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A Common Coil Magnet for Testing High Field Superconductors*

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Abstract

A one-meter long magnet has been fabricated to provide background field for testing racetrack shaped coils made from high field materials such as Nb_3Sn, Nb_3Al and the new high temperature superconductors, BSCCO and YBCO. The magnet is of the double aperture common coil type and uses high current Nb-Ti main coils to produce an applied field of approximately 7T on inner coils fabricated from pre-reacted tape conductors. The performance of the magnet is summarized along with test results from insert coils wound from N_3Sn ribbon conductor.

1 INTRODUCTION

Superconducting magnets for accelerator applications have been made almost exclusively from the ductile alloy NbTi. In the LHC machine at CERN the superconducting coils will be operated in superfluid helium to extract the highest possible performance from this versatile material. Future accelerators designed to operate at even higher fields and temperatures will have to utilise superconductors with less desirable mechanical properties. The A15 compounds N_3Sn and Nb_3Al have much higher upper critical fields than NbTi but are brittle and can only be subjected to limited mechanical strain. This is also true for the new high temperature superconductors such as BSCCO and YBCO so that magnets made from these materials must be formed by either reacting the conductor after winding or developing a design in which the conductor is subjected to limited stress during fabrication. Gupta [1] has proposed a magnet with flat racetrack shaped coils readily wound from high aspect ratio conductor. In this geometry the magnet has two apertures with magnetic fields of opposite polarity, ideal for colliding beam machines. This configuration also allows the minimum bending radius of the conductor to be determined by the separation of the apertures. A magnet of this type is illustrated in Fig. 1. It can be viewed as two classical "window frame" magnets in a single yoke. Both the windings shown on the right side of the diagram are part of the same racetrack coil with

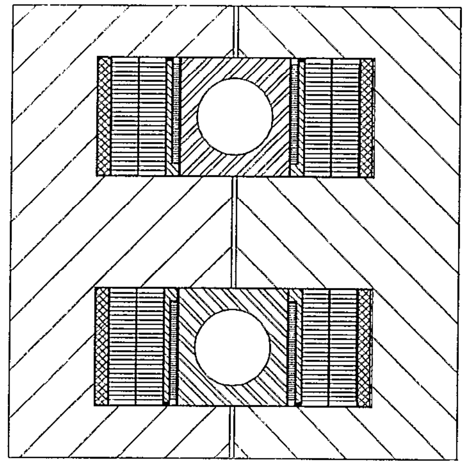

Figure 1 Cross section of the windings in the common coil magnet. The turns on the right form one half of the upper and lower dipoles, but are part of the same racetrack coil. Similarly, the turns on the left side form the other half of each dipole. The test windings are positioned inside the high current cable coils in a region of relatively uniform field.

the upper block of conductors forming one half of the windings of the top magnet and the lower block of conductors forming half of the lower magnet, thus the name "common coil". The magnetic force distribution in this device is quite different than in a Cosθ coil so that most of the force is across the width of the conductor rather than across its thickness. This is because the coils are connected in opposition to force the flux up or down thru the apertures as illustrated in Fig. 2. Because the coils are flat and the minimum bending radius can be quite large they are ideally suited to fabrication from relatively brittle conductors.

2 MAGNET DESIGN

Since the present high cost and limited performance of high temperature superconductors (HTS) makes it impractical to design a double dipole using only HTS material, we have

