Fermi National Accelerator Laboratory

TM-1493

Measurements of Magnetic Field Alignment*

M. Kuchnir and Ed. E. Schmidt
Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

November 6, 1987

*Presented at the 10th International Conference on Magnet Technology (MT-10), Boston, Massachusetts, September 21-25, 1987

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

MEASUREMENTS OF MAGNETIC FIELD ALIGNMENT*

M. Kuchnir and Ed. E. Schmidt
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

Abstract

The procedure for installing Superconducting Super Collider (SSC) dipoles in their respective cryostats involves aligning the average direction of their field with the vertical to an accuracy of 0.5 mrad. The equipment developed for carrying on these measurements is described and the measurements performed on the first few prototypes SSC magnets are presented. The field angle as a function of position in these 16.6 m long magnets is a characteristic of the individual magnet with possible feedback information to its manufacturing procedure. A comparison of this vertical alignment characteristic with a magnetic field intensity (by NMR) characteristic for one of the prototypes is also presented.

Introduction

For beam orbit calculations and magnet installation the spatial distribution of the magnetic field inside an accelerator magnet has to be referred to external fiducials or monuments. In the Tevatron superconducting dipole magnets, a vertical wire loop (Wilson Coil) inside the warm iron laminations was used for aligning the direction of the field with external fiducials. This scheme is not feasible with cold iron magnets, like the SSC dipole magnets. Therefore, a procedure using transfers between fiducials in the iron laminations to the cryostat external monuments is used. This procedure can be simplified if fiducials are used just for centering the coil and an electrical gauge that measures the angle between the field and the vertical is used for field alignment. This gauge is also used to verify the nonexistence of twist and irregularities due to tooling i.e., fabrication quality control.

Gauge Description

The gauge described here has some similarities with the one developed by G. Knies and R. Kresse.[1] It uses a permanent magnet for detecting the direction of the magnetic field (like a compass) and an electrolytic bubble level sensor for measuring this permanent magnet angle with respect to the vertical.

The permanent magnet, mounted on jewelled gimbals, is available commercially.[2] This gimbals system is modified and attached to the G-10[3] end cap of a cylindrical G-10 tube in such a way that the axis of rotation of the magnet is perpendicular to the axis of the G-10 tube (See Fig. 1). The axis of rotation of the magnet is held in a rotatable frame which pivots around an axis parallel to the axis of the G-10 tube, therefore, parallel to the beam trajectory in the dipole magnet to be measured. For a vertical magnetic field the permanent magnet will be vertical and the rotatable frame will be horizontal. The electrolytic bubble level[4] is glued to this frame and senses its deviation from the horizontal which is used as the measure of deviation of the dipole magnetic field from the vertical. A set of weights and counter weights, not shown in Figure 1, had to be attached to the rotatable frame in order to bring its center of gravity in line with the axis that supports it or slightly below it. The easy motion of the electrolyte liquid in the bubble level sensor makes this mechanical balancing adjustment a rather sensitive operation and the use of a toroidal bubble level sensor[1] might simplify this operation.

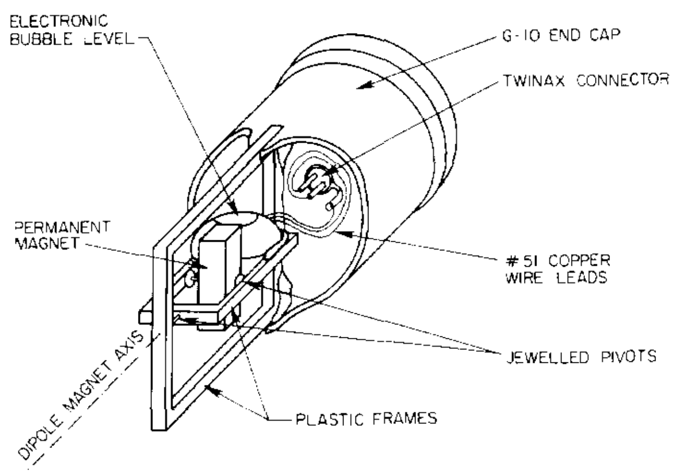

Fig. 1. Probe schematic

It was found that the orientation of the probe had an effect on the output reading of the level. The effect was strongly reduced with the elimination of some magnetic material (nickel plating of the Twinax connector, and elimination of an iron based ground lug), and by using #51 copper wire for the three leads connecting the bubble level sensor to the Twinax connector in the container. Even with these improvements the probe had to be kept oriented within ±5 degrees.

