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SUPERCONDUCTING DIPOLE MAGNETS FOR THE LHC INSERTION REGIONS

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Abstract

Dipole bending magnets are required to change the horizontal separation of the two beams in the LHC. In Intersection Regions (IR) 1, 2, 5, and 8, the beams are brought into collision for the experiments located there. In IR4, the separation of the beams is increased to accommodate the machine's particle acceleration hardware. As part of the US contribution to the LHC Project, BNL is building the required superconducting magnets. Designs have been developed featuring a single aperture cold mass in a single cryostat, two single aperture cold masses in a single cryostat, and a dual aperture cold mass in a single cryostat. All configurations feature the 80 mm diameter, 10 m long superconducting coil design used in the main bending magnets of the Relativistic Heavy Ion Collider recently completed at Brookhaven. The magnets for the LHC, to be built at Brookhaven, are described and results from the program to build two dual aperture prototypes are presented.

1 INTRODUCTION

The magnets being built by Brookhaven as part of the US/CERN LHC Accelerator Project have been described in several earlier papers [1,2,3]. This paper updates those reports and describes the construction and test results of a prototype magnet (DMP401) recently built and tested at Brookhaven. This magnet performed well and meets the technical requirements for the LHC. A second prototype will be built and tested before construction of full length magnets commences. More complete technical descriptions of the magnets are given in several recent documents [4,5].

2 LIST OF MAGNETS

A list of the dipole magnets currently planned for construction at Brookhaven is given in Table 1. There are several changes with respect to the earlier plans [2], in particular a revised aperture separation for D2. These magnets all have a magnetic length of 9.45 m and a coil aperture of 80 mm. The coils are of the same design as used for RHIC. The 2-in-1 magnets have Kawasaki high-Mn KHMN stainless steel collars.

The magnetic fields required in the magnets vary by machine energy and location. Table 2 summarises the various field requirements.

Table 1: Dipoles to be built by Brookhaven for the LHC.

Name	Type	Cold Masses in One Cryostat	Aperture Separation, Cold (mm)	Number (Spares)
D1	1-in-1	1	---	4(1)
D2	2-in-1	1	188	8(1)
D3a	1-in-1	2	420	2(1)
D3b	1-in-1	2	382	2(1)
D4a	2-in-1	1	234	2(1)
D4b	2-in-1	1	194	2(1)

Table 2: Magnetic fields required in the magnets.

Magnet	IR Location	Field (T) for E (TeV)		
		0.45	7.0	7.56
D1/D2	2 & 8	0.244	3.797	4.091
D2	1 & 5	0.176	2.742	2.954
D3/D4	4 left	0.215	3.343	3.602
D3/D4	4 right	0.220	3.415	3.679

3 PROTOTYPE MAGNET

3.1 Design & Construction

In order to check the design and to validate the planned construction techniques, two prototypes magnets were planned. These have the same cross section as the D4b magnets but are one-third of the final length. This cross section is shown in Fig. 1. A photograph of the first completed prototype is shown in Fig. 2.

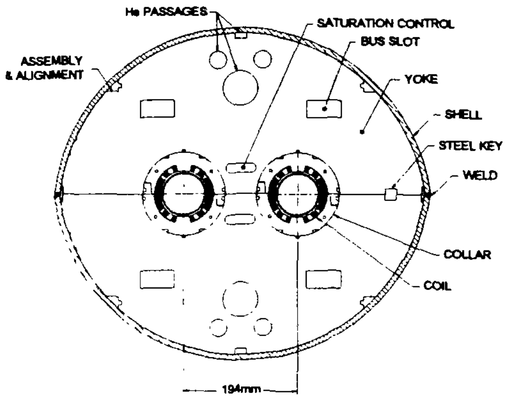

Figure 1: Drawing of the prototype (D4b) magnet.

