Tests of 40 mm SSC Dipole Model Magnets with Vertically Split Yokes

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Abstract

Several 1 meter long, 40 mm aperture model SSC dipole magnets with vertically split yokes have been built and tested at Fermilab. In addition to the yoke design, these magnets were used to evaluate several variants of the collet clamps which apply prestress to the magnet ends. The magnets were instrumented with voltage taps for quench localization and strain gage based devices for measuring stresses, forces and deflections resulting from cooldown and excitation. Tests were carried out in a vertical dewar at temperatures from 3.8°K to 4.4°K. The quench and mechanical behavior of these magnets will be presented and magnetic field measurements will be shown. A comparison with an earlier series of magnets with horizontally split yokes will be made.

I. Introduction

The current design for the Superconducting Super Collider (SSC) dipole magnet incorporates a vertically split yoke[1]. There are several advantages which a magnet utilizing this style yoke has over magnets with yokes split in the horizontal direction. These include improved clamping of the collared coil at its horizontal mid-plane and ensured closure of the yoke mid-plane gap under all circumstances. The former results in better mechanical stability during excitation and the latter improves field quality and eliminates the possibility of non-reproducible behavior with thermal cycling[2]. To gain experience with this design and to determine if there were any mechanical flaws which could lead to unacceptable quench behavior, three 40 mm dipole model magnets were built and tested at Fermilab during the period that the necessary tooling for 50 mm dipoles was being assembled . In addition, an ongoing program at Fermilab to improve the coil end clamp took advantage of these magnets to test a design variant. This paper will report the results of these tests.

The three magnets built and tested with vertically split yokes were designated DS0313, DS0314 and DS0315. These were identical in design with the exception of modifications to the end clamp. We will also report the results of tests of DS0311, the last in the series of 40mm horizontally split yoke magnets built at Fermilab, for comparison. These magnets were instrumented with 55 voltage taps for quench localization, 14 strain gage transducers (8 active and 6 compensating) to measure inner and outer coil stress at the pole, and 4 strain gage assemblies to measure end force[3]. Strain gages were also mounted on the shell of the magnet and the end can. The tests were carried out in a vertical dewar at 4.3°K, 4.2°K and 3.8°K, as determined by carbon resistor thermometers mounted on the shell of the magnet.

	DS0311	DS0313	DS0315
Yoke Type	Horizontal	Vertical	Vertical
No. of Quenches			
Thermal Cycle 1	36	32	31
Thermal Cycle 2	44	12	11
Quench Velocity	72±5 m/s	70±5 m/s	73±5 m/s
Pole Shim			
Inner	12 mils	17 mils	17 mils
Outer	7 mils	6 mils	5 mils
b_2 (warm,yoked)	4.6±0.2 units	2.4±0.1 units	2.2±0.1 units
Pre-cool Stress			
Inner (Ave)	8800 psi	10650 psi	8900 psi
Outer (Ave)	11600 psi	13750 psi	8800 psi
Post-cool Stress			
Inner (Ave)	3600 psi	6000 psi	4900 psi
Outer (Ave)	8400 psi	12650 psi	6150 psi
Stress at 6600 A			
Inner (Ave)	≈0	1800 psi	1850 psi
Outer (Ave)	6600 psi	11650 psi	5150 psi

II. Quench History

One measure of the quality of a magnet is its quench performance. The quench histories of magnets DS0313 and DS0315 are shown in Figure 1 and summarized in the table.[4,5] Both magnets reached their plateau current at 4.35°K, (the operating temperature of the SSC), and at 4.2°K without training, but required 2 (DS0313) and 1 (DS0315) training quenches to reach plateau at 3.8°K. Short sample tests of the cable used in these magnets indicated that the plateau currents of DS0313 would be significantly higher than those of DS0315 at comparable temperatures, and this is seen in the plots. The origin of the plateau quenches in the high field inner coil pole turn of these magnets and the observed temperature dependence of the plateau current (which matches the predicted dependence) gives us confidence that these are not

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quenches induced mechanically. DS0313 underwent two thermal cycles while DS0315 underwent 3 thermal cycles, for a total of 44 and 59 quenches, respectively. DS0315 seems to have required 1 retraining quench before reaching plateau on its third cycle, although this quench was only 24 A below the envelope of currents for plateau quenches and was in the pole turn . The large number of high ramp rate quenches during the third cycle were at 300 A/s and were cleansing quenches induced during magnetic measurements.

