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FABRICATION AND TEST RESULTS OF A HIGH FIELD, NB_3SN SUPERCONDUCTING RACETRACK DIPOLE MAGNET*

R. Benjegerdes, P. Bish, D. Byford, S. Caspi, D.R. Dietderich, S.A. Gourlay, R. Hafalia, R. Hannaford, H. Higley, A. Jackson, A. Lietzke, N. Liggins, A.D. McInturff, J. O'Neill, E. Palmerston, G. Sabbi, R.M.Scanlan, J. Swanson
Lawrence Berkeley National Laboratory, Berkeley, California, 94720

Abstract

The LBNL Superconducting Magnet Program is extending accelerator magnet technology to the highest possible fields. A 1 meter long, racetrack dipole magnet, utilizing state-of-the-art Nb_3Sn superconductor, has been built and tested. A record dipole filed of 14.7 Tesla has been achieved. Relevant features of the final assembly and test results are discussed.

1 INTRODUCTION

The goal of the LBNL Superconducting Magnet Program is to develop the technologies associated with very high field superconducting magnets. Cost-effective options will be needed for the next-generation high-energy physics accelerators such as the Very Large Hadron Collider and muon/collider rings. Simplicity is a key element of any cost-effective design and the "Common-Coil" racetrack [1,2], with its intrinsic dual-bore geometry, is an attractive candidate. Consequently, our program is primarily focused on the development of options offered by this design. Past work can be found in [3,4,5,6].

Generating fields above 10 Tesla requires the use of A15 compounds that are brittle and strain sensitive. For the foreseeable future, Nb_3Sn is the most practical conductor available. For high field applications a concurrent development program [7] is required to reduce conductor cost and improve performance. Following the successful test of a 6 Tesla racetrack magnet (RD-2)[4], we have been focusing on the design and fabrication of a 14 Tesla magnet (RD-3), at the edge of current technology, Fig. 1.

2 DESIGN

Details of the design and fabrication steps of RD-3 have been described elsewhere [6]. A cross section of RD-3

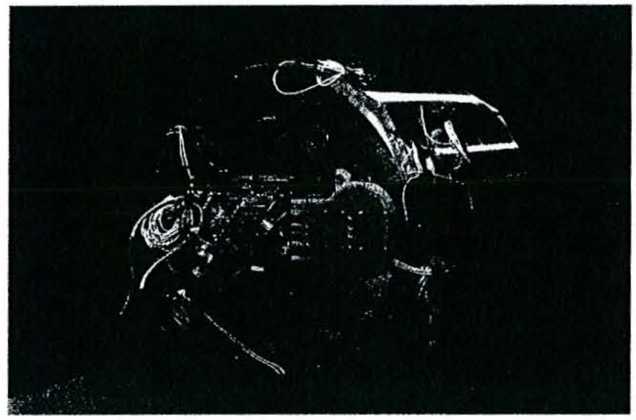

Figure 1. RD-3

(Fig. 2) shows the 3-layer design: two double-pancake outer coils and a single-layer inner coil. The general magnet parameters are given in Table 1.

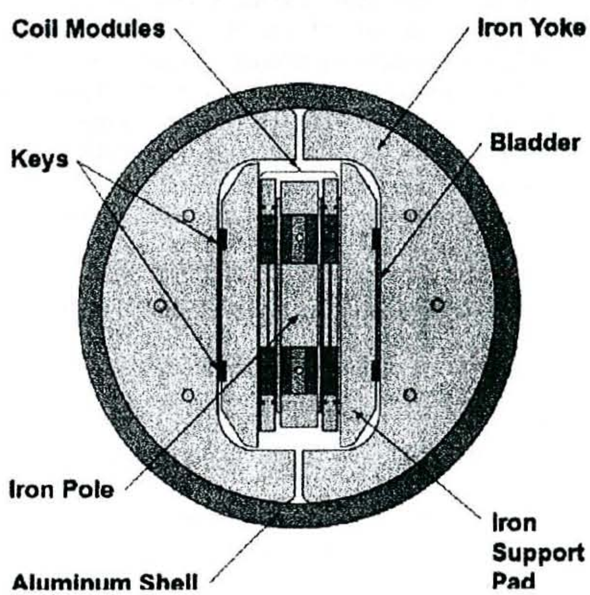

Figure 2. RD-3 Cross Section

For high fields, conductor performance is very important. The conductor, manufactured by Oxford Superconducting Technology, Inc, had a J_c over 2,000 A/mm^2, three times that used for RD-2.