In order to keep this probe properly orientated while pulling it through an SSC dipole magnet, a set of aluminum rods 1/2" in diameter and 72" long were made. These rods were drilled with 1/8" diameter holes spaced 70" apart on parallel diameters. Aluminum pins 1" long were then pressed into these holes. Special couplers provided with threads, nuts, and parallel slots to accommodate the aluminum pins were used to connect these rods. Keeping close tolerance on the pin alignments permitted very good angular control of the probe by an operator at the far end of the magnet. See Fig. 2. Fiberglass-reinforced teflon tape around the couplers and the G-10 tube of the probe reduced the friction to the beam tube wall of the dipole magnet. Graduation marks along the set of rods and couplers permitted the position of the probe within the dipole magnet to be determined.

The electrolytic bubble level, electrically, can be thought of as a potentiometer to be used with AC excitation. To minimize the number of leads, a bridge circuit was formed with a "zero adjustment" potentiometer at the far end of a 21 m long shielded

*Work suported by the U. S. Department of Energy.

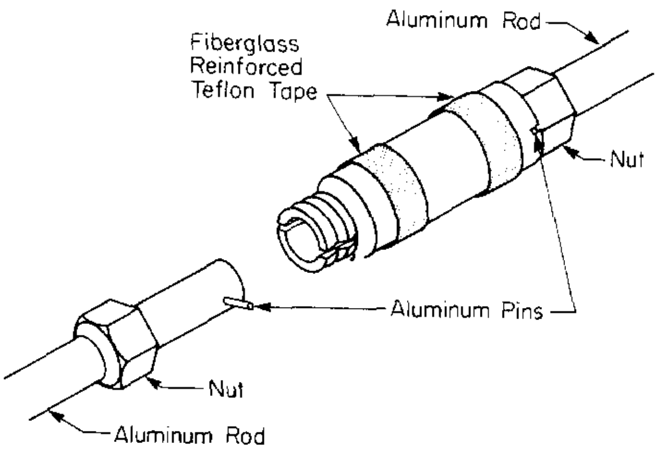

Fig. 2. Coupling for probe handling rods.

(twisted pair Belden #9452) cable. It was found that the physical placement of the cable did not affect the balance condition, but that the deviation from equilibrium was not just resistive. In order to detect the direction of unbalance, an AD630 synchronous demodulator chip triggered from the audio excitation was used. At the present stage of development an external excitation source and an external digital voltmeter are used. Figure 3 shows the schematic diagram of the electronics.

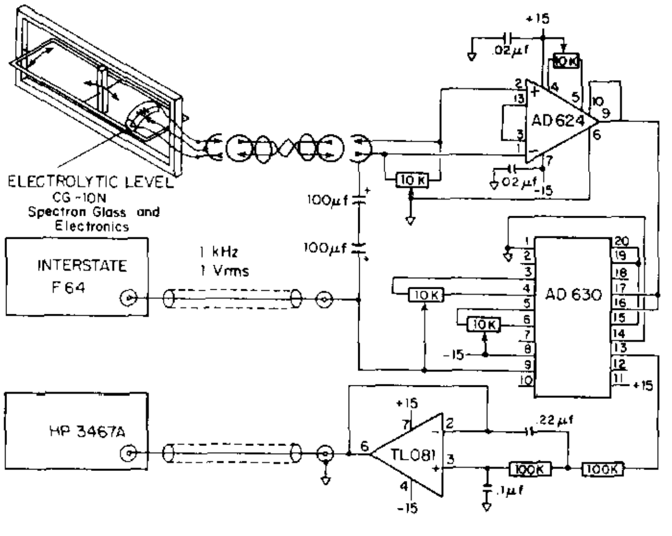

Fig. 3. Schematic of electronics

In actual data collection, 3 channels of a HP3467A logging multimeter were used for recording magnet current, magnet voltage and probe output. The amplitude of the INTERSTATE F64 function generator excitation source (1V, 1kHz) was also monitored. The variation of the source amplitude was smaller than 1% and not considered in correcting the probe output. The current (10A) and voltage across the dipole magnet, was used to monitor its resistance and therefore its temperature.

Calibration

An electromagnet from the Antiproton Source (20 in. Bumper) with a 15"x15"x20" useful field volume was used for calibration. This magnet was installed on a plate supported by 3 adjustable screws, two of which are parallel to the probe axis. A Wyler electronic level gauge was used to measure the inclination of the top surface of the magnet laminations. The assumption is made that this surface is perpendicular to the direction of the field, which is solely determined by the laminations. This gauge, is sensitive to 1 arc second.

Calibration curves before and after the set of measurements in D0002 are shown in Fig. 4.