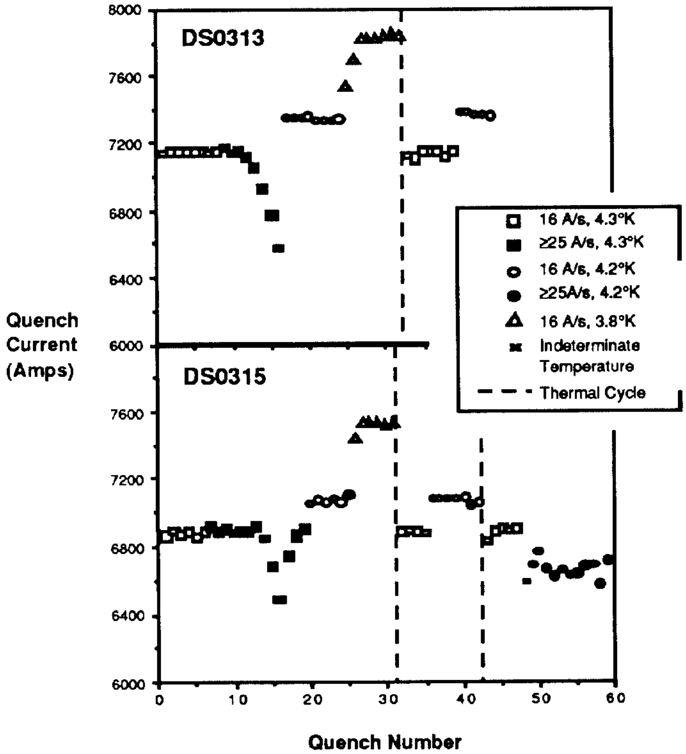

Figure 1. The quench history of magnets DS0313 and DS0315. The ramp rate for plateau quenches was 16 A/s. The test plan also included a study of the quench current as a function of ramp rate.

Magnet DS0314 never reached a plateau during its test cycle but quenched erratically in its lower inner to outer coil splice region. Upon disassembly it was found that an excessive amount of putty was used to hold a voltage tap in place in this region and this had prevented the splice from being clamped properly. This magnet is in the process of being reassembled for retest to determine if this was the only problem hampering its performance and we will not discuss it further in this paper.

III. Mechanical Behavior

It is widely accepted that good quench performance requires that the coils of a magnet remain clamped azimuthally within their collars when the magnet is fully excited. To provide this clamping the coils are initially stressed to between 8 and 12 Kpsi during assembly. Ideally, the prestress is attained by molding the coil appropriately oversized for a collar cavity designed to provide the best field quality. Accomplishing this generally involves a lengthy iterative process. To achieve the correct prestress for this short run of magnets, the coil was shimmed at the pole using adhesive backed kapton. The thickness of the required kapton shimming was estimated using a combination of a simple spring model for the behavior of the coils within the collar cavities and experience obtained from previous magnets. The table shows a comparison of the average inner and outer coil stress at room temperature, at 4.3°K and at 4.3°K at 6500 amps. The error on the absolute values of these numbers is estimated at 1000 psi statistical and 1000 psi systematic, however the relative error between measurements on a single magnet are much smaller. It can be seen that, except for the outer coils of DS0313, the warm prestress fell within the desired window for these magnets. Figure 2 shows the stress at the pole as a function of current squared. The slope of these curves is comparable for all three magnets. None exhibited unloading up to the operating current, indicating that the initial warm prestress was adequate.

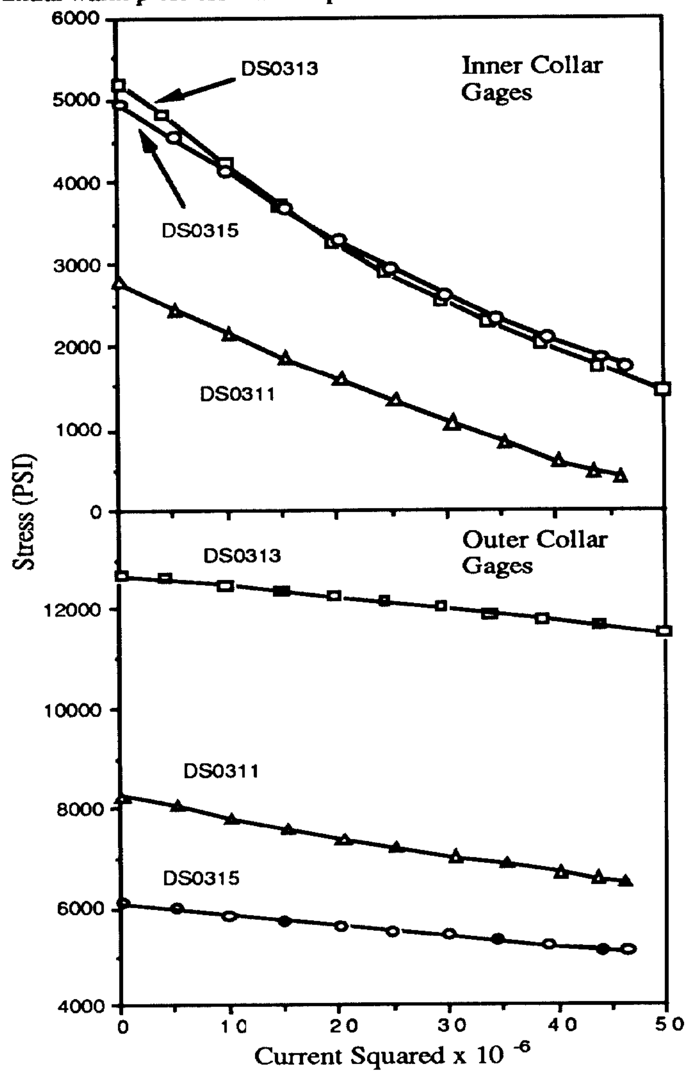

Figure 2. Inner and Outer coil stress as a function of current squared after the plateau current had been achieved .The data points shown are the average of all the working gages (nominally 4) in the magnet.