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Table 1. RD-3 Magnet Parameters

Main coil spacing	25 mm
Computed quench field at 4.2 K	14.6 T
Peak field, inner layer	14.9 T
Peak field, outer layer	11.5 T
Maximum current (predicted)	10.9 kA
Number of main coil layers	3
Straight section length	500 mm
Number of turns (half magnet)	50+49+49
Nominal height of each main coil	80 mm
Minimum coil bend radius	70 mm
Vertical bore spacing	220 mm
Yoke outer height and width	300 mm
%Cu Inner/Outer	47.3/57.3
I_c Inner 12T/15T	540/265 A
I_c Outer 12T/15T	382/180 A

3 FABRICATION AND ASSEMBLY

The construction of high field magnets requires careful consideration of the mechanical support structure design. Aside from the conductor, the support structure is the most important factor in developing a robust and cost effective high field magnet.

RD-3 is a Nb_3Sn common coil dipole designed to exceed 14 Tesla. At that field, the average Lorentz side force is 15.4 MN/m (1 M-lb/ft) or a total of 12.0 MN over the 780 mm coil length, acting to push the windings apart. In order to manage these large forces, a new support structure design was developed for RD-3 that uses inflatable bladders as a temporary internal "press" to load the coil modules inside an aluminum shell. This configuration utilizes the best features of the simple cantilevered structure used in the successful test of RT-1 [5], but eliminates coil displacement.

The bladders, placed between the coil pack and the iron yoke, simultaneously compressed the coil pack to 70 MPa, and tensioned a 40 mm thick structural aluminum shell to 155 MPa. The shell was highly instrumented with strain gauges to record all phases of assembly and testing. Keys were inserted to maintain pre-stress when the bladders were deflated and removed, leaving the shell with 140 MPa of tension. Measurements were compared with ANSYS calculations to determine the final stress in the shell and coil.

No creep was observed over many days at room temperature, (Fig. 3). During cool down, stress in the shell increased to 250 MPa due to the relative thermal contraction between the shell and the iron yoke.

This system simplifies magnet assembly substantially, and easily contains the large Lorentz forces without the need for precision parts. The magnet structure reaches maximum stress after cool-down. During operation, reactive forces between the two halves of the magnet are replaced with Lorentz forces within the coils, leaving the stress in the structure unchanged. As long as the coil structure is pre-stressed beyond the Lorentz forces, the two coil halves will not separate. The shell pre-stress of RD-3 has been designed for an equivalent field of 16 Tesla, providing a sufficient safety margin for the current design field.

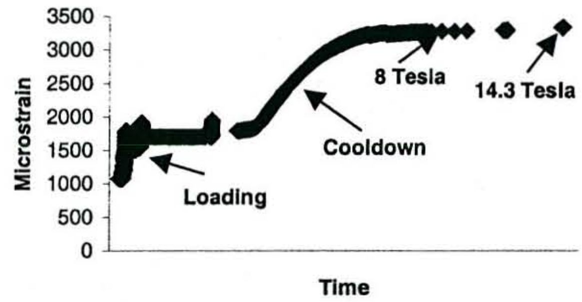


Figure 3: Pre-stress history, from loading through cool-down and magnet excitation for the first cycle.

4 TEST RESULTS

The final assembly of RD-3a was completed in August 2000. During the first ramp, an insulation failure occurred, which resulted in arc damage to two coils. The damaged coils were rebuilt and RD-3b was tested in two cycles, one starting in late April '01, followed by a thermal cycle in early Jun '01.

All the Nb_3Sn/NbTi joint resistances were measured, and found to be very low ($R < 1$ nano-ohm). The first training quench occurred at 8.1 Tesla (Fig. 4). The magnet trained slowly, exceeding a field of 14 Tesla after 35 quenches. A plateau was reached at an average value of approximately 14.2 Tesla. However, the quenches at this field level still exhibited features typical of motion-induced training quenches, indicating that the magnet may not have been at the short sample limit.