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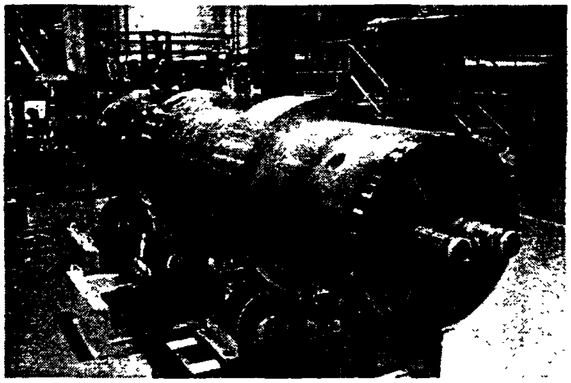

Figure 2: Photograph of the completed prototype magnet.

The left upper, left lower, right upper and right lower coil sizes (seen from the lead end) were measured to be 65±20(std), 76±34, 18±18, 52±25 μm respectively, where 0±50 μm is nominal. Thus the left side coils were a little big, and the right side coils had a small top/bottom mismatch. Coil prestress in both apertures after collaring was 70±7 MPa. Fig. 3 shows the coil stress with excitation, after cooldown to 4.5 K.

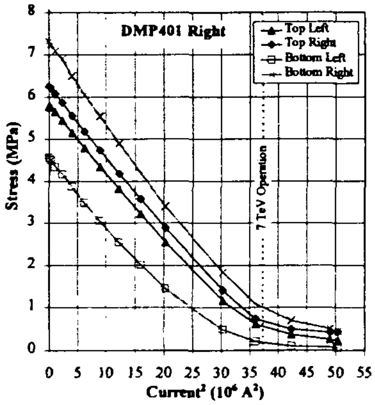

Figure 3: Stress vs. current in the right aperture. Four independent strain gauges measure the coil stress at a particular axial location. The behavior is as expected.

3.2 *Quench Performance*

Fig. 4 shows the quench performance of the prototype magnet. All quenches in this magnet were above the "7 TeV Operation" line, but were not at the short sample limit. The somewhat erratic quench current level, while acceptable because of the available margin, is probably due to imperfect fit-up of parts in the magnet, coupled with the very high copper current density in the conductor (1300 A/mm^2 at 8 kA) at quench [6].

3.3 *Field Harmonics*

Fig. 5 and 6 show the measured field harmonics at 3200 A excitation. The "expected" harmonics are discussed in an earlier paper [7] and are based on measurements in RHIC magnets. The errors bars shown are a sum of expected random errors (1 SD) and the range of possible systematic errors. The normal sextupole term (harmonic 3 in Fig. 5) is somewhat large and may point to a shim adjustment in production magnets. The skew quadrupole term in the right aperture (harmonic 2 in Fig. 6) may be caused by a coil size mismatch and/or an asymmetry in the assembly.

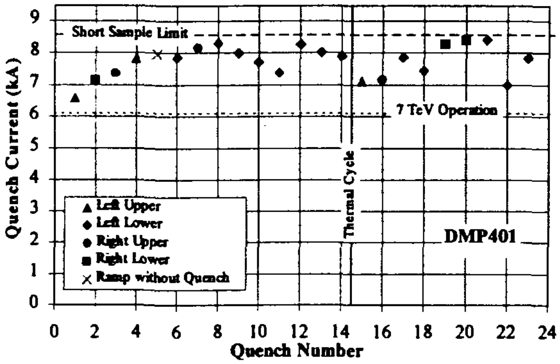

Figure 4: Quench performance. The line marked "7 TeV Operation" corresponds to 3.8 T in the magnet.

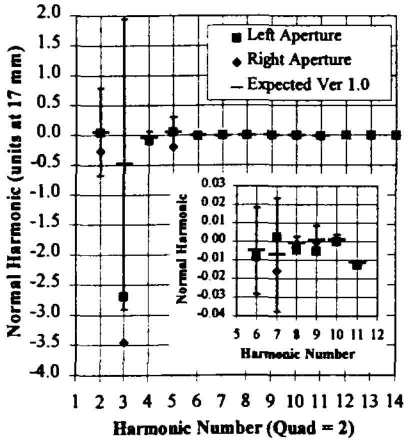

Figure 5: Normal harmonics measured in the magnet.

