Design of a high field Nb3Al common coil magnet for LHC upgrade

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Abstract

A high field Nb3Al/Nb3Sn combined magnet is under development, as a R&D program of "Advanced Superconducting Magnets for the LHC Luminosity Upgrade". There are totally 5 superconducting coils in this magnet, 3 Nb3Al coils sandwiching 2 Nb3Sn coils, with a common coil configuration. For the Nb3Al coils, the peak field is 13.2T, located at the center of straight part; for the Nb3Sn coils, it is 11.9T, located at the end part. Shell structure was adopted in the mechanical design, to simplify the future assembly process. The fabrication, assembly and test processes will be carried out in the following two years. The detailed magnetic and mechanical designs are presented in this paper.

1. INTRODUCTION

A research and development program of "Advanced Superconducting Magnets for the LHC Luminosity Upgrade" has been carried out since 2006, in the framework of the CERN-KEK cooperation program. It aims to develop high field superconducting magnets expected in the LHC luminosity upgrade with A15 superconductor. The first stage (2006-2008) has progressed in focusing to establish Nb_3Al superconductor and cable technology to prepare for the high field magnet application. At the second stage (2009-2011), a Nb_3Al common coil magnet will be fabricated, to demonstrate the feasibility of high field magnet wound with Nb_3Al cable, and also, as an R&D of the advanced structure for high field magnets.

The design of our Nb_3Al high field magnet has been started from 2007, under the collaboration with LBNL. The original 2D design was presented in reference [1]. This paper presents the detailed 3D design and some new modifications.

2. MAGNETIC DESIGN

The common coil configuration was adopted in the magnetic design of this magnet [2]. There are totally five superconducting coils, three Nb_3Al coils sandwiching two Nb_3Sn coils, as shown in Fig. 1. The two Nb_3Sn coils (coil2 in Fig. 1), wound with double pancake structure, help to increase the peak field of the magnet, which located at the centre of the Nb_3Al coils. For the three Nb_3Al coils, two of them (coil3 in Fig. 1) are wound with double pancake structure, and the third one (coil1 in Fig. 1) is wound with common coil structure. The two kinds of coils were designed with different straight lengths, to reduce the peak field at the Nb_3Sn coils. Fig.2 shows the load line of the magnet. For the Nb_3Al coils, the overall outer length is 200.5 mm; the width and the height are 100.5 mm and 30.8 mm respectively (14 turns per layer and 2 layers per coil). The peak field is 13.2 T, located at the centre of the straight part. For the Nb_3Sn coils, the overall length is 252.9 mm; the width and the height are 100.5 mm and 16.9 mm respectively (20 turns per layer and 2 layers per coil). The peak field is 11.9 T, located at the end part. The operation current is limited by Nb_3Sn coils.

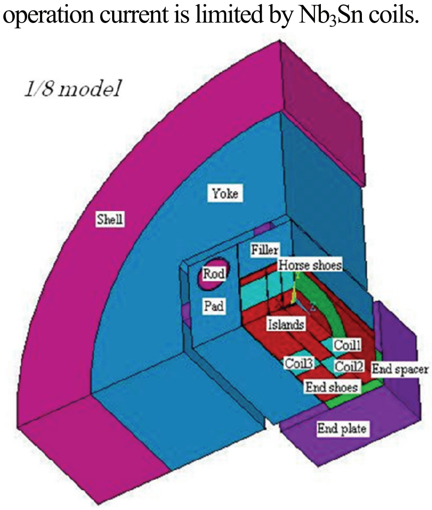

Fig. 1. 1/8 model for the magnetic and mechanical simulation

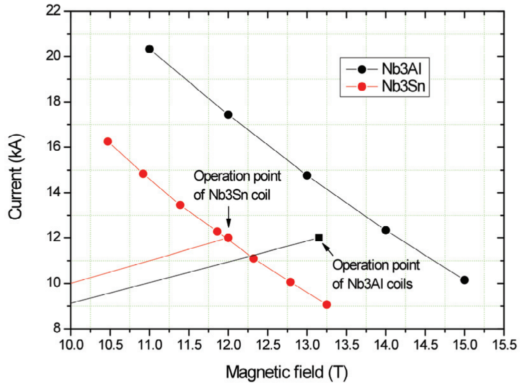

Fig. 2. Load-line curve of the magnet

The main design parameters of the magnet are shown in Table 1. The parameters of the Nb_3Al conductor and coils are shown in Table 2.