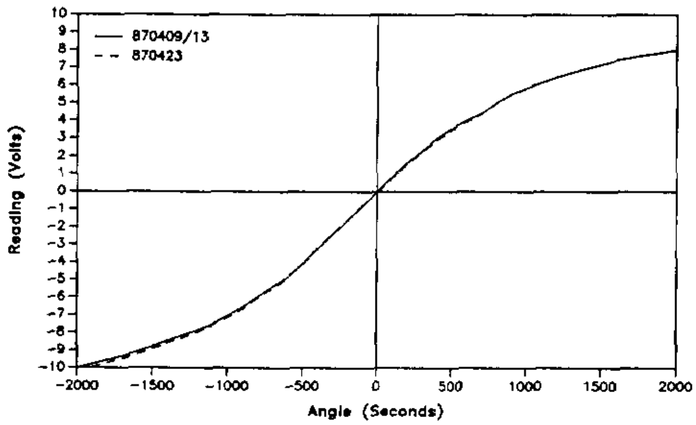

Fig. 4 Calibration curves

The reproducibility implied in this measurement set is typical, but when time intervals of weeks or rough handling is involved, recalibrations are needed. Although phase shifting the demodulator triggers and reducing the gain could significantly improve the linearity, these features are not currently incorporated and an interpolated calibration curve is used.

Measurements

The vertical tilt profile of the dipole magnet is obtained by pulling the probe through the beam tube and stopping every 3" for a measurement. Inscribed marks (3" apart) along the set of handle rods and couplers are used to position the probe. Two passes are made with the probe, one with the probe pointing toward the lead end of the dipole magnet and one with the probe pointing away from it. This yields symmetric profiles or signatures useful for compensating the zero offset in the calibration of the probe. Such a set for magnet D0001 is shown in Fig. 5. The lack of perfect symmetry is not due so much to the reproducibility of the probe as to the different positions of the sampling points in each pass. The natural fiducials against which the 3" markings were adjusted were not necessarily separated by a multiple of 3". The paper tape output from the voltmeter along with the probe position recorded by the operator is entered into a computer for processing and plotting. For the SSC dipole magnet D0001 the average (actually half of the subtraction) of both passes is compared with its NMR scan[5] in Fig. 6. Not much of a correlation is evident.

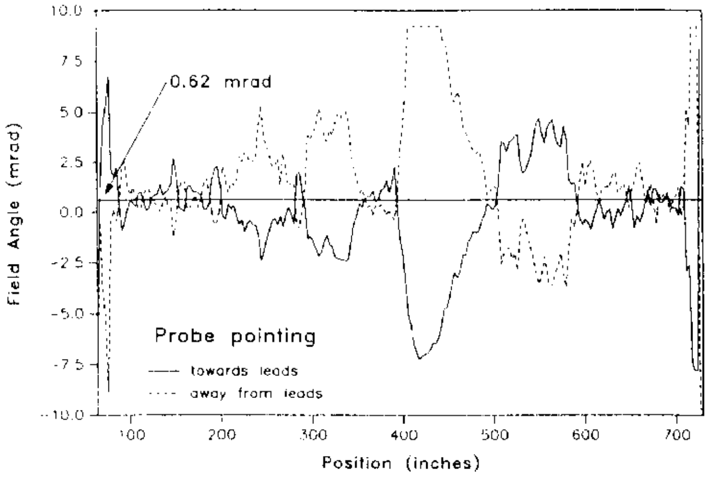

Fig. 5. Two passes of the probe through magnet D0001.

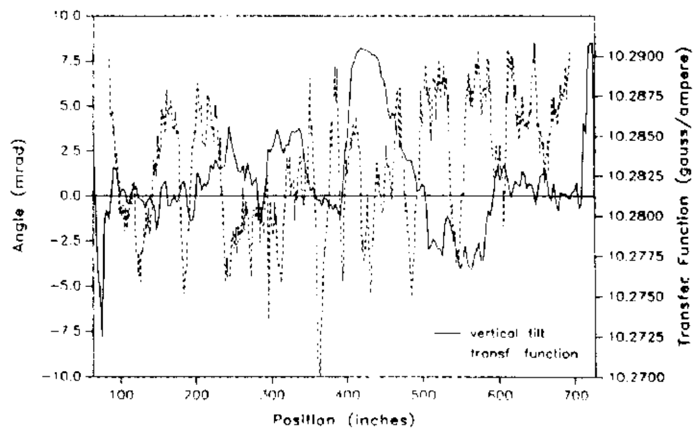

Fig. 6. Vertical tilt and transfer functions (NMR) profiles of magnet D0001.

