Tests of 1.5 Meter Model 50mm SSC Collider Dipoles at Fermilab *

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abstract

A series of 50*mm* diameter 1.5*m* model magnets have been constructed. The test of these magnets gave convincing results concernig the design of the 50*mm* cross section of the SSC collider dipoles.

I. Introduction

A series of 1.5 meter model magnets for the SSC collider dipole with 50*mm* inner diameter have been built and tested at Fermilab based on th earlier work of the 40*mm* diameter magnets. The primary purpose of these magnets is to verify the design of 50*mm* dipoles and to determine necessary features of the full length SSC dipole constructions. Better understanding of the behavior of SSC dipoles is also expected through the experiments on these magnets.

The magnets are numbered DSA320 through DSA327. DSA320 was wound with practice cable. It was used only to section and observe the placement of conductor and other internal components. DSA322 and DSA327 were used for mechanical study of the magnet at room temperature. Only DSA321 and DSA323 have been cooled and tested to date. This report mainly describes the test results of these magnets.

The magnet design uses W6733 cross section[1]. The cable insulation consists of Kapton type H film and epoxy impregnated glass tape. Machined G-10 coil end parts are used for the end spacers. The support of the end sections of the coil is made by collet style end clamps[2]. The return yoke is vertically split[3] so that it can give better mechanical support to the coil. Collaring shims at the pole were not used. The control of the preloading and field was made entirely by the accuracy of the coil and collar size. The magnet was instrumented by 57 voltage taps, 4 coil pressure gages and 4 end force gages. Pressure gages were used not only to observe the electro-magnetic forces but also to determine the construction parameters.

II. Construction

The magnet consists of 4 coils, two shells in upper and lower halves. Each coil was wound on a mandrel with tension of 380 to 390N. The end spacers[4] were designed so that the stress in the cable was minimized by using computer programs established in the 40*mm* magnet development. However, parameters for cable characteristics are not yet perfect. The total length of the end section turned out to be 1.6*mm* longer than the design.

The coil shape is formed in the curing press during the heat treatment of epoxy. The molding tooling which contains the coil is pressed until the tooling gap is completely closed. The coil pressure during the curing at 130°C could be, at most, 95MPa.

The coil size is affected by the conductor size and molding process as well as the tolerances of the tooling. The coil size is measured, under pressure of 83MPa, by the measurement press at every 3 inches of the coil. Coils are slightly oversized compared to a stainless steel "master". This gives a preload of 10ksi (69kPa) and 8ksi (55kPa) in the inner and outer coil, respectively. Size distribution of the coils produced for this series of magnets using the same tooling is shown in Fig.1. The deviation in the size is not satisfactory either within the coils or between coils. Improvements in the process and the tooling are under way.

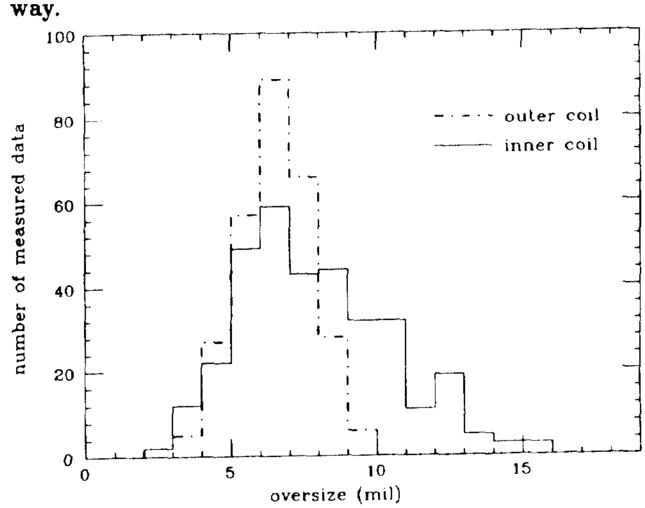

Fig.1: Size Distribution of the Coil

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The assembly of the four coils is made by surrounding them with ground insulation made of 5 mil Kapton sheets in collar laminations. The collar is then pressed to be closed and keyed. A sheet of thin brass armour (called a "collaring shoe") is used to protect the outer coils from being scratched by the collar. The width of the shoe for DSA321 was later found to be too short. This may have caused the pole turn instability of the outer coil. The preload in the coil is basically created by the oversize pressure of the coil against the collar surface. Yet, since many tolerances and frictions are involved in the compression of the coil, the relationship between pressure and the size is not straightforward. Figure 2 is the plot of the collaring experiences.

