



Fermi National Accelerator Laboratory

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**Production Measurements on the
Quadrupole Correctors for the
New Low-Beta System
for the Tevatron Collider**

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Abstract

Each of the Low Beta Systems for the Tevatron Collider requires 12 spool pieces; eight of the spool pieces contain superconducting quadrupoles as part of the low beta insertion as well as standard correction magnets. The remaining four provide correction magnets, beam position monitors, and current feeds for the neighboring low beta main quadrupoles. Thirty-two of these new spools have been fabricated. We describe here the mechanical, cryogenic and magnetic properties of these new spools as determined in the production test and measurement activities.

Introduction

Table I is a list of spool types for the new low-beta system [1]. The notation is adopted from the Tevatron convention where types "A" through "H" had been used for the Energy Saver/Doubler spool types [2]. The first two types, J

lar in design to the main quadrupoles for the low-beta system [3], and the M/N types have a one-shell quadrupole fabricated from segmented 5-in-1 conductor in their upstream sections [4]. L/P types have two (one horizontal and one vertical) beam position detectors in their downstream section and a set of high current leads to power the neighboring main quadrupoles. All concentric-wound correction elements, DSQ, DD, DDQ, are of the same design as in the previous spools [2]. The maximum gradient (current) for the M/N types depends on their lattice functions.

Measurement Results

All field measurements (warm and cold) and quench studies of completed spools were done at the Magnet Test Facility (MTF) at Fermilab.

Room Temperature Measurements

The initial magnetic field measurement of correction coils was at room temperature. The harmonic content of the magnetic field (poles two through eight) is measured by powering each coil to a few hundred milliamps by an 11 hertz oscillator and a Morgan coil is rotated through one revolution in 64 steps. At each step both the driving current and the Morgan coil voltage are measured. The harmonic amplitudes are determined by a Fourier transform of the data [2]. Figures 1 and 2 show the field strength and angle measured for each coil.

The beam detectors in L and P type spools are used to measure the transverse beam position. This requires that the center line of these detectors with respect to the magnetic center line (or the geometric centerline in L spools) be known. An R.F. device designed for the Energy Saver magnets[5] was used to measure the center line of beam detectors. This system uses a wire stretched along the magnetic axis and is excited with a 53 MHz R.F. signal. The traveling electromagnetic fields on the wire are picked up by the detector plates and the difference voltage from these plates gives the offset of the detector with a precision of ± 10 mils..

Table I: Low-Beta Correction Elements

Spool Type	Up-stream Magnet	Down-stream Magnet	Gradient (kG/m)	I (A)	Total No.
TSJ	717(24")	DSQI	1407.0	4832	3
TSK	717(24")	DSQII	1407.0	4832	3
TSL	DD(30")	NONE	—	—	5
TSM	S5(24")	DSQI	144.1	247	8
			632.8	1086	
			563.4	967	
TSN	S5(24")	DSQII	144.1	247	8
			632.8	1086	
			563.4	967	
TSP	DDQ	NONE	—	—	5
Total					32

717 = Two-shell, high current quadrupole.

S5 = One-shell quadrupole, segmented 5-in-1 conductor.

and K, contain a two-shell, high current quadrupole simi-

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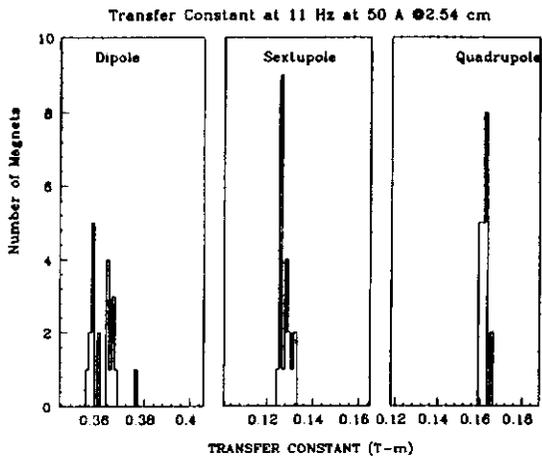


Figure 1: $\int B dL$ for coils in a DSQ package.

Cold Testing

Each spool was subjected to an extensive set of tests at 4.6 deg. K. A low current system (150 A) was used to study the quench performance of the correction coil package. Each coil was individually powered to 100 A and then they were powered in various polarity permutations to a maximum current of 75 A. The package would be qualified if no coil quenched during these tests.