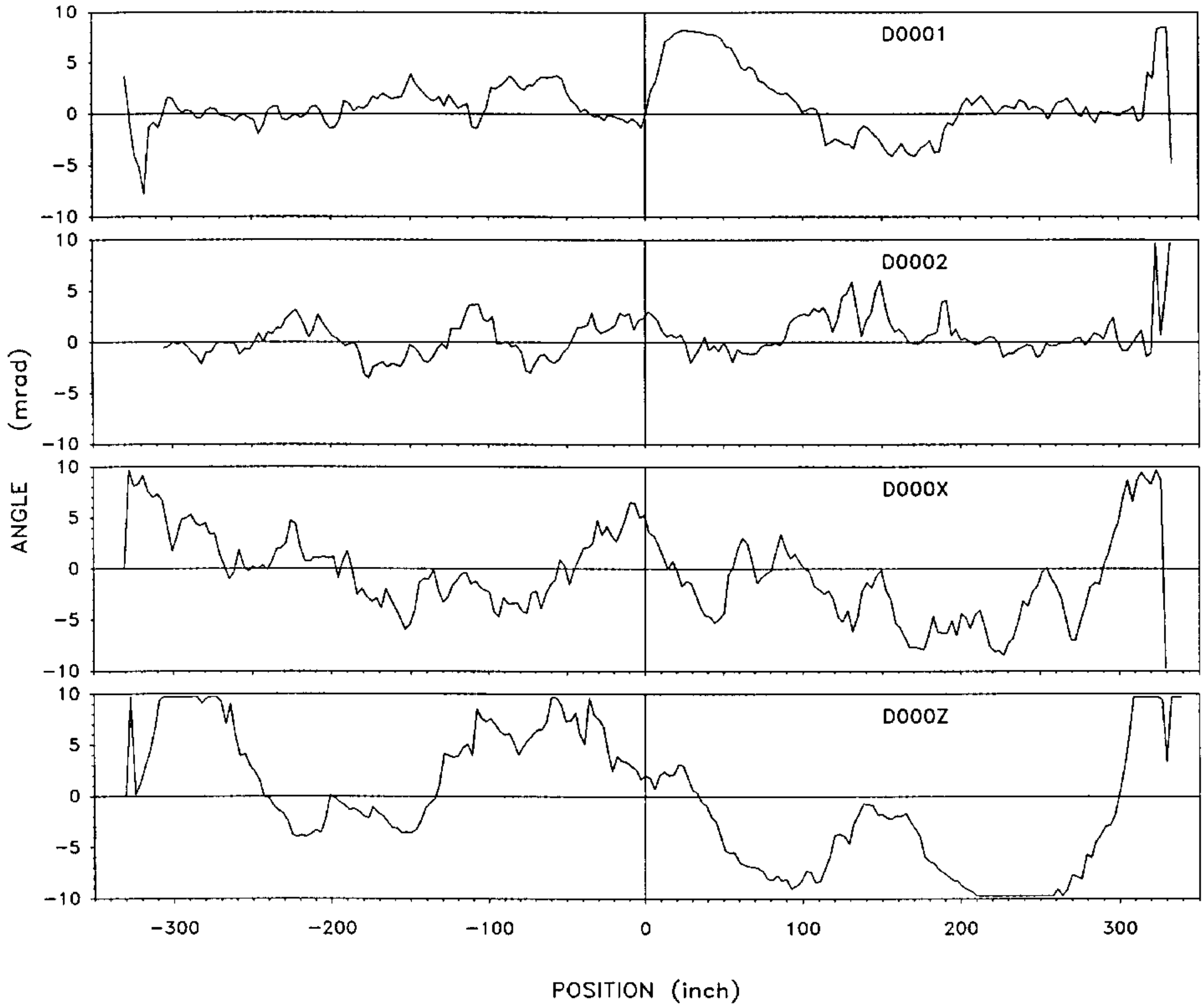

Fig. 7. Vertical tilt profiles of 4 SSC dipole magnets

Although this probe and its hardward/software system is not yet a developed product for production (i.e., its use is laborious) it has been tested or used as such in the alignment of five SSC prototypes dipoles (D0001, D0002, DS13, D000X and D000Z). Fig. 7 shows the profiles of 3 of them. About the magnets not shown, DS13 is not a full length prototype and the recent measurements of D000Z have not been completed yet.

Acknowledgments

We thank J. A. Carson for his interest in using the device as a produ~~ction~~ tool, W. F. Robotham for designing the handle rod and couplers set, D. M. Sorensen and his group for carrying on the measurements and N. Fenner for entering the data into the computer.

References

[1] G. Knies and R. Kresse, "A gravitation compass," Desy Hera 85-17,

[2] Magnaprobe Mark I - Manufactured by Cochranes of Oxford Ltd., Leafield, Oxford Ox85NT, England (Edmund Scientific used to distribute it in the USA).

[3] G-10 is an epoxy-fiberglass composite material available commercially.

[4] Model CG-10N - Manufactured by Spectron Glass and Electronics, 595 Old Willets Path, Hauppauge, N.Y. 11788

[5] M. Kuchnir, Ed. E. Schmidt, R.W. Hanft and J. B. Strait, "NMR Measurements in SSC Dipole D0001", TM-1420, Sept. 12 (1986) Fermilab.