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Magnetic Measurements of the XLS Magnets*

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Abstract-

The magnets designed and built for Phase 1(200MEV) of the XLS (X-Ray Lithography Source) project have all been measured and characterized. In this paper, the measurement system designed and utilized for the Phase 1 180 degree dipole magnets is reviewed. Hall probe measurements of the two dipole magnets, with a field of 1.1 Tesla at 1200 amperes, are discussed and presented. Phase 2 (700 MeV) of this project includes replacement of the two room temperature dipole magnets with superconducting dipoles (3.9Tesla).

Introduction

The two 180 degree dipole magnets for Phase I of the XLS project at the National Synchrotron Light Source were measured and characterized during the period 4/90-7/90. These magnets are currently installed in the 200 MEV machine at the NSLS. This paper documents some of the measurements and results obtained during this measurement program. These dipole magnets presented unique constraints to the measuring system due largely to the bending radius of 0.6037 meters, and the absence of a reference surface within the magnetic aperture.

Measurement Setup

In order to measure the magnetic field both in the body and in the fringe field of the XLS dipole magnets three stages were supported directly on the dipole, at the location of the magnet center as determined by fiducials on the magnet. The three stages consisted of a rotary stage, a height stage, and a radial stage (see Figure 1). The resolution of the rotary stage encoder was 2.5 arc-seconds (7 microns at $\rho = 0.6037$), and the range of travel was the entire 360 degrees. The height and radial stage encoders both had a resolution of 1 micron, with a total travel range of 10mm and 100mm respectively. A curved titanium arm which could reach about 92 degrees into the aperture of the dipole magnet was supported on these stages with a probe block at the end, which carried the hall probes. The sequence for the measurements was that one half (i.e. a 90 degree segment) of one magnet was measured, then the probe block was removed, the titanium arm was flipped, the probe block was remounted, and the other half of the same magnet was measured. Data was taken at several dipole currents, and the dipole current was monitored as a function of time.

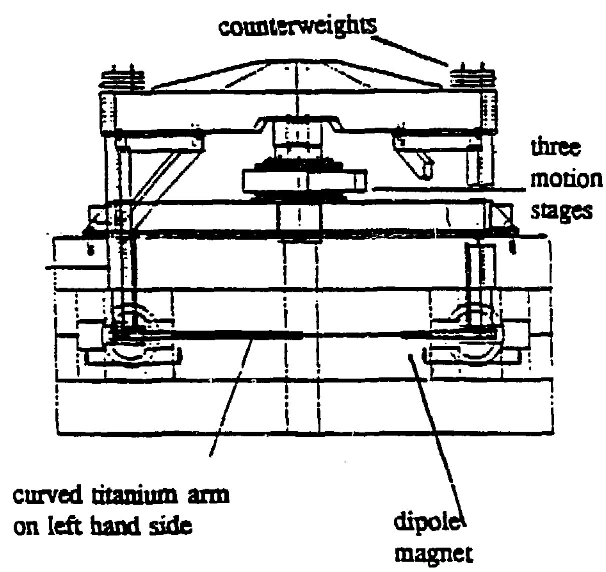

Figure 1 - The magnetic measurement setup for the XLS dipole magnets, with the three motion stages supported on the magnet, and the titanium arm reaching into the magnet aperture.

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The Hall probes used were modified Bell probes interfaced 'through a 'personality plug' which contained a memory chip with the calibration information, to Group 3 Teslameters. The probes were calibrated at the Group 3 facility as a function of temperature to 0.01%. Although we had several probes on the probe head, it turned out that only a single probe could be powered and used at any one time due to cross talk effects. The disadvantage of this method is that the measurement time was increased, since the probe had to be moved more times to obtain the data within a given aperture. However, since only one probe was used for the data the added complication of cross calibrating two or more probes was avoided. The full horizontal aperture of interest was accessible using a single probe, since the vacuum chamber was not installed during the tests and therefore the movement range of the titanium arm was relatively unrestricted. Had this not been the case, we would have had to use more than one probe and average the voltage over time to remove the cross talk oscillations. For the SXLS magnet, probes which should allow simultaneous readings are planned. During the measurements of the superconducting magnets, the vacuum chamber will be in place, and therefore the aperture available is much more constrained than it was in the warm dipole magnets.