3. MECHANICAL DESIGN

Fig. 3 shows the magnetic force distribution of the coils during excitation. For the coil1, opposite direction magnetic forces are applied to the two layers, which will strongly divide the coil1 into two parts, damaging the insulation materials between the two layers, and also cause a big movement of the Nb_3Al cable. For the coil2 and coil3, the magnetic forces are trying to separate the coils with the islands and horse-shoes. All these forces should be overcome, to protect the insulation materials from being damaged, and minimize the movement of the Nb_3Al cable during excitation.

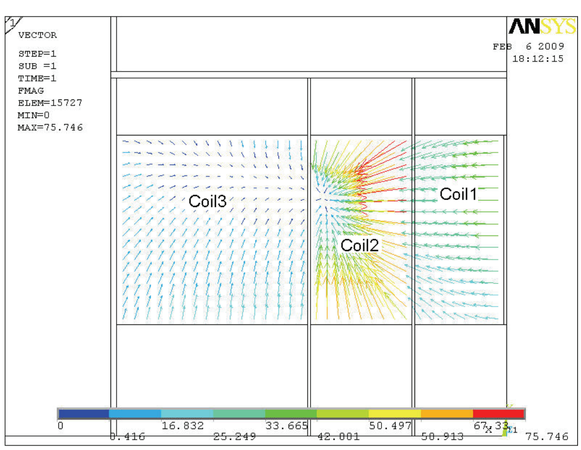

Fig. 3. Magnetic force distribution at the straight part

To simplify the future assembly process, the shell structure was adopted in the mechanical design of the magnet [3], and four 36mm-diameter aluminum rods apply the axial stress to the coils. The thermal contraction of the aluminum shell and rods, together with the pre-stress applied at the room temperature, overcomes the Lorenz force during excitation, to prevent the separation of the coils from the insulation materials, islands and horse-shoes. With the assumption that the cryogenic cement can sustain 20 MPa separation stress at the low temperature, the pre-stress in three directions were

Table 1: Main design parameters of the magnet.

Operation current	12.2 kA
Peak field at the coils	13.2 T
Stored energy	71.8 kJ
Inductance	0.97 mH
Magnet Length	740 mm
Iron Yoke Dia.	500 mm
Al Shell Dia.	680 mm

Table 2: Parameters of Nb_3Al conductor and coils.

Nb_3Al Strand Dia.	1 mm
Cu/Non-Cu ratio	0.75
No. of Stands	27
Cable dimension	14.05*1.83 mm^2
Cable Insulation	0.25 mm
Coils No.	3
Turns No. per layer	14
Layers No. per coil	2

optimized. As shown in Fig. 4, in x direction, the pre-stress is applied with the bladder inserted between the yoke and the pad. The required magnitude is around 55 MPa. For the pre-stress in y direction, the bladder operation is not required. It is applied by the deformation of the aluminum shell during the bladder operation in x direction. In z direction, it is 159 MPa, and is applied by tightening the nuts at the end of the aluminum rods. All these efforts are made to insure the contact pressure around the coils larger than -20 Mpa during excitation (minus - separation; plus - compression).

