MAGNETIC MEASUREMENT OF THE PI BEND DIPOLE MAGNETS FOR THE IR-FEL AT THE THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY*

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Abstract

A family of large bending dipoles has been successfully magnetically measured, installed and is operational in the high power IR-FEL. These magnets are unique in that they bend the beam 180 degrees on a 1 meter radius. The optics requirements for the magnets include low fields, large horizontal apertures, tight field homogeneity, high repeatability of core field & integrated field, and control of the horizontal & vertical focusing terms that are designed into the magnets. Quantifying the optics requirements proved to be a difficult task, due to the magnet's mechanical construction and sharp bending radius. The process involved in measuring and achieving the results are discussed.

1 INTRODUCTION

The free-electron laser at the Thomas Jefferson National Accelerator Facility has delivered its 1st light and in the process, broken the record for power developed by a free-electron laser by seventy times (710 watts)[1]. In order to increase the power to the desired 1 kW level, the beam is re-circulated through the elements to the CEBAF-style SRF cryomodule. At the return legs of the transport system are the pi-bend dipole magnets. The pi-dipoles have a design bend radius of 1 meter and a bend angle of 180°. In conjunction with these physical constraints were very tight tolerances for the magnetic field measurements. The physical design of the magnets required that a new test stand for the magnetic measurements be developed.

2 MAGNET MEASUREMENT REQUIREMENTS

The lattice design of the IR-FEL was tightly constrained due to the low energy, high current, and the 5% relative momentum spread of the re-circulated beam [2]. The pi-bending dipoles are one of 6 families that are used for beam transport in the IR-FEL. The total number of dipoles is 27. Table 1 summarizes the operating range requirements for the pi-bends. Table 2 displays the specifications for the mechanical design values. The optical and design values are listed in Table 3[3].

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Parameter	Minimal	Nominal	Maximum
Energy (MeV)	33	42	79
Field (kG)	1.1008	1.4010	2.6352
Current (amps)	87.49	111.35	209.45

Table 1: Dipole Operating Range

Parameter (Unit)	Value
Distance between Coils (cm)	16.51
Length of Iron (cm)	309.02
Gap (cm)	5.08

Table 2: Mechanical Design Values

Parameter (Unit)	Value
Hysteresis Loop Current (amps)	$0 \rightarrow 220 \rightarrow 0$
Maximum Voltage (volts)	57.8
Effective Length (cm)	314.16
Good Field Width (cm)	11.00
End-Field roll-off integral (unitless)	0.27
Longitudinal field uniformity	$2\text{x}10^{-3}$/10cm

Table 3: Optical and Design Values

Measurement of the absolute core and integrated fields of the pi-bends was important since they were to be powered in series with several of the other dipole families. Precise control of excitation errors to avoid poor steering and focusing was necessary[4]. The tolerances for the magnetic field are listed in Table 4[3].

Constraint	Tolerance
Reproducibility of integrated field	$1\text{x}10^{-4}$
Accuracy of core field	$1\text{x}10^{-3}$
Accuracy of integrated field	$1\text{x}10^{-3}$
Tracking within dipole family	$1\text{x}10^{-3}$

Table 4: Dipole excitation error tolerances (rms.)

3 TEST STAND / PROBE CART

3.1 Hardware Setup

The pi-bend magnet presented many challenges when it came time to magnetically map the field. Typically, bend magnets at Jefferson Lab have been either an open face 'C' magnet design or one of a linear nature where a probe could be translated through the entire region. The 1 meter bend radius of the pi-bend magnets did not allow this. A probe mounted to a straight rod could only be inserted a few centimeters into the magnet.

A precisely manufactured wheel and cart which held two Group 3 Hall Effect Probes and two Metrolab NMR Teslameters was devised. The measurement wheel was manufactured in 4 sections allowing the magnet to be leveled and positioned precisely to a granite table without having to split the magnet. A sheet of 25mm aluminum plate was placed upon the granite table to facilitate the positioning of the wheel relative to the magnet. Figure 1 shows the magnet aligned to the table and the wheel. The long rod that hangs over the table was used to move the wheel through the dipole.

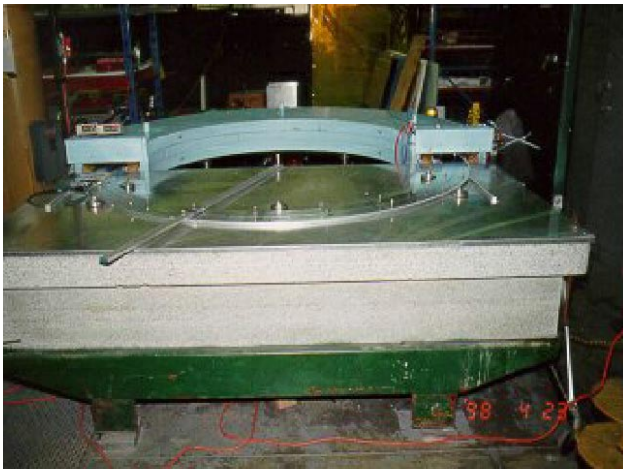

Figure 1: Test Stand, DY Magnet and Measurement Wheel

Once the magnet was positioned relative to the table, the wheel was threaded through the core, piece by piece. The bottom of the wheel was covered with a Teflon base which allowed easy movement of the wheel. Precision tooling balls had been placed onto the magnet during manufacture using a CNC machine to a tolerance of ±0.08 millimeters. To ensure that the wheel was properly centered about the magnet, a theodolite alignment check was carried out. This verified the precision of the wheel and how well it had been centered about the pole face (approximately ± 0.15 millimetres).

