MAGNETIC MEASUREMENT OF THE 10 KW, IR FEL 180 DEGREE DIPOLE*

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Abstract

A family of large bending dipoles has been magnetically measured to support the 10 kW IR-FEL upgrade. This upgrade will allow for a wider wavelength range and an increase in the machine energy to operate between 80 MeV/c and 210 MeV/c. The dipole magnets allow the beam to bend 180 degrees over a 1 meter radius. The requirements for these magnets include varying field strengths, large horizontal apertures and parts in 10,000 field homogeneity as well as setability of core and integrated field. This paper will describe the process involved in measuring and achieving these requirements.

1 INTRODUCTION

A 10 kW infrared free-electron laser is being constructed at the Thomas Jefferson National Accelerator Facility. The pi bend dipoles (GY) are located at the two arcs of the new transport system. Each has a bend radius of 1 meter and bend angle of 180 degrees. They are designed to handle varying field strengths (0.27T to 0.71T) required to operate the machine between 80 MeV/c and 210 MeV/c. Included in the pi bend dipole are two sets of trim coils used for beam path length adjustment. Tight specifications on the magnet setability and the integration of trim coils into the magnet required an exploration of hysteresis procedures to ensure core field setability.

Twenty-two bending dipole magnets make up six dipole families required to run the accelerator. The GY dipoles are included in the arc string along with the GQ and GX dipoles and use a current shunt to compensate for small core field deviations between the GY and other dipole families [1].

2 SETUP, CALIBRATION, & ACQUISITION

The GY dipoles were designed with stringent field requirements shown in Table 1 [2]. The GY was primarily set and configured for the nominal operating energy of 145 MeV/c. All integral measurements were made using Group 3 Hall probes calibrated against Metrolab NMR probes. A total of four probes were read for each measurement, 2 Hall Probes and 2 NMR probes, with the analysis done using Microsoft Excel.

Table 1. Dipole excitation error tolerances (rms.)

Constraint	Tolerance
Accuracy of core field	2.5×10^{-4}
Core Field Uniformity	1.0×10^{-4}
Accuracy of integrated field	2.5×10^{-4}
Integrated Field Uniformity	1.0×10^{-4}

The initial mechanical inspection of the magnet revealed delamination of the electrical grade steel, Purcel gap faceplates. These plates were subsequently stripped from the magnet, cleaned up, and reglued to the magnet pole face. Afterward, the pole face flatness was measured to be flat within ± 80 microns.

2.1 Hardware Set Up

A measurement stand adapted from the DY dipole, used in the original Jefferson Lab FEL Demo, was modified to accommodate the larger GY dipole shown in Figure 1 [3]. The stand consisted of a 25 mm aluminum plate mounted to a granite table, made level and coplanar with the magnet's bottom pole face. The 1 meter wheel, used for the original DY measurements, was used to move the probes circumferentially through the magnet. The wheel, which could be split into four sections, was fed through the magnet using wheel guides mounted on the aluminum plate. The wheel guides were used to align the wheel radially with the magnet from survey data taken with a three dimensional Faro portable CMM machine. This system alleviated the need to split the magnet to install the measurement system.

An aluminium probe holder was used to align Hall and NMR probes to the magnets radius. The Hall probes were placed 10 cm apart at the outsides of the probe holder. NMR probes were positioned 1.67 cm inside, adjacent to each Hall probe. The probe holder was first positioned at the inmost radial position for the first data run. For six additional runs the probe holder was moved outboard 1.67 cm allowing the Hall probes to take data over the entire 20 cm good field region. This method allowed overlapping data sets to be taken at several positions including along the magnet center line, confirming data repeatability in any given set of measurements to ~0.02%.

