magnet design, including its incorporation into the design of a complete one meter cold mass is presented.

INTRODUCTION

LARP is presently building 90 mm aperture (LQ) [1] and 120 mm aperture (HQ) [2] R&D niobium tin quadrupole cold masses in support of the upgrade to the LHC [3] at CERN. These cold masses utilize aluminum shell support systems with "bladder and key" technology [4-9]. This alternate structure [10] attempts to employ all the benefits of the existing LQ and HQ structures while making important improvements. Specifically the structure includes holes in the yoke for helium cooled heat exchangers. The structure replaces the bolted pads / collars with more traditional keyed aluminum collars while still utilizing the support shell and "bladder and key" assembly for reliable coil loading. In this structure the parting planes of the yoke coincide with the coil midplanes to permit continuous alignment of the coils to the exterior survey locations in the helium vessel. Finally the structure utilizes the stainless steel helium vessel for support of axial Lorentz forces, eliminating tie rods and permitting the maximum area for helium cooling. Since last presented [10] the design has been further developed. Presented here are the latest design and assembly features and an update to the analysis results.

DESIGN

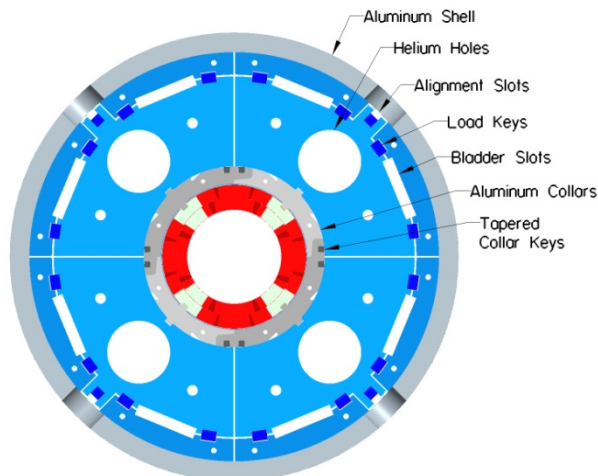The latest 2-D cross-section of the cold mass structure is shown in Figure 1.

Figure 1: 2-D View of Support Structure.

The design of the yoke has been modified to provide more direct transfer of alignment from the collars to the outside of the coldmass. The outer yoke has been split to allow direct access to the inner yoke through the holes in the support shell without the need to transfer alignment between the inner yoke and outer yoke. The width of the loading bladders has been increased and the number of bladders has been reduced. Other minor changes, including the incorporation of yoke load keys that function independently from the alignment keys, have been incorporated to aid in assembly and to ensure that proper alignment is maintained.

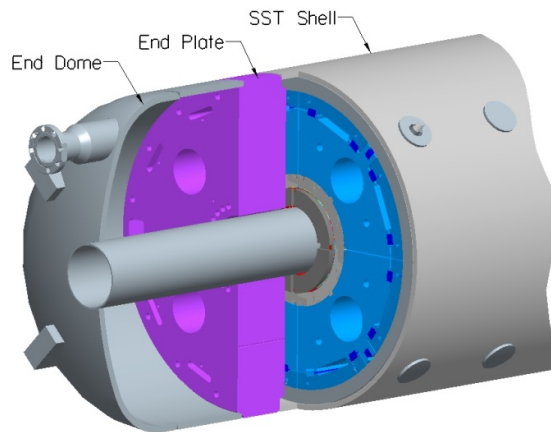A 3-D cutaway view of the coldmass can be seen in figure 4.

Figure 4: 3-D Cutaway View of Coldmass.

ANALYSIS

ANSYS finite element modeling was repeated for the updated 2-D mechanical structure. Loading was performed in five steps; collaring, full bladder pressure at assembly, yoke shims installed with no bladder pressure, cool down to 4 K and powered to 220 T/m flux gradient. Collars are designed to apply a modest coil prestress at assembly of 20 MPa. Series 7000 aluminum is used to withstand the resulting local stress in the keyway of approximately 400 MPa. Collars have a mechanical stop at the midplane which is closed after collaring, preventing over-stressing of the coils at room temperature. Figures 5 and 6 show the stress in the collar during assembly and resulting coil stress at collar assembly, respectively.
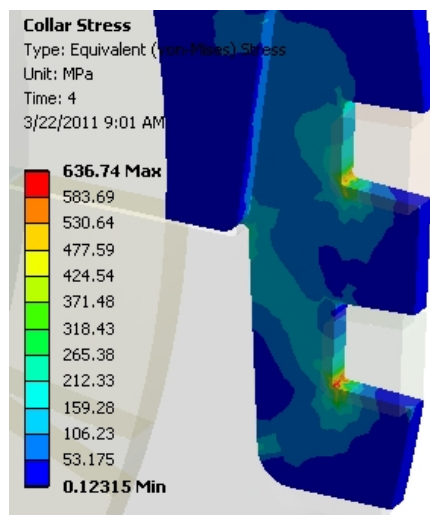

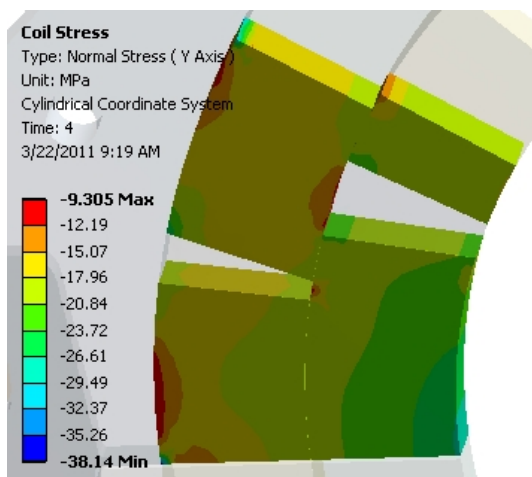Figure 5: Equivalent Stress in Collar at Key Insertion.

