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Abstract

In the fabrication of both 40 and 50 mm collider dipole superconducting magnets, surveys of the direction of the magnetic field along their length have been taken. This data besides being used for certifying compliance with the specifications for the finished magnet, yields interesting information on the straightness and rigidity of the coil placement between some stages in their manufacture and testing. A discussion on the measuring equipment and procedures is given. All of the 40 mm magnets that were built or cryostat at Fermilab have at least one of these surveys, and a summary of the data on them is presented. Most of the 50 mm magnets built and cold tested at Fermilab have been surveyed before and after insertion in the cryostat and before and after being cold tested. A summary of this data is also presented.

1 Introduction

Early in the development of full size SSC collider dipole magnet prototypes the need arose for certifying the orientation of the magnet cold mass in its cryostat. A simple instrument that measures the direction of the local magnetic field with respect to gravity was designed and built to accomplish this task[1]. The data collected with this instrument as function of position inside the beam tube (sweeps) yield more than the average direction of the magnetic field which is used for the orientation task.

The plots of field direction vs. axial position are characteristic for each magnet and can be used as magnet identifying FAP (Field Angle Probe) signatures. Changes in the signature of a magnet were seldom observed in the 40 mm series. From these signatures one can infer the twists in the coil if the iron magnetization is assumed uniform. The need for this assumption comes from the fact that these measurements are carried out at low fields (typically .01 T) with the magnet at room temperature and energized with currents of 10 A or less.

All the prototypes of the first series (with 40mm diameter beam tubes) were swept with this instrument at least once if they have ever been at Fermilab. Most of them were measured before and after insertion in their cryostats. The effort involved in carrying out these measurements in the early days and the schedule pressure restricted more extensive testing.

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The procedure for carrying out these measurements has evolved from taking over 12 hours to approximately 2.5 hours, mostly through automation[2] which still today includes manual displacement of the probe from point to point (76.2 mm apart) along the beam tube. Efforts have been made to move the probe automatically [3].

For the prototypes of the second series (with 50mm diameter beam tubes), this data was designated as a required part of the set of magnetic field quality characterization parameters and specifications for them were developed. Also they were swept more frequently, usually at four to six different stages in their fabrication. These stages are designated in Tables I and II as the following:

A. before insertion in the cryostat
B. before leaving the manufacturing building (ICB)
C. after installation in its test stand at MTF (Magnet Test Facility) before cool down
D. after cold testing while still installed in the test stand
E. between test cycles at MTF
F. while in storage waiting for shipment to the SSC Laboratory.

In this paper we proceed by briefly describing the measuring system, showing a typical set of data for a typical recently measured magnet, discussing its parameterization for presentation in tabulated form and presenting tables with most of the measurements taken so far.

2 The Measuring System

All the data presented in this paper have been taken with the probe described in reference [1]. This probe consists of a small permanent magnet in a gimbal, 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 .0254 m.

Improvements since the description in reference [1] have been: a data acquisition system[2] that evaluates the final angle of the permanent magnet before it settles down (reducing the measuring time and static friction problems), and guides the operator through the measuring procedure; a set of stops that limits the angle range of the floating frame

Table I
FAP Measurements Summary
40mm Magnet Tests

Magnet	Date	Max. (mrad)	Min. (mrad)	S. Dev (mrad)	Noise (mrad)	Stage
DD0001	870120	5.0	-7.5	2.72	0.44	D
DD0002	861112	6.4	-3.9	2.40	0.94	B
DD000X	870413	8.3	-9.6	3.52	0.51	A
DD000X	870421	8.2	-9.0	3.78	0.73	A
DD000X	870513	7.7	-10.1	3.94	0.65	B
DD000X	880319	7.4	-8.5	3.48	0.59	D
DD000Z	870912	8.5	-7.5	4.77	1.66	C
DD000Z	871003	10.3	-9.1	6.17	0.61	B
DD0010	871212	11.2	-8.1	4.52	0.85	C
DD0010	880602	10.4	-8.9	3.72	0.28	D
DDA010	890314	4.7	-6.3	2.32	0.34	A
DDA010	890408	5.3	-6.7	2.35	0.33	B
DD0011	880531	8.7	-10.1	4.12	0.79	A
DD0011	880625	9.6	-8.7	3.94	0.35	C
DD0012	880122	7.8	-11.6	4.13	0.66	A
DD0012	880203	9.1	-10.3	4.48	0.41	C
DD0012	880211	9.3	-10.1	4.43	0.31	C
DD0013	880708	8.2	-8.3	2.96	0.32	A
DD0013	880909	7.3	-8.5	2.85	0.34	C
DD0014	880302	5.5	-10.2	3.06	0.43	A
DD0014	880527	5.2	-7.9	2.66	1.00	C
DD0015	880910	4.8	-6.2	2.79	0.27	A
DD0015	880928	4.7	-5.8	2.69	0.26	C
DD0016	881230	5.5	-5.2	2.05	0.28	A
DD0016	890119	4.9	-5.3	2.09	0.36	C
DD0017	890117	8.0	-5.6	2.05	0.45	A
DD0017	890203	7.6	-7.1	2.26	0.46	C
DD0017	890927	9.2	-6.9	2.22	0.56	D
DD0018	890302	8.3	-8.9	2.89	0.73	A
DD0018	890721	8.0	-11.4	3.24	0.43	D
DD0019	890812	4.9	-5.2	2.16	0.56	A
DD0019	890828	5.2	-4.1	2.01	0.37	C
DD0019	900209	4.9	-3.9	1.84	0.35	D
DD0026	890911	4.7	-7.0	2.41	0.27	A
DD0026	891010	4.7	-6.5	2.43	0.38	C
DD0027	900208	5.3	-6.7	2.43	0.72	A
DD0027	900314	5.9	-7.1	2.51	0.29	C
DD0027	901011	5.5	-6.3	2.18	0.31	D
DD0028	900423	6.2	-8.1	3.14	0.34	A
DD0028	900730	6.8	-7.7	3.33	0.59	B
DD0028	900928	7.1	-6.5	3.22	0.34	C
DD0028	901205	6.0	-6.3	2.87	0.45	D
DC0202	901102	8.3	-4.1	2.16	0.34	A
DC0202	901210	7.1	-4.1	2.26	0.29	B
DC0301	901004	3.6	-4.8	1.21	0.39	B
DC0304	910221	4.3	-3.8	1.35	0.37	B
DC0304	910311	3.3	-3.4	1.11	0.44	C
DC0304	910424	2.4	-3.3	1.08	0.29	D
DC0306	910410	4.3	-4.1	1.40	0.43	B
DC0306	910423	5.1	-3.6	1.66	0.49	C
DC0306	910627	4.3	-4.2	1.65	1.33	D

