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Author
Barale, P.J.

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MAGNETIC MEASUREMENTS OF THE 5 METER QC SERIES QUADRUPOLES AT LAWRENCE BERKELEY LABORATORY

Paul Barale,[1] B. Benjegerdes[2], S. Caspi,[2] M.I. Green,[1] A. Lietzke,[2] R. Schermer,[1] C. Taylor,[2] and D. Van Dyke[1]

[1]Engineering Division*
[2]Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720 USA

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[1]Engineering Division*
[2]Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory, University of California
Berkeley, CA 94720

INTRODUCTION

From May 1991 to September 1992, magnetic measurements were performed on six 5 meter prototype SSC quadrupoles designed and built at Lawrence Berkeley Laboratory (LBL). In addition, one of the quadrupoles was disassembled, reassembled and remeasured. The purpose of this paper is to review the magnetic measurements program and give an summary of some of the results of the magnet testing.

THE MAGNETIC MEASUREMENT PROGRAM

The "MFM" Magnetic Measurement System

The "Magnetic Field Measurement" (MFM) System is a general purpose rotating coil, harmonic analysis magnetic measurement system developed at LBL for measurement of the SSC 5 m prototype quadrupoles. The system has the following significant features:

1. Externally driven tangential measuring coils with quad and dipole bucking coils
2. External optical encoder - angular position to 43.75 μradians absolute
3. Integrated induced voltage measured using digital integrator system
4. Analog bucking to obtain high resolution harmonic content of magnetic field
5. UNIX workstation and VME crate in host-target configuration - all real time data acquisition tasks in dedicated VME crate, operator interface, data analysis and display, and other non-real time tasks in UNIX workstation.

The MFM control, acquisition and analysis software packages were all written in C and developed at LBL. Acquired data is corrected for linear drift, rotated into a 'standard' frame of reference (south pole at 45^{o} when viewed from the non-lead end), and corrected for differences between search coil axis of rotation and the magnetic center of the magnet. In addition, all warm measurements are taken with both positive and negative currents and the results averaged, to remove effects of external fields (e.g. earth's field, iron remnant

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magnetization in yoke, etc.).

The Measurements Program

All magnets were measured both at room and cryogenic temperatures. Our typical test program includes the following:

Room Temperature	Cryogenic
1. Uniform field region, ±14 A	1. Uniform field region, 0->6.6->0 kA
2. Axial scan, ±14 A	2. Axial scan, 3kA
	3. Harmonic decay, 640A

Operational details of these tests can be found elsewhere[1].

Both the measurement hardware and software were under development during the measurement of QCC401 and QCC402, consequently the testing of these two magnets was not as extensive as the remainder of the group. In addition, scheduling and research emphasis dictated somewhat the test selection from magnet to magnet.

RESULTS

Axial Scan

The axial scan data provided the most interesting and useful results. Figure 1 illustrates one unexpected effect noted in all cold axial scans. As can be clearly seen, the b5 multipole (first allowed harmonic of b1, the quadrupole) is distorted for positions < 140 cm and > 400 cm, leaving a "uniform field" region of ~260 cm. Centered in these distorted regions are the strain gauge packs, whose influence is integrated over a wide region by the 1 meter long measuring coil. A similar effect can be seen in the b9 (second allowed) harmonic. The effect is not seen in the warm axial scans.

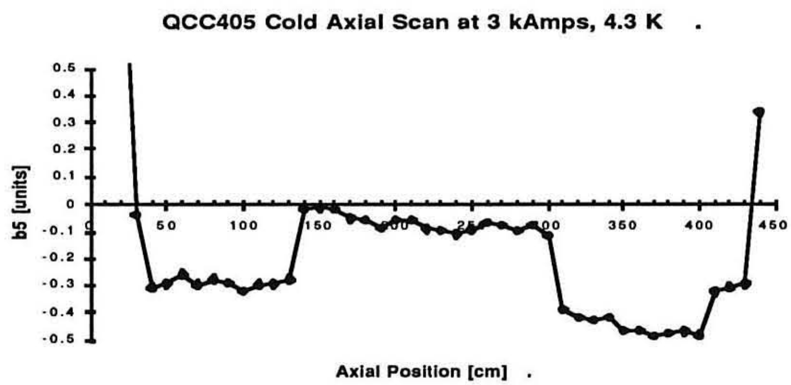


Figure 1. b5 vs Axial Position for QCC405 Cold Axial Scan

Multipole Summary

Table 1 summarizes the average cold axial multipoles for magnets QCC402 through QCC406. The data quoted are the average values over all axial scans and can be considered representative of the "uniform field" region of each magnet at 3000 amps. Detailed explanation of the analysis used to obtain these results are available[2].