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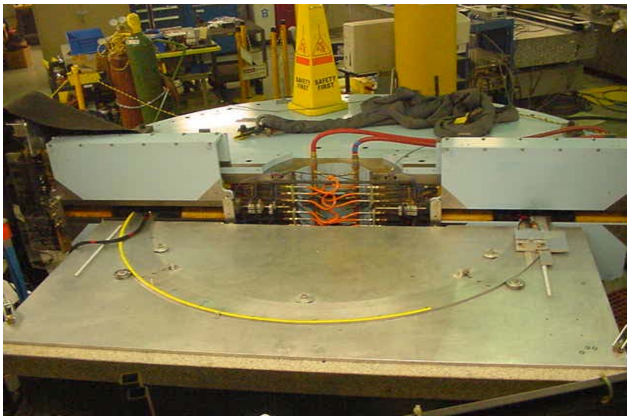

Figure 1: GY Measurement Stand

2.2 Probe Position Calibration

Circumferential positional information was taken from a scale on the wheel as the wheel was rotated through the magnet. Calculations were then made in the analysis spreadsheet to account for scale inaccuracies, scale offset from probe positions, and differing arc distances with respect to radial probe position. This calibration sequence allowed for accurate positional data collection throughout the magnet.

2.3 Hall Probe Calibration

NMR probes, which provide absolute field information at the 10^{-5} level, were used to calibrate the Hall probe by stacking the respective Hall probe on top of its normally adjacent NMR probe. The probe stacks were then positioned in the circumferential centre of the GY. Hall and NMR values were recorded in 15, five-amp increments. Due to the extreme operating range of the GY, a current range specific to each momentum was used for calibration. A linear fit was then made for the 15 data points taken for each of the respective Hall-NMR combinations. This difference was plotted on the ordinate, against the Hall probe readings along the abscissa. The slope and offset of these respective fits were applied to each Hall probe's data readings. Field integral readings between both hall probes, along the 1 meter radius, matched to ~0.01% with the respective calibrations applied but only matched to ~0.15% without the calibrations applied.

2.4 Data Taking

Hall probes provided an effective method to collect core field and integral data because of their large field range. As transverse data sets are taken, NMR probes positions overlapped with Hall probe positions providing an efficient method to back check core field data accuracy.

Circumferential integral measurement runs were taken at the seven radial locations through the magnet for 80, 145 and 210 MeV/c momenta.

Table 2. Circumferential Step increment.

Circumferential Positions (cm)	Step Inc (cm)	Probe Location with respect to Magnet
-40 to -10	1.0	Outside Magnet
-10 to 10	0.2	Enter
10 to 30	1.0	Trim Coil Slot
30 to 284	5.0	Good Field Region
284 to 304	1.0	Trim Coil Slot
304 to 324	0.2	Exit
324 to 354	1.0	Outside Magnet

The measurement sequence began with the wheel rotated to the zero point on its scale. The entrance measurements were made by moving the probe holder along a slot built into the wheel tangent to the 1 meter radius and normal to the magnet entrance for a distance of 30 cm. The probe holder was then locked to the wheel and the wheel was rotated incrementally through the magnet to the magnet exit position. Exit measurements were taken identically to the entrance measurements. Probe data was collected using varying step increments to increase the precision of the integral. Table 2 shows the varying circumferential step increments used while measuring the magnet.

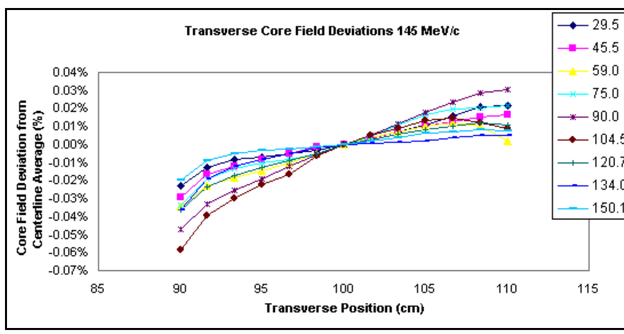

Figure 2: Transverse Core Field Deviation 145 MeV/c

Table 3. GY Parameters

Characteristic		Minimal	Nominal	Maximum
Momenta (MeV/c)		80	145	210
Field (kg)		2.6685	4.8367	7.0049
Set Current (amps)		83.87	152.30	222.78
Hysterysis Current (amps)	Max	118.69	226.01	228.27
	Min	6.43	6.44	6.51
Shunt Values (%)		1.09%	0.85%	-0.12%

3 RESULTS

The results showed a linear deviation in transverse core field of 0.005% per cm at 145 MeV/c shown in Figure 2. This deviation amounts to nearly 0.1% over the 20 cm good field region, causing the magnet to be out of specification by a factor of 10 [4].