and has since kept the calibration curve of the device from changing in normal use.

Other instruments[4-6] have since been described in the literature, nevertheless, a second system like this one has been manufactured to be sent to the SSC Laboratory.

Two of the characteristics of this system that reflect in the way the data is acquired are:

a) the rotational freedom of the floating frame of the gimbal is slightly compromised by the torque from the wires connecting the level sensor to the external case of the probe which therefore has to be kept aligned by the operator;

Table II
FAP Measurements Summary
50 mm Magnet Tests

Magnets	Date	Max. (mrad)	Min. (mrad)	S.Dev. (mrad)	Noise (mrad)	Stage
DCA311	911031	5.5	-7.5	2.82	0.38	B
DCA311	911104	5.0	-8.5	2.58	0.59	C
DCA311	911206	3.5	-6.4	1.89	1.03	D
DCA312	911016	4.8	-4.7	2.61	0.37	A
DCA312	911112	5.6	-4.2	2.25	0.47	B
DCA312	911124	5.5	-4.0	1.88	0.44	C
DCA312	911220	2.4	-3.0	1.12	0.42	D
DCA313	911101	4.1	-3.0	1.42	0.50	A
DCA313	911212	4.9	-3.9	1.68	0.72	B
DCA313	911219	4.8	-3.6	1.68	0.37	C
DCA313	920116	5.2	-2.7	1.70	0.46	D
DCA314	911114	5.7	-6.2	3.17	0.37	A
DCA314	920107	4.8	-3.6	2.04	0.42	B
DCA314	920115	4.5	-3.8	2.10	0.38	C
DCA314	920207	4.2	-3.4	1.62	0.83	D
DCA315	911126	7.5	-3.6	2.31	0.25	A
DCA315	920123	6.7	-3.3	1.57	0.61	B
DCA315	920128	5.3	-2.7	1.30	0.43	C
DCA315	920221	3.7	-2.3	1.09	0.83	D
DCA316	911217	4.6	-3.5	1.92	0.41	A
DCA316	920208	3.6	-3.9	1.60	0.31	B
DCA316	920214	3.5	-4.3	1.68	0.84	C
DCA316	911220	2.4	-3.0	1.12	0.84	D
DCA317	920210	3.8	-2.9	1.79	0.27	A
DCA317	920309	4.6	-3.1	1.91	0.49	B
DCA317	920325	4.2	-3.3	1.92	0.49	C
DCA317	920403	3.7	-3.0	1.45	0.67	E
DCA317	920423	3.6	-3.2	1.50	0.40	D
DCA318	920225	3.0	-2.7	1.23	0.42	A
DCA318	920317	3.5	-2.5	1.18	0.45	B
DCA318	920413	4.1	-2.0	1.14	0.48	C
DCA318	920415	3.9	-2.1	1.11	0.48	C
DCA318	920512	3.2	-2.1	1.11	0.54	D
DCA319	920125	2.8	-3.7	1.47	0.45	A
DCA319	920224	4.1	-3.1	1.44	0.50	B
DCA319	920227	3.0	-3.4	1.29	0.36	C
DCA319	920320	2.6	-2.5	0.96	0.95	D
DCA319	920330	4.7	-2.7	1.06	0.52	F

b) the need for accurate zero determination; although the probe is frequently calibrated in a separate electromagnet that can be tilted with respect to gravity, the zero is most reliably determined by taking a pair of sweeps of data with the probe pointing to the opposite ends of the magnet.