Table 1. Multipole Summary [units]

	a2	a3	a4	a5	a6	a7	a8	a9
QCC402	-0.724	0.553	-0.091	0.222	0.012	0.028	-0.057	0.065
QCC403	1.296	-0.832	0.167	0.010	-0.008	-0.001	0.013	-0.013
QCC404	1.552	0.103	0.126	-0.115	0.015	0.031	0.029	-0.001
QCC405	-0.485	0.280	0.147	-0.046	0.036	0.023	0.005	0.000
QCC405A	-0.456	0.414	0.174	-0.043	0.034	0.017	0.005	0.002
QCC406	-0.662	0.467	-0.236	0.005	0.004	0.025	0.003	0.009
SSC Spec.	2.696	1.550	0.641	0.738	0.209	0.240	0.276	0.317

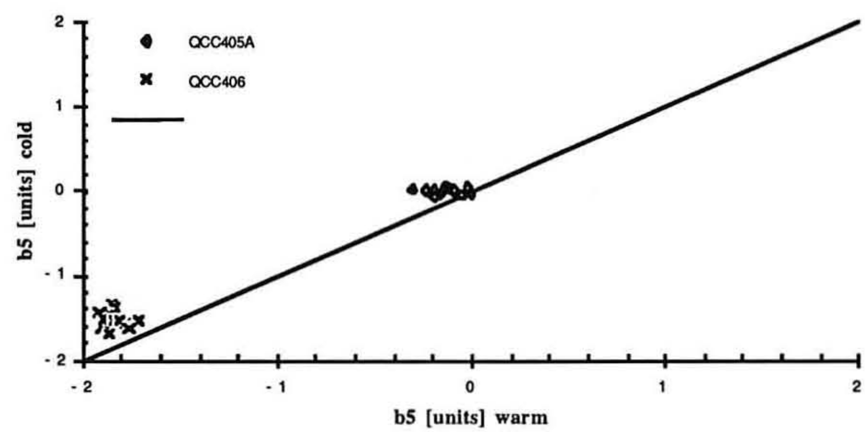
	b2	b3	b4	b5	b6	b7	b8	b9
QCC402	-0.284	-0.041	-0.195	-1.082	0.086	-0.072	0.002	0.102
QCC403	1.189	-0.155	0.058	-0.850	-0.025	0.041	0.101	0.234
QCC404	-0.694	-1.009	0.023	-0.352	-0.064	-0.014	0.023	0.147
QCC405	-0.184	-0.111	0.195	-0.082	0.044	-0.004	0.008	0.091
QCC405A	-0.151	0.306	0.215	0.004	0.043	-0.016	-0.002	0.087
QCC406	0.148	0.128	0.162	-1.486	0.028	0.006	0.001	0.177
SSC Spec.	2.696	1.550	0.641	1.680	0.209	0.240	0.276	0.776

SSC Spec. in this case is defined as 1 Systematic + 1 RMS for each multipole[3].

Warm-Cold Correlation

Multipole data obtained from warm and cryogenic axial scans were examined for correlation. Axial scan data was used to gain enough points to achieve statistical significance and because some of the multipoles were sensitive to axial positioning. Data distorted by the strain gauges were excluded. Figures 2 below illustrate the correlation for the first allowed multipoles. These multipoles were not corrected for persistent current magnetization effects in the cold measurements (expected to be -0.08 units for b5 and 0.004 units for b9). The data for these multipoles is clustered around points which lie on the diagonal, suggesting little geometric change during cooldown. All the low order multipoles (b2 through a4) exhibit some degree of correlation. In the higher order multipoles, the data lies on a line parallel to the x-axis, suggesting that these are dominated by noise in the warm measurements.[2]