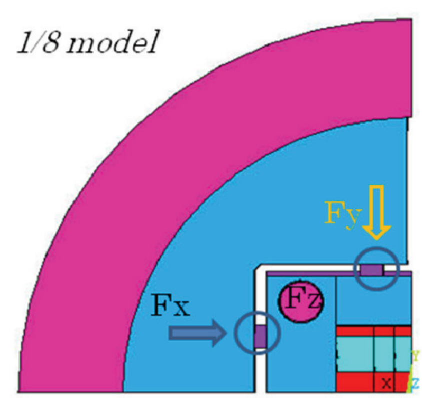

Fig. 4. Pre-stress application of the magnet

The magnitude of the pre-stress is strongly related with the shell thickness of the magnet and the support structure of the coils. With a thinner aluminum shell, the thermal contraction stress is small, so the higher pre-stress is required, and vice versa. For the common coil configuration, if no special structure to support the coils, most of the stress coming from the outside will applied to the islands and horse-shoes, at which part the material is much harder than the coils, as shown in Fig. 5 and Fig. 6. In other words, the stress is not efficiently transferred to the coils. As a result, the more thick aluminum shell would be required, but the coil winding and magnet assembly will be carried out in the most common and easy way. Another choice is to design some special support structures for the coils, to increase the efficiency of the stress transfer, as a result, to reduce the thickness of the aluminum shell. A cost we should bear for this method is that, the coil winding and magnet assembly processes become complicated. The sliding boundary between the coils and the surroundings is required, and also, the stress behavior of the coils is not as good as the former way.

Several bladders were tested with high water pressure. The bladders were firstly inserted into an aluminum shell, together with the yoke and shims, and then filled in the high pressure water. The burst pressure differs from 69 MPa to 103 MPa, generally satisfying our requirement for the future assembly process. The strain variation of the aluminum shell was also measured during the bladder test, and compared with the ANSYS simulation results. It shows that the simulation with friction coefficient 0.2 fits the experimental data well.

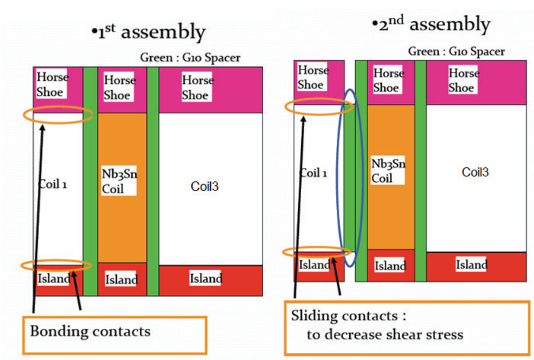

Fig. 5. Two types of support structures for the coils. Left: a common support structure; Right: a special support structure.

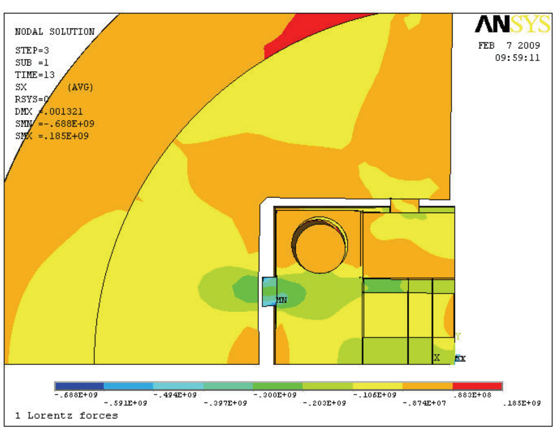

Fig. 6. Stress transfer from outside to the coil packs

4. DEVELOPMENT STATUS AND FUTURE SCHEDULE

The Cable for the first Nb_3Al coil has been fabricated and wrapped with ceramic insulation material. The winding process will start soon. For the following two Nb_3Al coils, the cable will be fabricated in the end of this year and the mid of next year. The magnet assembly and the test experiment will be carried out in the following two years.

ACKNOWLEDGEMENT

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REFERENCES

1. K. Sasaki et. al., Abstracts of CSJ Conference, Vol. 79 (2008), p.202
2. A. R. Hafalia et al., IEEE Trans. on Appl. Superconductivity, Vol.13, No.2 (2003), p.1258
3. A. R. Hafalia et al., IEEE Trans. on Appl. Superconductivity, Vol.12, No.1 (2002), p.47