The symmetry of these two sweeps results from the magnet FAP signature and its lack reflects the noise in the data as well as the care of the operator in keeping the external case aligned and in sampling the same spots on both sweeps. The fact that this system requires a specific polarity in the magnet prevents it from distinguishing contribution from the iron yoke magnetization inhomogeneities.

3 Data and Tabulation

Figure 1 shows the pair of sweeps of magnet DCA315 done on Jan. 28, 1992 (a date coded as 920128). By subtracting one from the other and dividing by 2, we get the FAP signature shown in Figure 2 as an average of the two sweeps compensated for the zero offset of the instrument. The average angle just reflects the installation

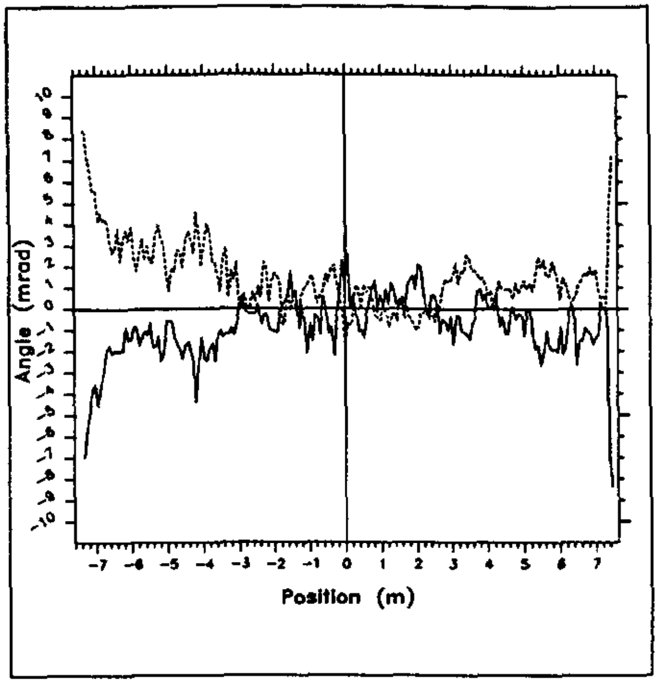

Figure 1. Pair of sweeps 920128 of Magnet DCA315 before cooldown at MTF. Solid line: probe pointing towards return, dashed line: probe pointing towards leads

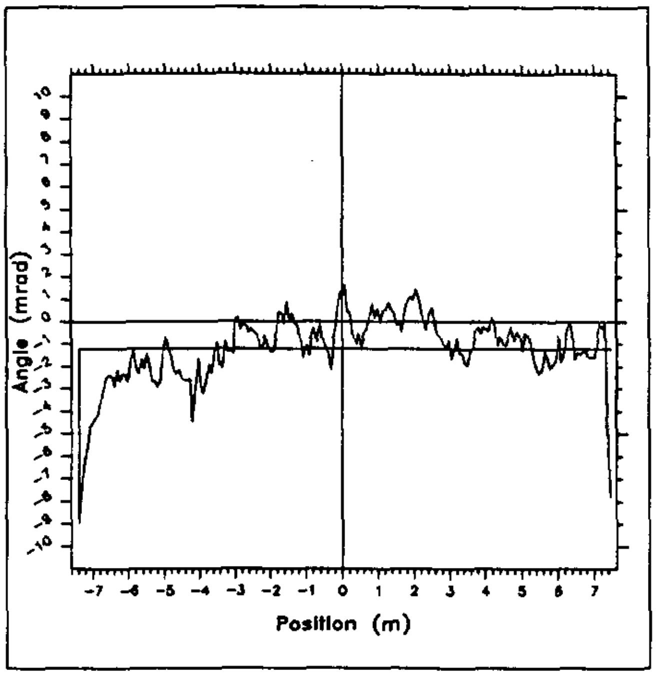

Figure 2. FAP signature at magnet DCA315 from pair of sweeps 920128

alignment error and is not a characteristic of the magnet.

Here this data is summarized by presenting the minimum and the maximum angles relative to the average along with the standard deviation of the FAP signature. A 4th parameter that provides an estimate of the uncertainty or lack of symmetry between the two sweeps is the standard deviation of the "background signature" obtained by adding the two sweeps and dividing by 2. This parameter is labeled noise.

In Tables I and II we present these summarizing parameters for the 40mm and 50 mm magnets respectively. For the 40 mm magnets a complete set of data has been compiled in an internal report by three of the authors[7]. The first column is the magnet label and the 2nd column is the coded date of the measurement. They are followed by the parameters described above and a letter describing the manufacturing/testing stage of the magnet as referred in the introduction.

The specifications for these magnets regarding the field angle have been changing recently and therefore could not be included here.

4 Acknowledgments

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