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M. Kuchnir, M. Bleadon, S.W. Delchamps, E. Schmidt, R. Bossert, J. Carson, S. Gourlay, R. Hanft, W. Koska, M.J. Lamm, P.O. Mazur, D. Orris, J. Ozelis, J. Strait and M. Wake

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

A. Devred, J. DiMarco, J. Kuzminski, T. Ogitsu, Y. Yu and H. Zheng

SSC Laboratory
2550 Beckleymeade Ave. Dallas, Texas 75237

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MAGNETIC FIELD ANGLE CHANGES DURING MANUFACTURE AND TESTING OF SSC COLLIDER DIPOLES*

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Fermi National Accelerator Laboratory
Batavia, Illinois, 60510

A. Devred, J. DiMarco, J. Kuzminski, T. Ogitsu, Y. Yu§, and H. Zheng
SSC Laboratory, Dallas, Texas 12345

Abstract--Measurements of the magnetic field angle along the length of collider dipole magnets are discussed. These superconducting magnets were built at Fermilab for the Superconducting Super Collider (SSC) by Fermilab and General Dynamics personnel. These measurements were made at four stages in the assembly and test sequence. The data show that changes can occur both during installation in the cryostat and as a result of cold testing. Most of the changes during installation are correlated with the welding of the tie bar restraints. But the changes observed as a result of the cold testing can be attributed to changes in the magnetization of the iron laminations.

I. INTRODUCTION

In a large project like the manufacture of 10,000 superconducting dipole electro-magnets for the collider ring of the SSC, many of the concerns, although not directly related to superconductivity are worth the attention of this forum. The high precision required in the placement of the superconducting cables is one of these concerns. In order to satisfy this requirement, quality control devices have been developed and used. One of these devices used in the fabrication and testing of the magnets is the field-angle probe(FAP)[1,2]. It measures the direction of the magnetic field produced by the two saddle-shaped coils of the magnet with respect to the vertical at one point on the center line of the magnet beam tube. A plot of this angle as a function of position along the magnet can be taken as a "signature" of the magnet. This signature reveals, among other things, the orientation of the magnet installation and the twists in its coil set. The range of angles is from -10 to +10 milliradians and a typical error at each point is a fraction of a milliradian.

For the 50 mm bore diameter collider dipole magnets built at Fermilab by General Dynamics and Fermilab personnel (in the technology transfer program) these field-angle measurements were carried out at least at four stages in the manufacturing/testing procedure, namely: before and after inserting the cold mass of the magnet in its cryostat; before and after cold testing the magnet. Comparing these signatures from one magnet it is observed that transportation of the magnet from one building to another nearby does not affect its signature, though insertion in the cryostat and undergoing the first cold-test do.

The measurements taken before and after insertion in the cryostat are used for internal alignment and have no relevance to the stability of the completed magnet. Since the collider cannot rely on magnets that change characteristics with every cooling, changes observed due to cold-test caused concern and led to the study presented here. This study uses the archived data accumulated from the standard production tests.

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† Current address: SSC Laboratory, USA; permanent address: KEK, Japan

§ Permanent address: Institute of Electrical Engineering, Beijing 100080, China

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II. MAGNET AND MEASURING INSTRUMENTS DESCRIPTION.

Figure 1 shows the cross section of these 15 m long magnets. The upper and lower saddle coils present together a cross section approximating a cos(θ) distribution[3].

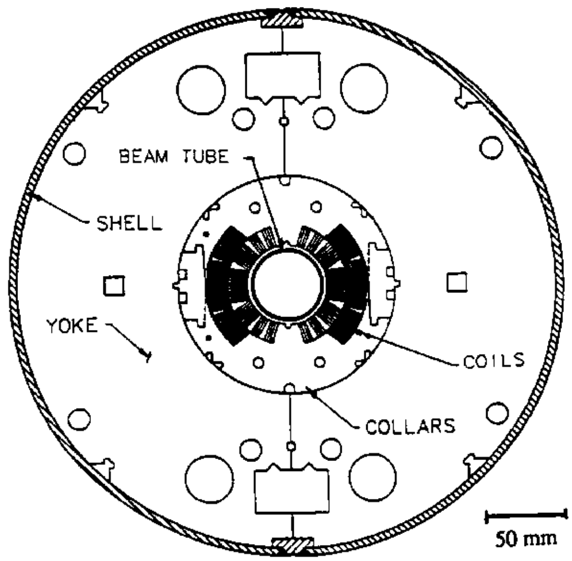

Fig. 1 Cross section of the cold mass of a collider dipole magnet

They are kept together by stainless steel lamination collars nested in pairs of iron yoke laminations which are finally held together by a strong vacuum-tight stainless shell[4].

Figure 2 presents a drawing of the FAP. It consists of a small permanent magnet in gimbals, on whose floating frame is mounted an electrolytic bubble level sensor. This probe is positioned inside the beam tube by means of a set of 1.83 m long connecting rods with distance markings every 0.0254 m. Data points are taken 76.2 mm apart by displacing the probe along the beam tube of the magnet.