QC Series W-C Correlations



QC Series W-C Correlations

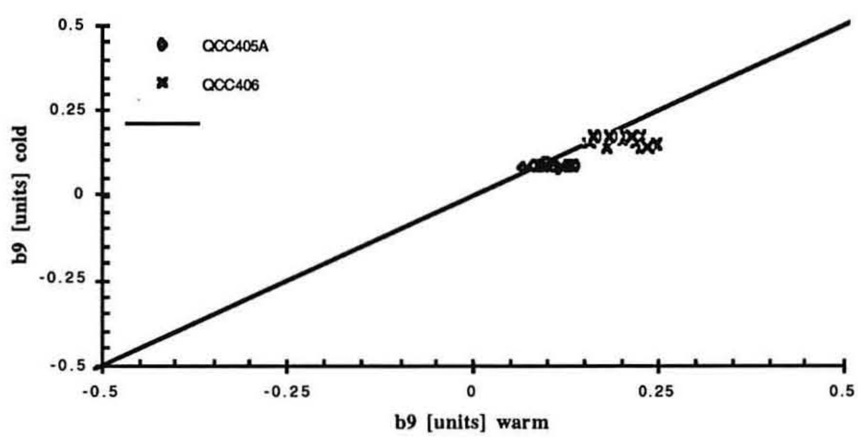


Figure 2. Warm-Cold Correlation of Allowed Multipoles

Injection Decay

None of the QC series quadrupoles exhibited significant injection current first allowed harmonic decay, in part due to small b5 values for the series (except for QCC406, where a significant b5 was deliberately designed in). However, even in QCC406, the decay is on the order of a tenth of a unit over an hour - considerably smaller than decays seen in the SSC dipole first harmonic. Decay for magnets QCC401 through QCC404 are not included in Figure 3 (below) as they are dominated by power supply instabilities. These instabilities were reduced for QCC405 and QCC406, and further corrected prior to QCC405A.

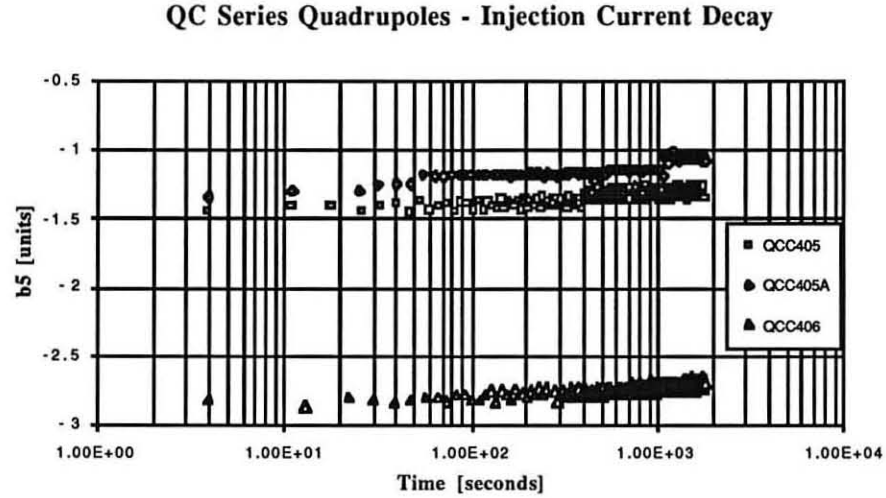


Figure 3. b5 Decay at Injection Current

SUMMARY

From the magnetic measurements performed on the QC series quadrupoles at LBL, it is clear that this design easily meets the SSC specifications on field quality. In addition, multipole decay during injection should not be a significant problem. Finally, it appears that there may be sufficient warm-cold correlation of the lower multipoles to allow for acceptance/rejection decisions to be based on warm measurements, particularly if a more sensitive coil, or higher currents are used for the warm measurements. On the down side, there can be significant local variations in field and field quality that will show up only on axial scans. These are, however, local variations and the effects are minimized when one considers the magnet integral field.

Overall, the QC series of quadrupoles and the related magnet measurement program have to be considered a success, from the standpoint of field quality.

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