Figure 6: Coil Stress After Collar Assembly.

A maximum bladder pressure of 27 MPa is applied which results in an average coil stress at the pole of 105 MPa and a peak coil stress at the inner layer pole near

the coil ID of 150 MPa. After keys are installed and bladder pressure is removed the coil pole stress reduces to an average of 92 MPa and a peak at the outer layer midplane near the coil OD of 116 MPa. Yoke and support shell stresses are all within acceptable limits during all stages of assembly.

During cool down the shrinkage of the aluminum support shell increases the loading of the coils to the extent allowed by the mechanical stops of the collars. Since the magnetic yoke steel shrinks less radially than the aluminum support shell and collars, and since the yoke quadrants do not contact each other at the midplane parting planes they therefore assist with the increasing of load on the coils during cooldown. Coil stress after cooldown reaches an average value of 156 MPa at the pole. Due to support shell loading and thermal contraction as a result of cooldown the coil midplane at the layer 2 outer radius is reduced by 385 microns.

With Lorentz forces applied the coil at the pole reaches a minimum of 20 MPa in tension which is within the allowable limit to prevent separation. As a result of the Lorentz forces the coil midplane at the layer 2 outer radius deflects 55 microns outward radially with respect to the position of the coil after cooldown.

A summary of the 2-D mechanical analyses of the azimuthal coil stresses and stresses in the support shell structure from assembly through test is provided in Table 1.

Table 1: 2-D Mechanical Analysis Summary

Parameters	MPa
AVERAGE COIL POLE	
σ_θ max with bladder pressure	-105
σ_θ max with keys installed	-92
σ_θ max at cool down	-156
σ_θ max ay 220 T/m, 1.9K	+20
SHELL	
σ_θ max with bladder pressure	199
σ_θ max at cool down	181
σ_θ max at 220 T/m, 1.9 K	206

ASSEMBLY

Coil are insulated and assembled into collars which are then loaded and keyed in a simple frame, see figure 2. Four pushers in precise slots load the collars using bladders of the same configuration as the coldmass assembly bladders. Narrow bladders load the tapered key into their keyways.
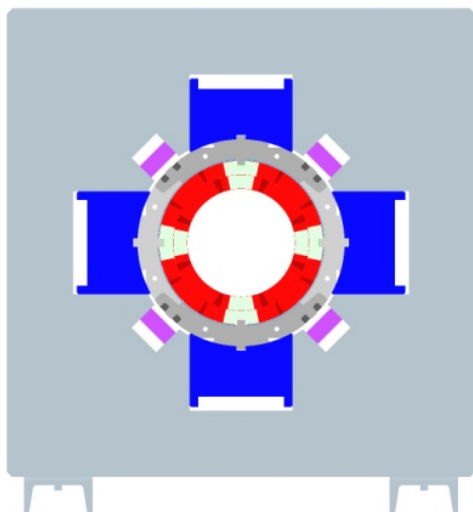
Accelerator Technology

Figure 2: Collaring Fixture.

Once the yoke and collar assembly has been inserted into the support shell, an alignment fixture, shown in figure 3, is used to maintain alignment during loading. Precise alignment pins will be inserted through the access holes in the aluminium support shell and will engage the keyways in the yoke to hold the yoke and collar assembly in precise alignment during the bladder loading operation.

The support shell is then inserted with radial clearance into the stainless steel helium vessel, and then aligned and secured using supports welded at the access holes. Some of the holes in the stainless steel helium vessel will then be used for installation of fiducials that permit alignment during later phases of assembly and magnet installation.
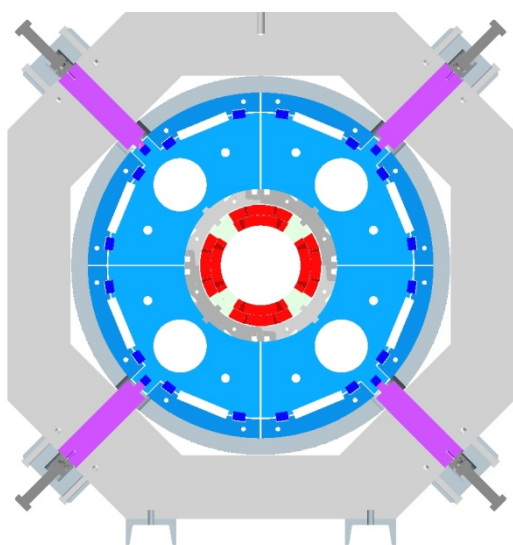

Figure 3: Yoke Alignment Fixture.

CONCLUSION

An alternate mechanical structure for 120 mm aperture Nb3Sn quadrupole magnets designed to operate in LHC is proposed. The mechanical analyses show that structure can properly support the coils during assembly and operation to 220 T/m and as such is an equivalent structural support system to the shell and key assembly presently used for the 1m HQ LARP quadrupoles. The structure has been designed to provide reliable alignment of coils needed to achieve field quality. A provision for helium cooling of the coils is incorporated into the structure. Analysis and cross section design is complete. Fabrication of parts and tooling for a 15 cm mockup is underway. Assembly and test of the mockup will be followed by fabrication and test of a 1 m magnet.

REFERENCES

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