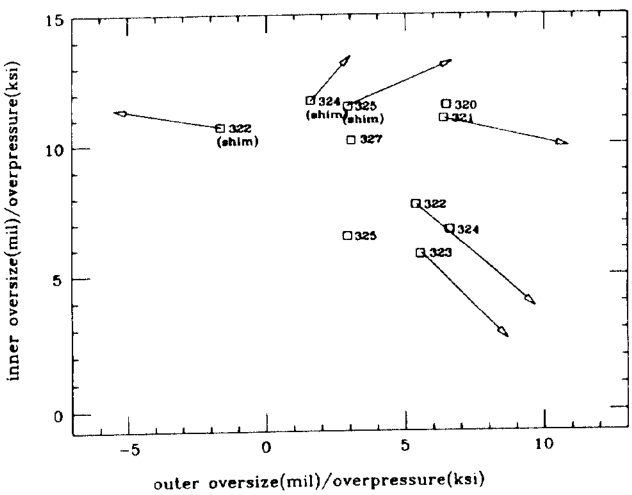

Fig.2: Size-Pressure Plot. Marked positions with magnet number represent the oversize of both coils in that magnet. The arrow represent the vector $(p_i - p_i^d, p_o - p_o^d)$, where p_i and p_o are the inner and outer coil pressure. Suffix ^{d} refers to design values.

Even if we have a large fluctuation in the data, target size of the molded coil can be obtained in this chart after accumulating the statistics. Magnets are then yoked, again in a press, to give a support against the electro-magnetic force. This process did not make a large change of the preloading because the vertically split yoke does not apply a vertical load to the coil. The observed effect of the creep was also small.

III. Quench Characteristics

Both magnets had excellent quench characteristics. DSA321 had one training quench at $7088A$ ($488A$ above the accelerator operation current) DSA323 had no training at all. Figure 3 is the plot of quench current as a function of temperature. All the quenches except one in DSA321 are on the critical current limit in the normal temperature range above $3.8K$. A special test under reduced temperature was made to see the possibility of advanced design. At $3.0K$ operation, the magnetic field reached $9T$. The mechanical strength of the support structures are no longer guaranteed at this field. Training was observed in such a high field range, but the stability of the magnet shown in this extraordinary excitation is a good indication of the effectiveness of the design.

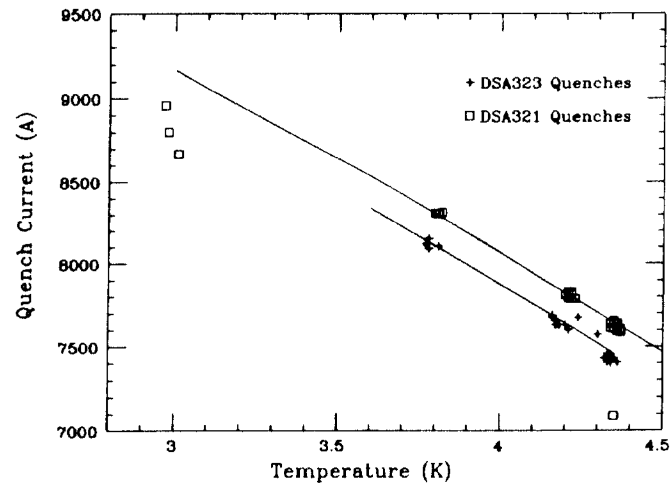

Fig.3: Quench Currents as A Function of Temperature. Solid lines are predictions based on short sample I_c

The ramp rate dependence of the quench current is shown in Fig4. The effect of dI/dt was observed at ramp rates above $80A/sec$. The quench current starts decreasing around this area and lost $160A$ in DSA321 and $260A$ in DSA323 for the ramp of $200A/sec$. The initiation point of the quench moves to different positions at higher ramp rates.

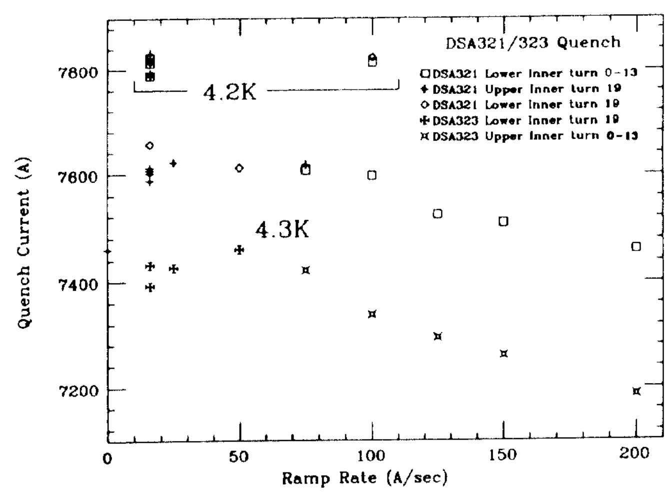

Fig.4: Ramp Rate Dependence of Quench Current

IV. Mechanical Behavior

The pressures in the coil were observed throughout the cool down and excitation. The pressure in the coil decreases due to the thermal contraction during cool down by about $3ksi$ ($20MPa$). Electro-magnetic force works to compress the coil causing the pressure at the innermost turn of the coil to decrease. The test results[5] showed there is sufficient pressure left in the coil after excitation. The behavior of the coil pressure was fairly repeatable and had a linear relationship with the square of the current. One exception was found in the upper outer coil pressure. The quadrant where one training quench took place in DSA321 changed the pressure by 1 ksi during the first quench. This indicates the existence of mechanical instability in that particular coil before the training.