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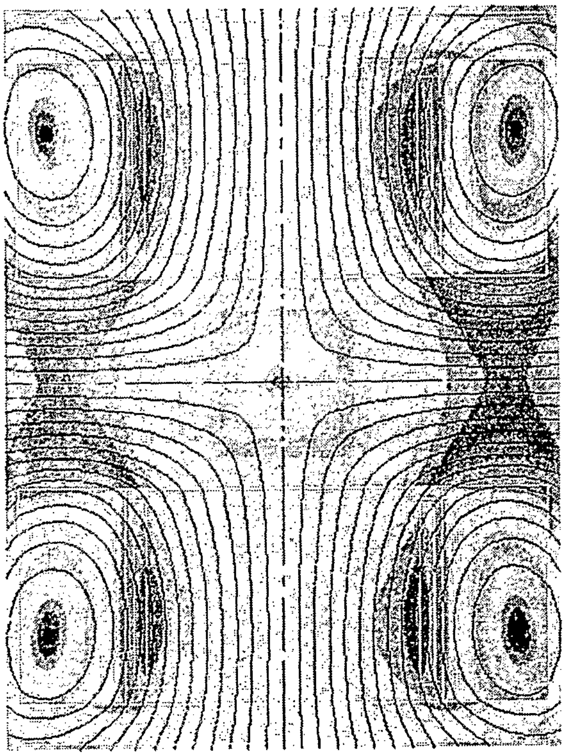

Figure 2. The field distribution in the straight portion of the common coil magnet. Field strength is indicated by the shading.

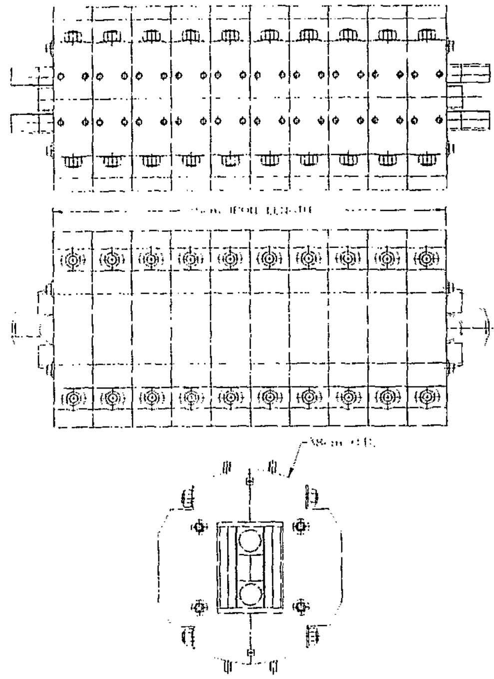

Figure 3. The mechanical details of the common coil magnet. The iron core is split vertically to facilitate changing the insert coils.

chosen a hybrid design where the main coils are made from NbTi cable (surplus from the SSC Project) and auxiliary or insert coils are made from developmental conductors (see Fig. 1). The NbTi coils are wound using techniques and insulation perfected by the SSC and RHIC Projects. Each coil is formed as a double pancake from a single length of conductor. The iron yoke halves are made of blocks cut from 3" thick plate and epoxyed together. Figure 3 shows the mechanical details. This yoke is split vertically so that the magnet can be separated easily to replace the insert coils.

Rectangular aperture pieces fit between the coils to simulate beam tubes and provide access for magnetic measurements. Mechanical loading of the coils is provided face on by the large bolts holding the yoke together and from the side by a series of set screws as shown in Fig. 3. The tape insert coils are wound on G-10 formers using Kapton insulation and then coated with epoxy. The magnet is assembled in halves and then bolted together. Only one connection is required between each set of coils so that changing inserts is relatively straightforward. The main coils provide a reasonably uniform field over the volume occupied by the insert coils.

When the current density and economic aspects of HTS conductors improve, the NbTi coils will be replaced.

3 MAGNET PERFORMANCE

The magnet exhibited considerable "training" when powered as shown in Fig. 4. A peak field of 5.8T was achieved before the first quench and 6.6T after five quenches. The maximum field expected based on measurements of the conductor used is 7.3T at 9kA. When the magnet is energized the coils are forced apart and the resulting motion is thought to be the source of the disturbances that initiate premature quenches. In principle a large part of this training could be eliminated by preloading the coils using the large bolts which hold the yoke halves together. In practice, it was found that turn to turn short circuits in the coil appeared at quite low pressure (~5mPa) so that it was not possible to put a significant preload on the coil and maintain electrical integrity. Despite this limitation the magnet was able to produce over 90% of the expected background field for testing insert coils. The shorting problem is confined to the transition region between the two halves of the double pancake winding. It is expected that improved insulation will allow higher preloading and reduced training in subsequent tests.