For the L and P type spools which contain the beam position detectors, two optical surveys, one at room temperature and one at 4.6 deg.K, of a target installed on the detectors were used to determine any possible movements of these detectors with temperature. No noticeable movements (< 5 mils) was detected in any of these spools.

Quench performance of the high gradient quadrupoles in the upstream section of J,K,M, and N types was studied with the test facilities used for testing of the SSC dipole magnets at MTF [6]. This system consists of two 5000 A PEI power supplies, a set of quench detection circuits for protection, and a 12 KA shunt to monitor the current. The S5 coils in M and N type spools were qualified if they quenched at currents over 1600 A (the operating current for these quadrupoles is 1100 A at 1 Tev). Generally, one

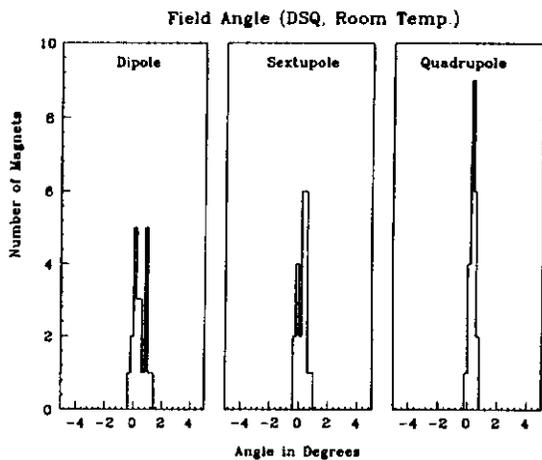


Figure 2: Field angle of coils in a DSQ package.

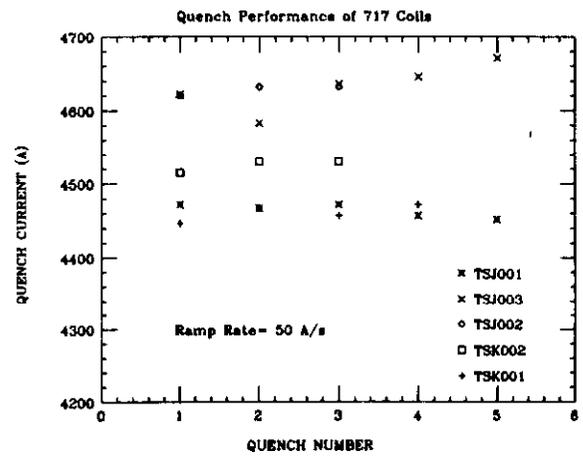


Figure 3: Quench performance of 717 coils at 21PSIA.

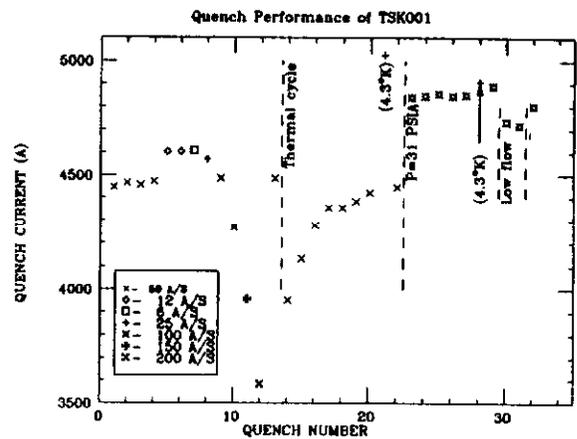


Figure 4: Quench performance of TSK001.

or two quenches were needed to reach the target current.

The 717 coils in the J and K type were designed to operate at 4815 A at 1 Tev. Figure 3 shows the quench behaviour of some of these magnets. As is seen they all quench, under the test conditions at MTF, below the required current. However, the operating pressure of the single phase liquid helium in the accelerator tunnel is higher by 10 psi than the MTF test conditions. Increasing the test pressure from 21 to 31 psia moved the quench current to about 4850 A. Figure 4 shows the extensive quench study done on one of these magnets. Included in this figure are the ramp rate studies, high pressure quenches, and some quenches at lower temperature (4.3° K). The training-like behaviour shown after a thermal cycle was a major concern. How was it that the magnet did not show this behaviour during the first cool down? The main difference between the two sets of quenches was that the second set was done as soon as the magnet was declared cold by the instrumentation on the test stand whereas the first set of quenches were done after the magnet had been "soaking" overnight. This indicated that some parts of the coil were taking longer to cool down than shown by the test stand thermometry. It should be noted that due to space limitation in the tunnel the coil is hung with a graphite post inside the cryostat. It was proposed that this graphite