The end force gages ("bullet" gages) of the coil indicated that there is about $12kN$ longitudinal force increase in the end when the magnet is excited to $8000A$ while the total end force is estimated about $3kN/(kA)^2$. Such a small number compared to the electro-magnetic force in the coil, implies that most of the stretching force in the magnet is transferred to the yoke skin through friction between coil and support structure.

V. Field Quality

The field quality of the magnet was measured by multipole coils[6]. The sextupole and decapole components are plotted in Fig.5 as a function of the current. Effect of the pinning of the flux in the superconductor is seen as the hysteresis of the multipoles. Saturation effect of the iron yoke is designed to be canceled by the notches in the midplane. This mechanism seems to be working beautifully. The field component in DSA323 achieved the design criteria without shimming, which is a good indication for the mass production of the SSC dipoles. The off design values of field components in DSA321 could be caused by the geometrical error due to the wrong size of the brass shoe. Overall performance of the tested magnets are listed in Table 1.

The remnant field of DSA321 was measured using a Rawson-Rush rotation coil. Figure 6 shows the field pattern[7] observed after a ramp. This effect has been observed in other S.C. Magnets[8]. The origin of this periodic pattern is not yet confirmed but the experiment[9] with temperature gradient found that this effect is not a result of trapped strand current but a local magnetization effect.

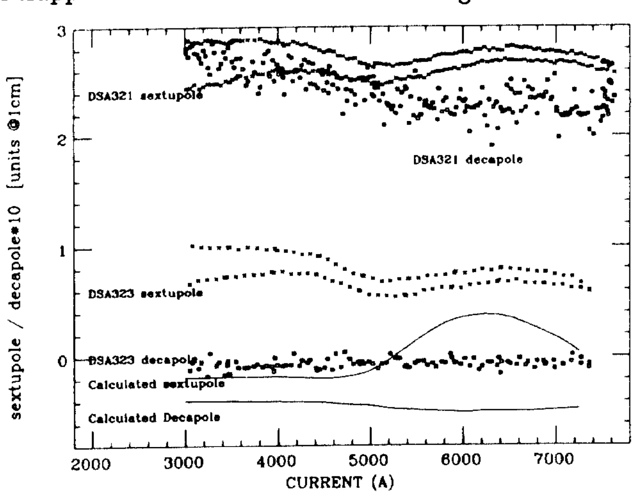

Fig.5: Harmonic Components

Table 1. Field Performance

	Design	DSA321	DSA323
Transfer function @5kA	1.040	1.036	1.033
Quench Current @4.3K	≥6600A	7642A	7460A
sextupole @1cm,unit	≤0.8	2.6	0.60
decapole @1cm,unit	≤0.08	0.26	-0.01

VI. Conclusion

The first series of 50mm dipoles performed very well. Although we still have difficulties in the detailed control of end shape, coil size, pressure and field, the basic design of the magnet is proved to be valid by this model magnet study.

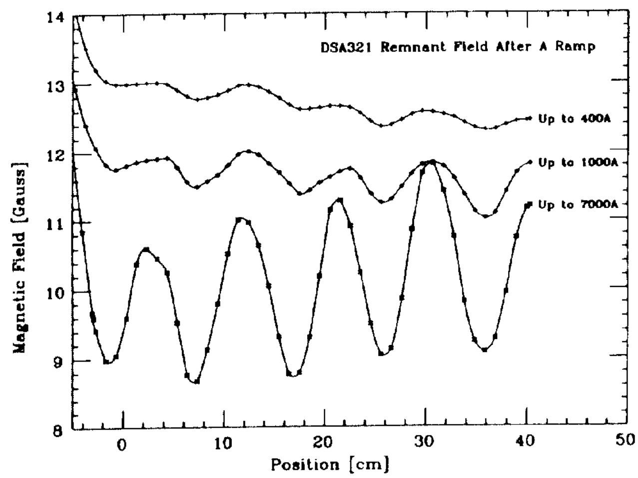

Fig.6: Periodic Pattern in Remnant Field

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