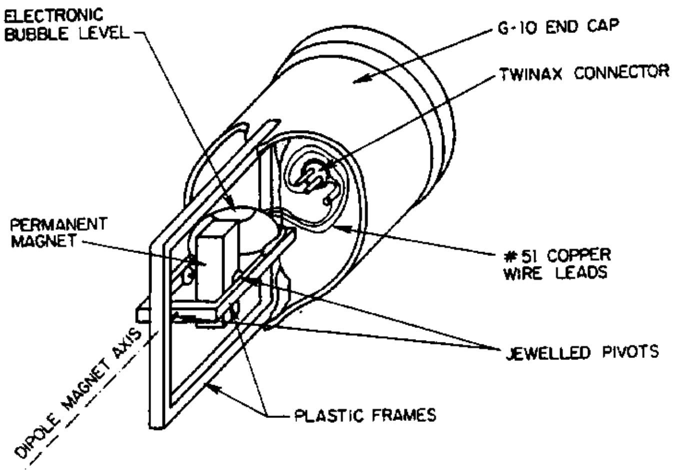

Fig. 2 Field-angle probe (FAP).

Another instrument used in the testing of these magnets is the so called "mole" described by Ganetis et al[5]. It contains precision coils executing precise motions that allow measurements of the multipole components of the magnetic field. These multipoles describe the distortions of the magnetic field averaged over the length of the measuring coils which is of the order of 0.3 m. The mole also contains a level sensor. The mole is a much more elaborate instrument than the FAP and although not specifically designed for measuring field angles, some of the measurements made with it can be compared with averages of the FAP data over the length of the measuring coils.

III MAGNETIC MEASUREMENTS AT LOW TRANSPORT CURRENTS

In order to prevent overheating of these magnets, room temperature measurements are restricted to transport currents of 10 A or less and the resistance of the coils is monitored to prevent the average temperature from reaching values that might affect the mechanical stresses incorporated in them. A current of 10 A generates a magnetic field of 10 mT in the beam tube. At this level the magnetic measurements can be affected by the local earth field (in the case of collared coil with no yoke) or by the remnant magnetization of the iron yoke.

Such problems could be avoided by performing measurements with both +10 A and -10 A. The current reversal does not affect the contribution from the magnetization or local fields. So the difference of these measurements excludes these contributions and the sum of these measurements is twice the value of these contributions. Unfortunately, the FAP was not designed for such measurements. Its small permanent magnet and its level sensor are assembled in a way to require a specific polarity for the current through the magnet. The FAP data therefore always reflects yoke magnetization changes along with coil twists and is insufficient to distinguish between them.

In the field angle measurements themselves a similar technique is used to eliminate offset errors and check the reproducibility of the data. Two signatures are always obtained, one for each of the possible longitudinal orientations of the FAP. Plotted together they form a symmetrical pattern. The degree of symmetry reflects the quality of the data. The final signature is one half of the difference of the two signatures. The sum of the two signatures is a cancellation yielding twice the value of the offset and whose standard deviation is a measure of the reproducibility of the data.

At several FAP measurements made after cold test recently, unusual, non-constant, cancellations have been observed. They are consistent with a drift during the measuring time and are not presently understood. The data on which this paper is based is free from this phenomenon.

A. Changes due to insertion into the cryostat

A comparison of the signatures of these magnets before and after insertion in their respective cryostats show that less than 50% of them present significant change in their signature. They are: DCA312, DCA314, DCA315 and DCA316. Figure 3 shows these signatures for the one of them with largest change.

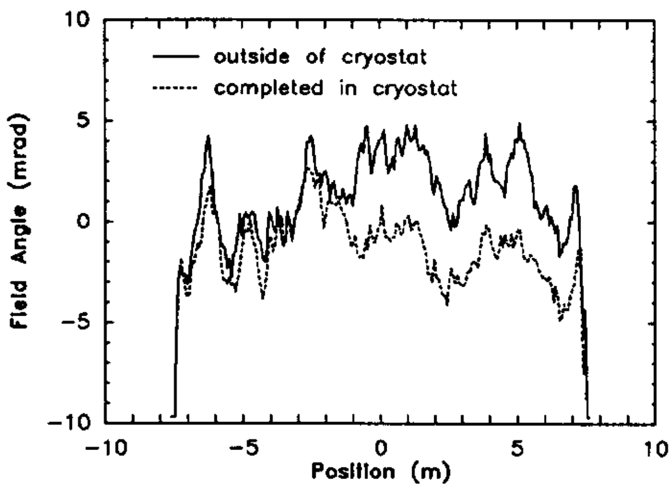

Fig. 3 FAP signatures of magnet DCA316

There is some consistency among the axial positions at which displacement-like changes start or stop. These locations referenced to the center of the magnet are compatible with ±1.06 m, ±2.12 m, ±4.24 m and ±5.30 m. At these positions the tie bar restraints are welded to the shell.

B. Changes due to cold-test

The cold-test of these magnets involve currents up to 7 kA and the iron yoke is subjected to fields as high as 5 T, more than enough to saturate them. The remnant yoke magnetization after the first cold-test is likely to be very different from that prior to it. This change can be detected with the FAP as apparent mechanical deformations of the coil. For most magnets, it appears that there is a significant difference between the measurements taken prior to the first cold-test and the measurements taken after it.

