Magnetic Field Properties of SSC Model Dipole Magnets *

M.Wake, R.Bossert, J.Butteris†, J.Carson, S.Delchamps, T.S.Jaffery, W.Kinney, W.Koska, M.J.Lamm, R.Sims†, J.Strait and M.Winters†
Fermi National Accelerator Laboratory, Batavia, IL. 60510 U.S.A
†SSC Laboratory, Dallas, TX 75237 U.S.A

Abstract

SSC 1.5m model dipole magnets were built and tested at Fermilab. Magnetic field properties were studied in term of transfer function variation and multipole components. The results were satisfactory. Observation of periodicity of remanent field along the axis is also reported.

1 INTRODUCTION

A series of 1.5 m model dipole magnets[1] were built and tested[2] at Fermilab. Based on the model magnet experience, Fermilab has already built two successful full scale magnets. Technology transfer to the industry was made by accepting industry people for the construction of another 7 magnets at Fermilab[3]. This report describes the magnetic field properties and related phenomena measured during the development of the 1.5 m model dipole magnets. The testing was made in a 3.6 meter long vertical dewar located in the superconducting magnet R&D laboratory (Lab2) at Fermilab. The magnet has anti-ovalized collar with vertically split yoke[4] to maintain the horizontal interaction between collar and yoke during the operation. End sections of the coil are clamped by collets[5] so that the inner-outer splice can be ramped up to the low field region. End cans were made with aluminum alloy and stainless steel.

Table I. Transfer Function

Magnet	W/O Iron T/kA	Warm T/kA	Cold T/kA
DSA321	0.795	1.042	N/A
DSA323	0.794	1.043	1.042
DSA324	0.794	1.043	1.043
DSA326	0.793	1.042	1.044
DSA328	0.794	1.041	1.042
DSA329	0.796	1.041	1.044
Design	0.794	1.045	1.045

Cold measurements are at 2000A. Warm measurements are at 10 A.

*Work supported by U.S. Department of Energy

Presumably this has no effect to the field property. Insulation of the cable and wedges were made by Kapton and epoxyed glass wool. Elimination of glass wool in wedges was tried in some magnets.

2 TRANSFER FUNCTION

Transfer functions of the magnets were measured as dipole component of the field by tangential coil. Rawson-Lush type 789 rotating coil was also used for the measurement. Table I shows the summary of the results. A new method[6] of transfer function measurement at room temperature was tried using ESR (Electron Spin Resonance). The magnetic field can be measured with ESR probe in a precise manner at low current without cooling the magnet. It does not need any mechanical motion. It gives "absolute" result independent on the geometry of the probe. It measures localized field rather than the average field over the length of the pick up coil. Figure 1 is an example of the measured results.

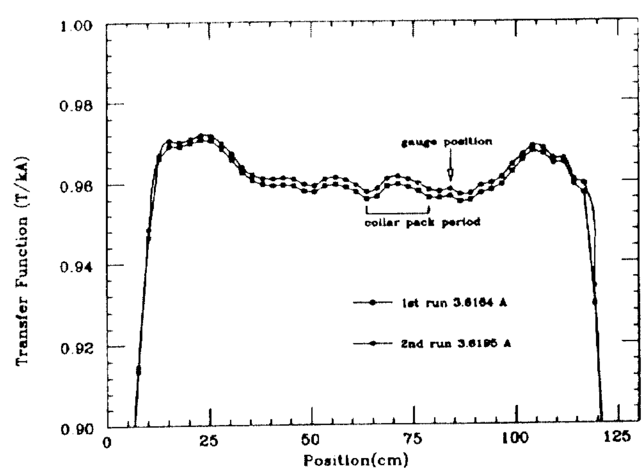

Fig.1 Transfer Function Distribution.
ESR measurement results from magnet DSA324. The iron yoke was previously magnetised in opposite direction.

The advantage of ESR over NMR is the small gyromagnetic ratio. It provides a larger signal at very low field. On the other hand, spin to spin relaxation caused by the long range dipole interaction between spins makes the resonance signal broad. It is due to this fact that the accuracy of the ESR measurement is not as well defined as it is in NMR. Though it has a large dipole broadening, in some chemical compounds which have overlaps in electron wave function have moderately longer relaxation because of the exchange of electrons. Crystalline organic radicals such as diphenyl picryl hydrazyl (DPPH) are the typical material which are relatively stable in this kind. Our measurement used DPPH ($g = 2.0036$) as the sample and the sample size was about 5 mm cube. The probe measures $10mm \times 20mm$ in cross section. Although ESR signal has line width of a few tenth of gauss, the clear line shape without wiggle makes it possible to define the center of resonance by electronics. As shown in Fig.1, the collar package periodicity of the magnet and the slight magnetization of the pressure gauges are visible. This could be used for the inspection of the collard coil.