In addition to the gages used to monitor pole stress, a set of four gage sets are used to measure the force between the end plate of the magnet and the coils. The end force is initially set to approximately 250 pounds per gage set, for a total of about

1000 pounds, at room temperature. Figure 3 shows the family of curves for the three magnets as a function of current squared for the same runs as in Figure 2.

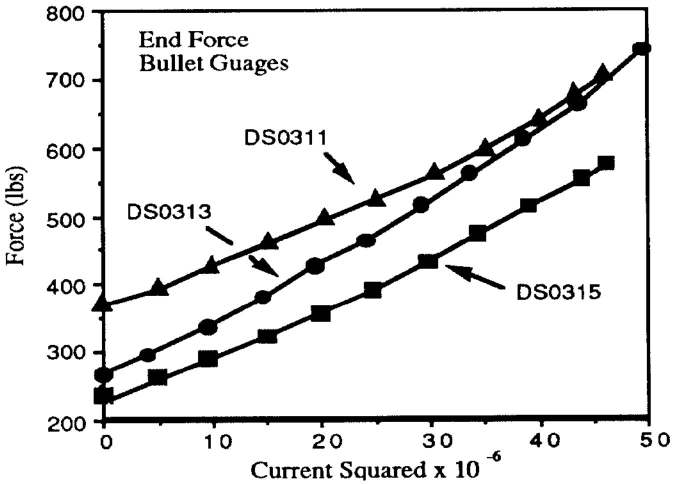

Figure 3. End force as a function of current squared.

IV. End Clamp Design

Several of the magnets in the horizontally split yoke series experienced a number of mechanically induced quenches originating in the ends. The Fermilab design uses a collet clamping system consisting of a can which clamps four insulating blocks around the coil to supply prestress for the end region[6]. For the horizontally split yoke series of magnets the can was fabricated from stainless steel and the insulators were made of machined G-10 with the fibers in the azimuthal or transverse direction. Since the G-10 with azimuthally oriented fibers shrinks faster than stainless steel on cooldown, it was believed that significant prestress loss ocurred which may have lead to the end region quenches. While the G-10 with fibers oriented in the transverse direction does not have the prestress loss on cooldown problem, it is very difficult to manufacture. DS0313 was built with the standard end clamp configuration using G-10 insulators with azimuthally oreinted fibers, while DS0315 was built using molded stycast for the insulators and an aluminum end can. The latter configuration should result in a higher prestress after cool down and is easier to obtain in production quantities. Neither DS0313 or DS0315 quenched excessively in the end region. For a detailed discussion of the end clamp studies see reference 7.

V. Magnetic Field Measurements

Magnetic field measurements are made at several times during the production and testing of the model magnets. Generally measurements are made of: the collared coil assembly, the yoked magnet prior to cool down, the cold magnet at 5000 A, and the warm magnet after testing is completed. Table 1 summarizes the measurements of the sextupole moment, which is the most sensitive component to variations in shimming at the pole, for the warm yoked magnet. It can be seen that measurements of DS0313 and DS0315 are consistent. A comparison of all the allowed multipole components is shown in Figure 4. These are acceptable considering no effort was made to optimize the field. An optimization of the field components is currently underway for the 50 mm magnets.

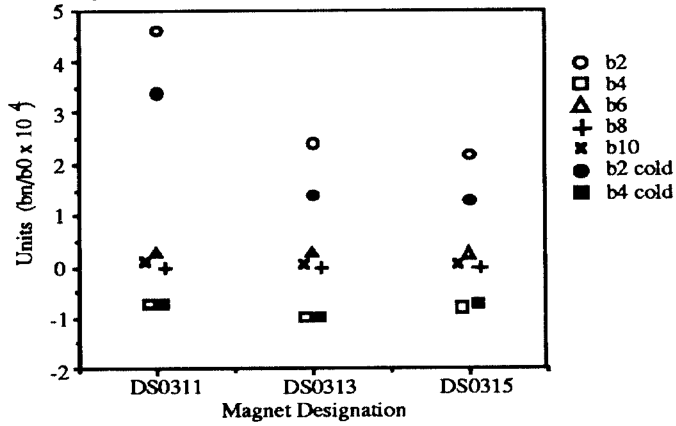

Figure 4. Warm and cold measurements of the allowed harmonics for DS0311, DS0313 and DS0315 in units of the ratio of the harmonic, (at 1 cm from the center of the aperture), to the dipole field, times 10^4.

VI. Summary

We have presented results of tests on two 40mm aperture SSC dipole model magnets with vertically split yokes. The performance of these magnets was very good from a quench and mechanical behavior standpoint. The magnetic field quality was acceptable considering no attempt at optimization was made. A third magnet did not achieve plateau however the probable cause for this was traced to a flaw in its assembly. It is currently being reassembled for retest.

We would like to acknowledge the work of the many engineers and technicians whose efforts made possible the results presented in this paper.

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