Most of the training quenches below 13.7 Tesla originated in the central (high-field) section of the inner coil module. Above this field, most of the quenches originated in the outer coil modules.

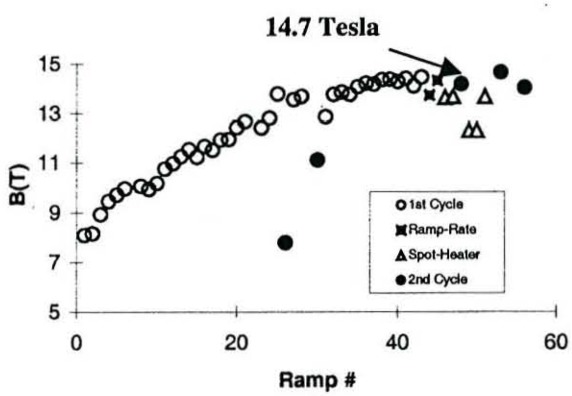


Figure 4: RD-3b Quench History.

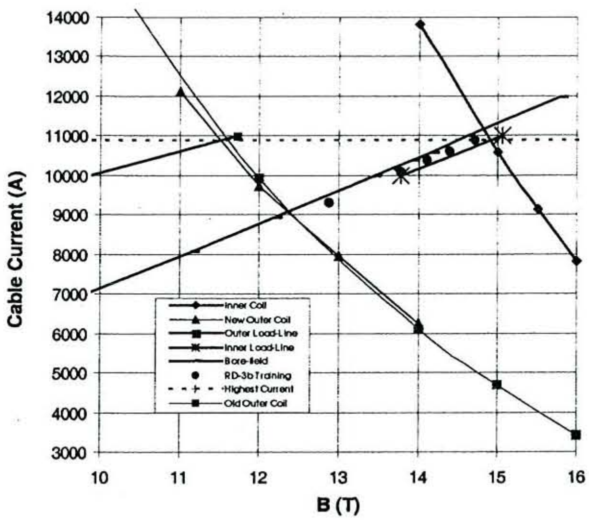


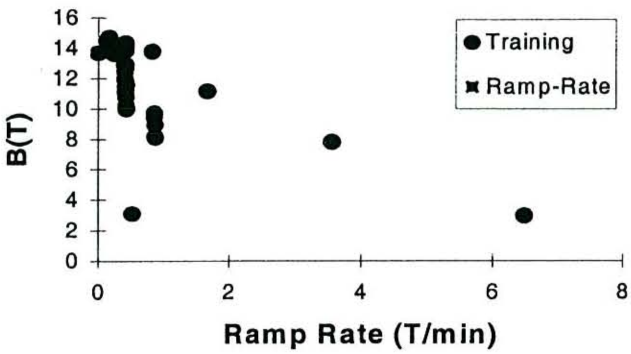
Figure 5: Load lines of inner and outer coils and the calculated bore field of RD-3b. The peak field load lines of both coils intersect their respective short sample critical current curves near the highest current obtained in the magnet (i.e. the last of the circular data points at 14.7T.

After a thermal cycle, the first training quench (Q48) occurred at the previously established plateau of 14.2T, indicating excellent retention of its previous training. During this test the magnet reached a bore field of 14.7T, which is near the short sample critical current limit for both coils (Fig. 5). The short sample critical current for the outer coils plotted in Fig. 8 are conservative. This is due to the old outer cable being a blend of three billets, nominally the same, but with one having a lower critical current than the other two. Although the new outer cable was made from the same billet, there was a front-end to back-end variation in critical current and the lower critical current value was used for modeling. Since strands of a cable can share current it is believed that the assumptions made here give the lower bound for the magnet performance. There is no degradation in critical current from cabling or magnet operation.

The ramp rate dependence (Fig. 6) exhibited a gradual, steady decrease, without evidence of a low ramp-rate plateau.

5 DISCUSSION AND CONCLUSIONS

We have shown that Nb_3Sn coils wound in the common coil (or racetrack dipole) configuration can achieve unprecedented dipole fields (14.7 Tesla) in accelerator magnets. The magnet performed within the range predicted by short sample strand data and behaved mechanically as predicted by TOSCA and ANSYS models. There is no degradation in critical current due to cabling or due to the Lorentz loads during operation.



6 ACKNOWLEDGEMENT

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