3 HARMONIC COMPONENTS

The harmonic components of the magnetic field was measured by tangential probe and multipole coil[7]. Table II summarizes the results. The variation of sextupole component,b_2 and decapole component,b_4 is caused by the difference of coil configuration shown in Table III. However, the behavior of these multipole components can not be fully explained by the shimming displacement[8] of the conductors. Unequal distribution of coil pressure may be causing additional displacement of the conductor. Large skew quadrupole components are understood as the up down asymmetry of the coil size.

Table II. Harmonic Components

Magnet	a_1	b_2	b_4	b_6	b_8	b_{10}
DSA321		+3.20	+0.22			
	-2.15	+2.95	+0.33	-0.08	+0.05	+0.02
DSA323	-0.33	+1.50	+0.13	-0.05	+0.05	+0.02
	+0.41	+1.38	+0.22	-0.08	+0.06	+0.02
DSA324		+1.94	+0.04			
	-0.00	+1.76	+0.19	-0.04	+0.05	+0.02
DSA326	+0.96	+2.24	+0.28	-0.03	+0.05	+0.01
	+1.03	+2.19	+0.35	-0.07	+0.06	+0.01
DSA328	+0.04	+0.43	+0.10	-0.03	+0.04	+0.01
	-0.10	+0.07	+0.26	-0.03	+0.06	+0.01
DSA329	-0.05	+1.28	+0.10	-0.03	+0.04	+0.01
	-0.67	+1.80	+0.08	-0.04	+0.05	+0.01
Design	+0.00	-0.18	-0.04	+0.00	+0.05	+0.02

Upper rows are cold measurements at 2000A and lower rows are warm measurements at $\pm$ 10A. Units are ratio to the dipole component in 10^{-4} at 1cm radius.

High harmonic components like b_8 and b_{10} seems to be insensitive to the variation of the coil configuration. These measurements were made carefully avoiding the magnetization effect[9] of the pressure gauges. Figure 2 shows the excitation behavior of b_2 and b_4. There is no symptom of conductor motion or yoke deformation. It is seen that the effect of iron saturation to the sextupole change is well suppressed by the holes at the horizontal plane of the yoke.

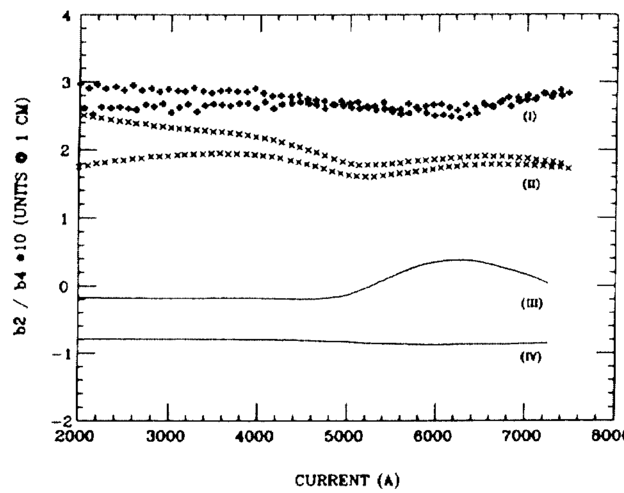

Fig.2 Excitation Behavior of b_2 and b_4
(I): measured b_2, (II):measured b_4, (III): calculated b_2, (IV): calculated b_4 in DSA326

4 PERIODIC FIELD

Field measurements in HERA dipole magnets uncovered a longitudinal periodic pattern which was not expected from the geometry of the magnet[10]. Although the direct effect of the periodicity would not be very large to the performance of the accelerator, the curious behavior of this pattern need to be understood to control the time dependence of the field quality which might be a large problem for the injection of the beam.

Periodicity in the remanent field was observed in all the SSC model dipoles. The wavelength of the periodicity was determined by the Fourier analysis of the data. The strand pitch of the SSC dipole magnet is 86$\pm$5 mm in the inner and 91$\pm$5 mm in the outer coil. The measured wave length was very close to the inner coil strand pitch in three magnets but was closer to that of outer coil in one magnet.