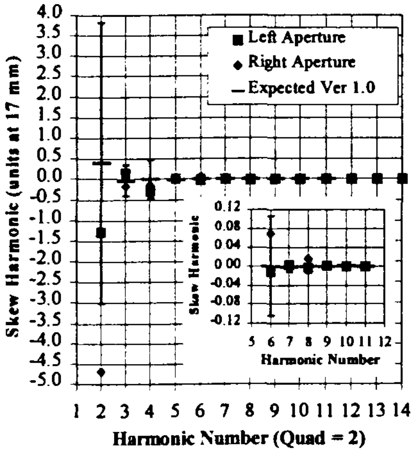

Figure 6: Skew harmonics measured in the magnet.

3.4 Low Field Effects

Field measurements as a function of current revealed a strong current dependence in the low field quadrupole term, Fig. 7, where no such dependence was expected. Other harmonics were as expected. The low field effect has been traced via a series of cold and warm measurements to the permeability of the iron yoke at low field and a remnant field from the iron yoke [8]. This permeability has not been directly measured but a value in the range of 100 to 200 with 10 to 30 A magnet excitation would explain the data.

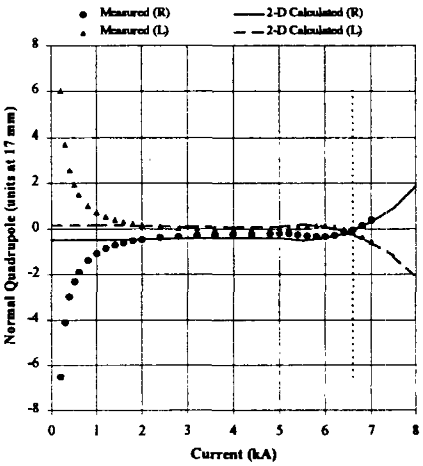

Figure 7: Measured current dependence of the quadrupole harmonic.

3.5 Angle Alignment of the Apertures

The prototype magnet was levelled on a surface plate and the angle of the field in each aperture was measured with respect to gravity using a calibrated rotating coil. The result is plotted in Fig. 8. The measured angle difference of the apertures (0.05 mrad) is small and is near the limit of resolution of the apparatus.

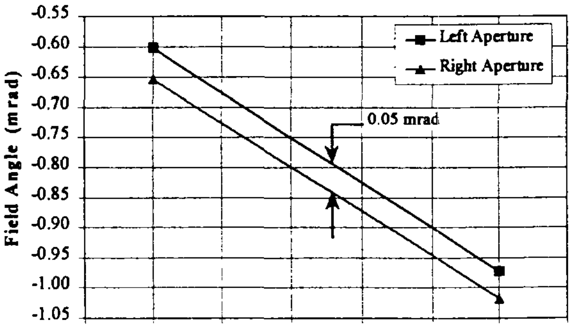

Figure 8: Field angle measured at two locations in each aperture by a 1 m long rotating coil, with the magnet yoke in a level orientation.

3.6 Quench Temperatures

The magnet was built with spot heaters and voltage taps in several coil locations. These permitted measurements of the temperatures reached in the coil during quenches, both without and with the quench protection (strip) heaters that are incorporated into the design. The results at the least favorable coil locations (midplane) are summarized in Fig. 9.

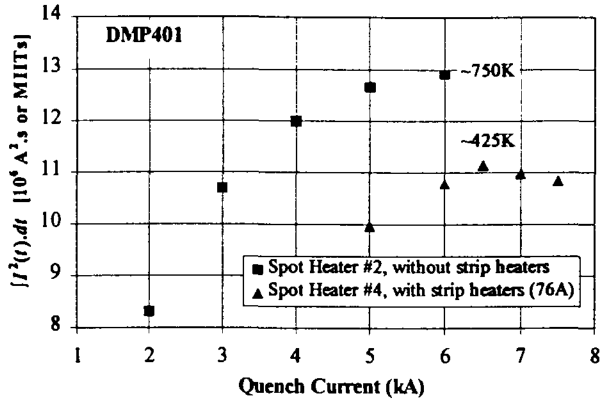

Figure 9: Measurements of quench temperatures in the magnet. Using the strip heaters as designed, the maximum temperature measured is an acceptable 425 K.

4 SUMMARY

The magnet comfortably exceeds the LHC operating field requirements. The field quality is generally as expected, but with several minor anomalies. The angle alignment of the apertures and the temperature rise at quench are well within required limits.

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