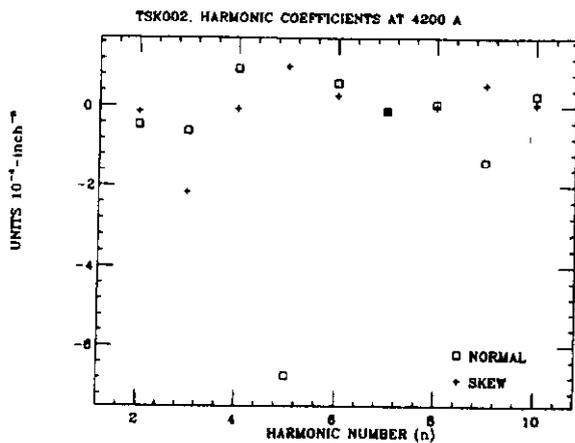


Figure 5: Harmonic moments of 717 coils
TSJ002, NORMAL 12-POLE

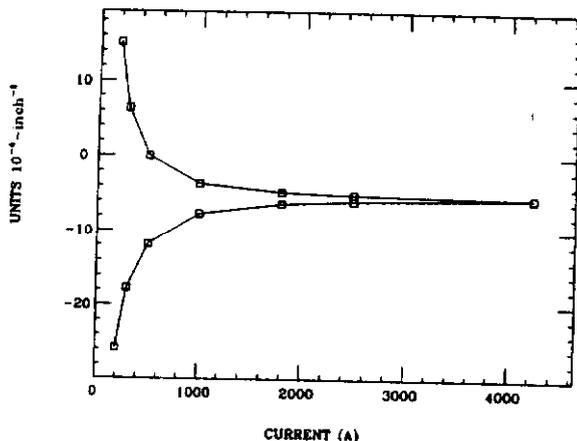


Figure 6: Current hysteresis of 12-pole moment

post was introducing some heat into the magnet producing a bubble of warm gas in the upper portion of the coil. Leaving the magnet cold for a longer period of time would shrink this pocket of warm gas, as it happened during the first cool down. Increasing the pressure would also raise the liquid level further up inside the cryostat causing a more uniform temperature distribution throughout the coil. It was, thus, concluded that the quench behaviour after the thermal cycle was actually a cooling curve and not a training one. Other magnets exhibited similar behaviour confirming the above hypothesis.

The magnetic field measurements on the S5 and 717 coils were done with the system used for the testing of all the Tevatron magnets [7]. The harmonic content of the field is measured with a rotating coil, and a stretched wire measurement is used to find the magnetic center and measure the integrated gradient and the field angle. Figure 5 shows the harmonic coefficients for a 717 coil as measured with the rotating coil. Both S5 and 717 coils have a large 12-pole moment built into them. Figure 6 shows the current hysteresis in the 12-pole moments as a function of current for a 717 coil.

The integrated gradient is measured with a stretched wire probe described in [7]. Figure 7 shows the measured $\int GdL$ for the S5 and 717 coils. For detailed discussion of

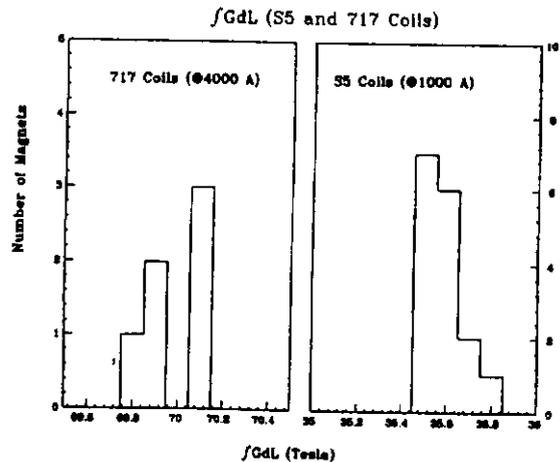


Figure 7: $\int GdL$ for S5 and 717 coils

magnetic performance of these quadrupoles see Ref. [8].

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