The amplitude of the periodicity varied from 0.2 mT to 1.2 mT depending on magnet and its excitation history before the measurement. Amplitude was large when the magnet stayed longer at high current[11]. Fig.3 shows one of the largest signals observed. It

Table III. Model Magnet List

Magnet Name	Wedge Insulation Material		End Can Material	Collar Shim (mm)		Coil Pressure (Mpa)		Coil Size (mm)	
	Inner	Outer		Inner	Outer	Inner	Outer	Inner	Outer
DSA321	GW+K	GW+K	S.Steel	0.00	0.00	62	86	0.28	0.16
DSA323	GW+K	GW+K	S.Steel	0.00	0.00	52	72	0.15	0.14
DSA324	GW+K	GW+K	Aluminum	0.13	-0.13	76	60	0.19	0.15
DSA326	GW+K	GW+K	Aluminum	0.00	0.00	69	56	0.20	-0.05
DSA328	GW+K	K+K	Aluminum	0.09	-0.13	70	45	0.14	0.07
DSA329	K+K	K+K	Aluminum	0.09	0.00	69	39	0.14	-0.08

GW: 0.01 mm thick glass wool, K: Half wrap of 0.05 mm thick Kapton. Coil sizes were measured in the azimuthal direction relative to a reference block made of stainless steel.

is necessary to accumulate more data to determine the decay behavior but the change in the first 3 to 4 hours was much larger compared to the change in the next 24 hours. There seems to be two components in the periodic field with different decay time constant. Some times they had different spatial phase. The one with very long time constant remained local even if the temperature at one end of the magnet was brought above normal transition temperature[13].

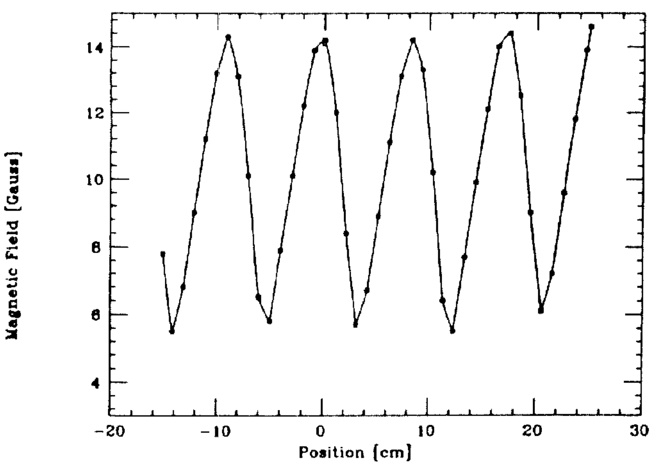

Fig.3 Periodic Field Pattern
DSA324 after a ramp to 7000A for 20 minutes.

5 CONCLUSION

The magnetic field properties of 1.5 m model magnets were measured and were found close to the design. Some interesting phenomena were also studied.

6 REFERENCES

[1] R.C.Gupta *et al.*, "SSC 50 mm Dipole Cross Section," in pp587,"Supercollider 3", J.Nonte *ed.*,Prenum Pres, New York (1991)

[2] M. Wake *et al.*, "Tests of 1.5 Meter Model 50 mm SSC Collider Dipoles at Fermilab", Conf.Rec. of 1991 IEEE Particle Acc.Conf., 2173 (1991)

[3] M.J.Blessing *et al.* "Construction Experience with Fermilab-Built Full-Length 50mm SSC Dipoles", submitted to 1992 IISSC, NewOrleans, March 1992

[4] J.Strait *et al.*, "Mechanical Design of 2D Cross-section of the SSC Collider Dipole Magnet", Conf.Rec. of 1991 IEEE Particle Acc.Conf., 2176 (1991)

[5] S.Delchamps *et al.*, "SSC Collider Dipole Magnet End Mechanical Design", Conf.Rec. of 1991 IEEE Particle Acc.Conf., 2185 (1991)

[6] M.Wake, "ESR Field Measurement of SSC Magnets", Fermilab TS-SSC-92-002 (1992)

[7] M.J.Lamm *et al.*,"Magnetic Field Measurement of 1.5 Meter Model SSC Collider Dipole Magnets at Fermilab", submitted to 12th Int.Conf.on Mag.Tech. MT12, June 1991, Leningrad ,USSR.

[8] R.Gupta, "Effect of The Azimuthal Variation in The Cable Thickness on the Field Harmonics in SC 50 mm Dipole Cross Section", BNL Magnet Division Note 379-1, (1991)

[9] S.Delchamps,"Effect of Strain Gage Blocks on Normal Sextupole Moment in DSA321 and DSA323", Fermilab TS-SSC-91-104 (1991)

[10] H.Bruck, *et al.* "Observation of a Periodic Pattern in the Persistent Current Fields of the Superconducting HERA Magnets", Conf.Rec. of 1991 IEEE Particle Acc.Conf., 2194 (1991)

[11] T.Jaffery,"Test Results of Fermilab 50mm Aperture Model Magnet, Fermilab TS-SSC-91-158

[12] M.Wake,"Periodic Field in SSC 40 mm Dipole and Its Temperature Gradient Effect", Fermilab TS-SSC-91-041 (1991)