4 INSERT COIL PERFORMANCE

The first set of insert coils were wound from Nb_3Sn tape 3mm wide and 0.3 mm thick. These dimensions are typical of HTS conductors and this coil was intended as a benchmark for comparing the performance of these new materials with more conventional low temperature superconductors. The test consisted of setting the applied field at a predetermined level with the main winding and then increasing the current in the insert coils until a quench occurs. The results are shown in Fig. 5. The field on the test coil increases slightly with current due its self field. The conductor used in this coil appears to be inherently unstable since the quench currents are well below the critical current at all field levels and independent of applied field. The coils do not train but quench randomly at values between 200 and 300 amps. The conductor used in these coils is made by diffusing tin into a thin niobium sheet to form a Nb_3Sn layer on each side and then laminating with copper stabilizer. Since the superconducting material is in a continuous film large magnetization currents can develop during ramping possibly leading to premature quenching. Additional tests at very low ramp rates are scheduled for the next experimental run to examine the dynamic properties of these coils.

5 CONCLUSIONS

The training behaviour observed in the main coils indicate improvements are needed in the mechanical structure of the magnet. Improving the insulation so that higher prestress can be applied during assembly should reduce or eliminate this problem. While the performance of the insert coils is considerably below expected levels, they do provide a useful reference point for gauging the performance of similar windings made from HTS conductor.

6 ACKNOWLEDGEMENTS

Among the many members of the RHIC Magnet Division who contributed to the development of this magnet, three deserve special mention. Lon Werner was responsible for winding the main coils and assembling the magnet, Larry Welcome fabricated the insert coils and Andy Sauerwald performed the testing.

7 REFERENCES

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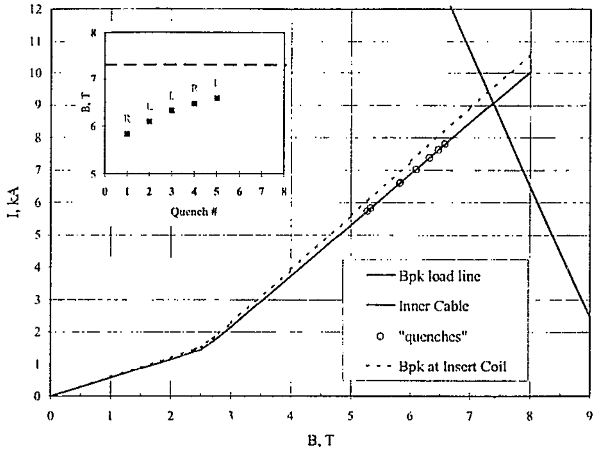

Figure 4. The training behaviour of the main winding of the common coil magnet.

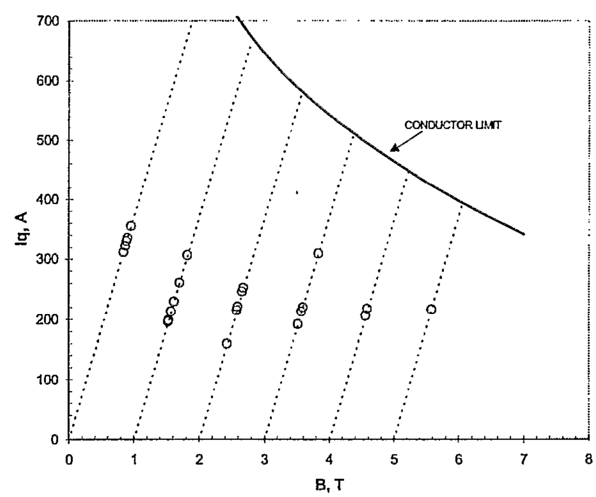

Figure 5. Nb_3Sn insert coil quench currents plotted against the applied field for ramp rates greater than 1A/s