The data acquisition and stepping motor stage motion was computer controlled, with an IBM 386 type computer. A program (written in C) read an input file which consisted of the positions in space at which the measurements were to be taken. A waiting time was put into the sequence so that the vibrations of the arm were damped prior to reading the hall probe voltages and temperatures. With our setup, we found that a pause of about 20 seconds after moving the stages prior to taking the data yielded hall probe readings which were stable in time. Typically, the scans we took covered a radial distance of +/- 26mm about the design radius of 0.6037m, in steps of 4.5mm, and measured at increasingly close angles as the end of the magnet and the fringe field were approached. Towards and in the fringe field, the data was taken at 5mm increments in path length. The scans typically took about 20 hours, and interspersed throughout the measurement points at regular intervals there were reference measurements at the center of the magnet (a high field point), and at a points far in the fringe field of the magnet (a low field point). Examination of these points revealed no long term drift in the data points. Over many days, both of these reference data points varied by +/-0.4 gauss, which is comparable to the resolution of 2 parts in 10^5 for a full scale (3 Tesla) reading.

Data Analysis and Results

The hall probe data as a function of radial position was fit to the fourth order polynomial

$$B = B_0 + B_1 x + B_2 x^2 + B_3 x^3 + B_4 x^4$$

via a least squares fitting procedure. The coefficients in this expansion are identified as the dipole, quadrupole, sextupole, octupole, and decapole respectively. The data is fit over the range of the design radius 603.7mm+/- 26mm, corresponding roughly to the vertical aperture between the two pole faces in the magnet, which should be within the radius of convergence of the multipole expansion. A plot of the data at a path length as a function of radial position about the design radius of 0.6037m is given in figure 2 for 4 different path lengths S, with the magnet powered at 1200 amps (maximum current). Here, S=0 corresponds to the middle of the magnet. These plots graphically display the changing contributions of the various terms of the multipole expansion as a function of path length, and the rapid changes which occur near the ends of the magnet.

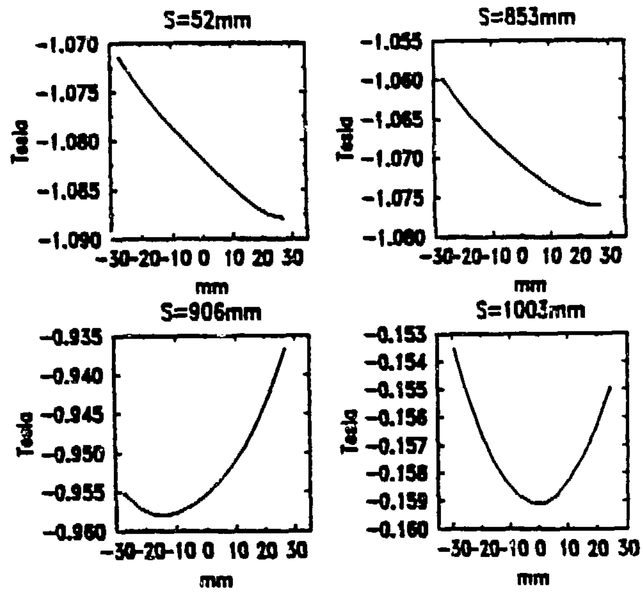

Figure 2 - These plots show the field values at paths lengths S = 52, 853, 906, and 1003mm through the dipole magnet, as a function of radial position about the design radius of 0.6037m.

Each of these transverse scans at a given angle can be fit to the multipole expansion, and the resulting coefficients can be plotted as a function of angle or, alternatively, as a function of path length, through the magnet. Some typical data plotted in this way is shown for one of the dipole magnets in Figure 3 at 1200 amps. The large gradients in all the terms in the field expansion at the ends of the iron in the magnet is graphically evident.

In addition to analyzing the field data in terms of the moments of the magnetic field at any given angular position of the magnet, the dipole field was also integrated along the