Transverse integral measurements were consistent with the transverse uniformity measurements, showing a 0.1% deviation over the 20 cm good field region. To correct for this, an existing quadrupole trim magnet will be used as a simple and eloquent fix to counter the focusing effects of this deviation.

Integral measurements also showed a -0.596% difference in measured field integral relative to the design integral at the 1meter radius. It is impossible to make this shortage in field integral up by using the adjustable field clamps on the GY, so four 0.9525 cm steel plates were attached to the ends of the magnet to increase the field integral, without affecting core field. A current shunt will be used to correct for the deviation between the GY magnet and other magnets along the arc string operating together on a common power supply. Current parameters and shunt values are listed in Table 3. Final measurements show the field integral matching the design to 0.005% with the core field matching to –0.014%. Similar results were obtained at 80 and 210 MeV/c showing the field integral matching to –0.069% and 0.139% and the core field matching to –0.015% and –0.033% respectively. Table 4 shows the uniformity of the core field and Table 5 shows the uniformity of the integral across the good field region.

Table 4. Deviations from Design Core Field

GY001 Core Field Uniformity			
Radial Position (cm)	**80 MeV/c**	**145 MeV/c**	**210 MeV/c**
90	-0.031%	-0.053%	-0.069%
100	-0.015%	-0.014%	-0.033%
110	0.000%	-0.007%	-0.028%

Table 5. Deviations from Design Field Integral

GY001 Bdl Uniformity			
Radial Position (cm)	**80 MeV/c**	**145 MeV/c**	**210 MeV/c**
90	-0.044%	0.033%	0.177%
100	-0.069%	0.005%	0.139%
110	-0.051%	-0.005%	0.114%

Final a nalysis of the field integral showed a deviation 0.06% across the good field region for all three momenta. Figure 3 shows the deviation from uniformity across the 20 cm region. Additionally, tests using the path length correcting trim coils built into the pole face of the magnet verify their ability to easily vary the field integral within the range of the deviation. Trim coil effects on the GY design integral are shown in Figure 4.

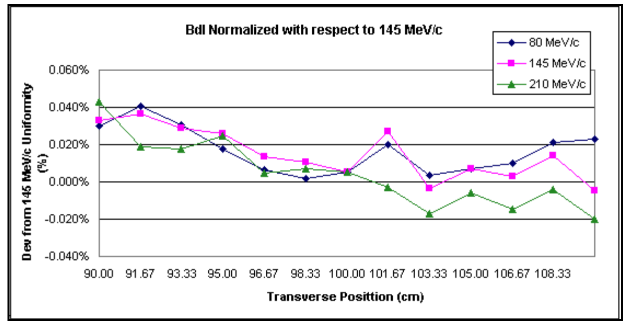

Figure 3: Field Integral Uniformity with respect to 145 MeV/c

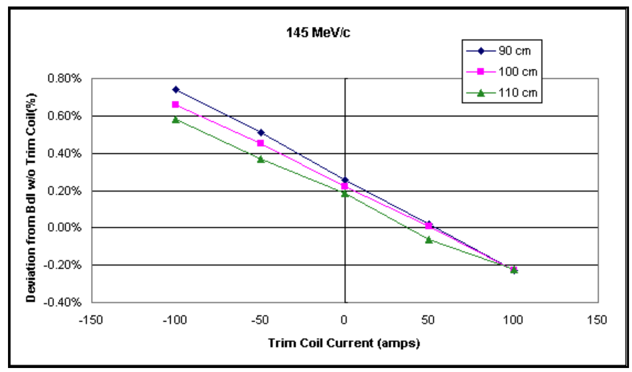

Figure 4: Integral Deviations using Trim Coils

4 CONCLUSIONS

The adapted measurement stand proved to be an effective tool in the collection of core and integrated field data throughout the range of the magnet. The data obtained lead to the implementation of several solutions allowing the magnet to sufficiently meet specifications. Notably, the discrepancy between core and integrated field was solved by the addition of face shim and the slope in the transverse field will be corrected by use of a quadrupole trim magnet.

5 REFERENCES

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