As an illustration, Figure 4 shows the FAP data taken before and after the first cold-test of magnet DCA312. The question whether this change is mechanical or resulting

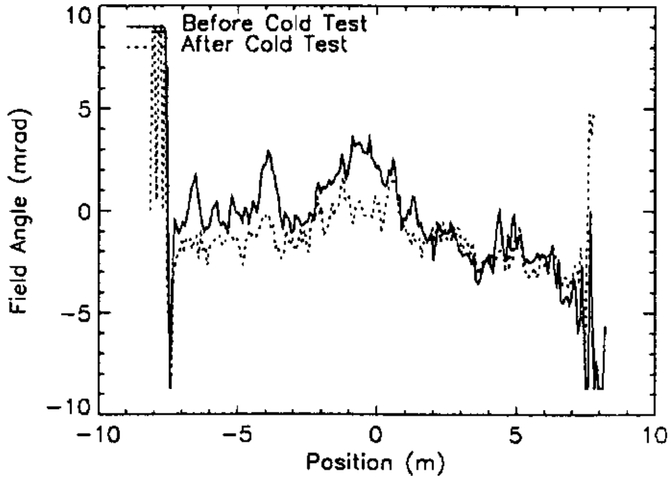

Fig. 4 Field-angle probe data before and after the 1st cold-test of magnet DCA312.

from changed magnetization can be answered by looking at the mole measurements. The mole measurements are performed at both +10 A and -10 A, but the absolute values of the field angle cannot be trusted, because the gravity sensor implemented in the mole (version BE) used is not reliable. However, since the mole is not physically moved between current reversals at a given location, we can average these two measurements and estimate the amplitude of the effect due to the iron magnetization. Figure 5 shows the amplitudes of these distortions as derived from the mole measurements performed before and after the first cold-test of magnet DCA312.

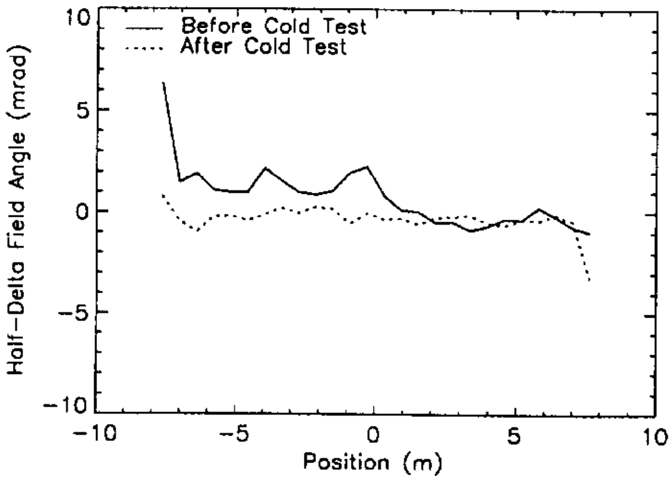

Fig. 5 Mole data change upon reversal of magnet current.

The distortions before the cold-test are significant, while those after it are nearly zero. This indicates that, before cold-test, the iron yoke laminations are randomly magnetized, while, after cold-test, the strong dipole field experienced with the passage of a high current, has forced the magnetization to become symmetrical. Having found this change in the iron remnant magnetization, we can now compare the difference between the two curves in Figure 4 and that between the two curves of Figure 5 as is done in Figure 6. The two resulting curves appear to lie atop of each other.

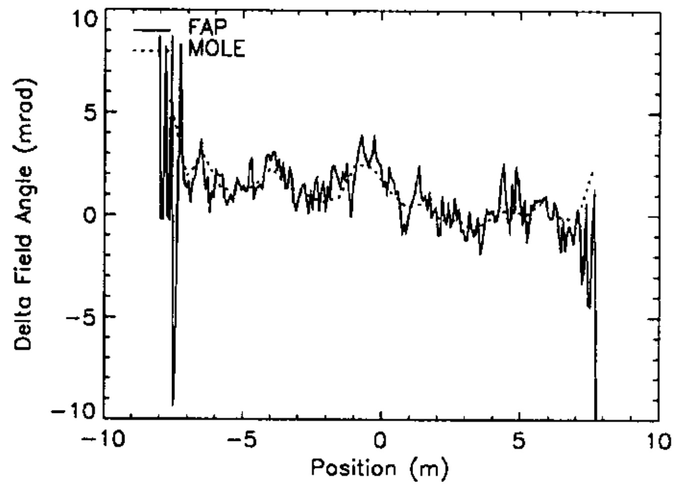

Fig. 6 Comparison between mole and FAP data.

IV CONCLUSIONS

Field-angle changes during the assembly of the cryostat around the cold mass occurred for only some of the magnets and have a correlation with the welding of the tie bar restraints to the shell of the cold mass of the magnet.

Agreements like the two curves in Figure 6 indicate that the change in the field-angle probe data before and after the first cold-test result exclusively from the changes in iron yoke magnetization and therefore one does not expect to see further changes with cold-test or during operation of the collider.

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