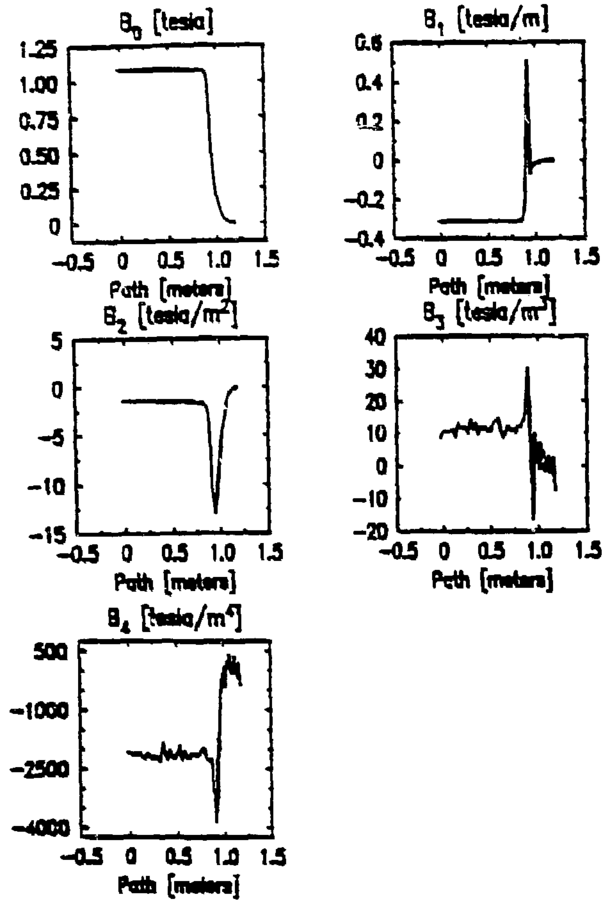

Figure 3 - These plots show the fitted coefficients to the multipole expansion for an XLS dipole magnet at full current (1200 amps).

length of the dipole and its fringe field in order to determine the effective length of the magnet. The effective length is defined as the field integral divided by the field at the magnet center. In the XLS ring, there is an multipole corrector magnet near either end of the dipole magnets at about 1110 mm away from the magnet center. In order to simulate this during the data acquisition, which is crucial for length measurements, a steel plate was positioned at the location of the multipole corrector magnet to act as a field clamp. Alternatively, we took the field data without the field clamp, and simulated the reflection due to the corrector magnet by reflecting the data obtained at path lengths greater than 1110mm i.e. by adding the negative of these data points to the corresponding points at path lengths less than 1110. In terms of the field integral, this yields a corrected field integral which is the field integral at 1110 minus the integral from 1110 to infinity. The magnitude of this correction was typically about 1mm for each half of each magnet. The data modified in this way agreed with the steel plate data to 0.1mm., demonstrating the validity and applicability of this approach.

In the initial configuration of the magnets, each half of each magnet was about 9mm too long, i.e. the effective length of each magnet was about 18mm longer than desired. This length was physically shortened in 3 steps. First, the magnet was disassembled and machined to have removable end plates, which removed about 3.2mm of material from each half of the magnet. After this procedure, further reductions in length were greatly simplified since only the end plates had to be removed, machined, and reinstalled. The parameters measured for the two dipoles are listed in table 1.

Dipole Design Values		
.5 L(mm)	948.5	
B(T)	1.1	
B1(T/m)	-.321	
B2(T/m²)	-1.49	
Dipole Measured Values		
	Dipole "1"	Dipole"2"
L(mm)-RHS	948.2	947.3
L(mm)-LHS	948.5	948.3
B(T)@1200amps	1.0847	1.0821
B1(T/m)	-.298	-.317
B2(T/m²)	-1.53	-1.37

Table 1 - This table compares the design values for various parameters of the XLS dipole magnets to the measured values. Note that the measured quadrupole and sextupole values have been scaled to a 1.1 Tesla dipole field, to enable easier comparisons to the design values.

From Table 1 it is clear that the field in dipole 1 is lower than that in dipole 2, given the same operating current. This can be compensated with a shunt across one of the dipoles, since they will be powered in series. Also, dipole 1 is about 1 mm longer than dipole 2, and an asymmetry in dipole "2" length data is observed between the two halves of the magnet. The integral field data for the two halves consistently showed a magnet length about 1mm longer for one side than for the other. This difference cannot be explained as solely due to the length of the iron, because a translation of the multipole data does not simultaneously null the quadrupole and sextupole asymmetry. The quadrupole strength in the two magnets differs by ≈ 6%. This difference is well within the range of the quadrupole coils on the magnet, which deliver ≈ +/- 13% quadrupole strength. There are sextupole pole face windings on the magnet also, can provide ≈ +/- 60% of the magnet sextupole.

This paper is intended to summarize some of the salient features of the XLS dipole magnets, as determined by the magnetic measurement program. A more complete summary of the measurement results is planned. The authors would like to acknowledge the assistance of G.Stenby and C. Brite throughout the measurement program.