To ensure that all areas of the good field would be mapped, the four probes were attached to a 1mm thick G10 panel, parallel to each other and separated by 22.2mm. The two Hall Probes were mounted on the outside of the panel, with the two NMR probes in the middle positions. This panel was then mounted to the cart, and moved to seven different transverse positions on the cart, one for each longitudinal measurement sequence. The seven positions (separated by 11.1mm) covered the good field region by collecting data at radii ranging from 93.3 cm to 106.7 cm. This in turn provided a method for verifying the Hall Probe calibration by overlapping a NMR probe path and a Hall Probe path along the same radial path.

3.2 Measurement Sequence

Figure 2 shows the beginning of the path that the longitudinal measurements take. The 1st measurement begins 30 centimeters perpendicular to the entrance point of the magnet. At this position the wheel is not moved, but rather the cart travels along a slot notched in the measurement wheel. The cart continues in a straight line until the entrance point is reached.

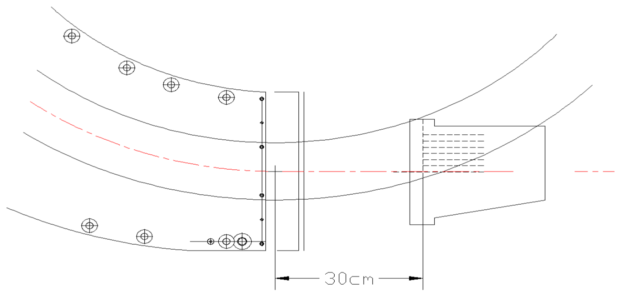

Figure 2: Plan View Cart and Pi-Bend Entrance

At the entrance point, the cart was locked to the wheel and then rotated through the magnet until the exit point was reached. At the exit, the cart was unlocked from the wheel and measurements were taken along a 30 centimetre line perpendicular to the exit. Figure 3 shows the cart entering the magnet. Seven runs were taken, moving the G10 sheet holding the probes to a new radial position on the cart. Probe readings were taken at each of the 361 positions along the path. Distances between measurements varied from 1 centimetre outside the magnets field, to 2 millimetres at the exit and entrances to the magnet, and 5 centimetres in the body of the magnet where the field was consistent.

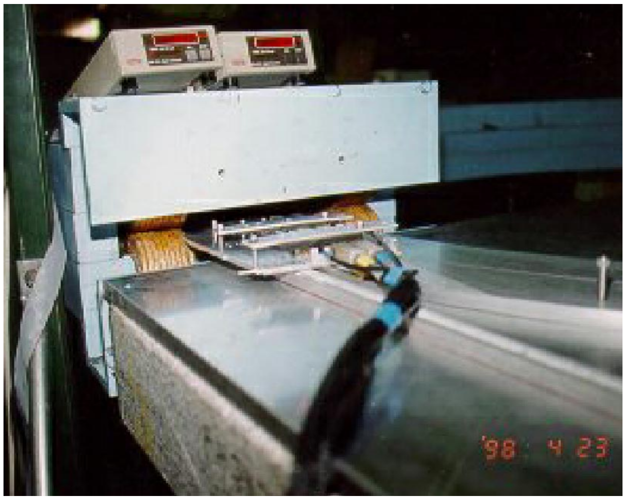

Figure 3: Cart Entering Pi-Bend Magnet

4 ANALYSIS

4.1 Probe Position Calibration

The longitudinal positions consisted of 2 straight line portions combined with a unique radial component for each of the seven positions. The wheel was checked dimensionally using a precise survey and then aligned to the magnet using tooling balls. A scale taped to the outside edge of the wheel and a pointer attached to the aluminium plate, determined wheel position along its path. Based on each of these positions, the precise location of the probes could be determined anywhere in the core.

4.2 Probe Calibration

Hall probes accuracy is dependant on the probe's perpendicularity to the field. To correct for this the hall probes were calibrated relative to the NMR probes. This was achieved by positioning the cart at the approximate magnet center and recording hall and NMR values at currents from 220 amps to 80 amps in 10 amp steps. This calibration was taken with the hall probes at the extreme outer positions and once when they straddled the center of the core.

4.3 Magnetic Data Calculation

Four measurement probes were read using the Jefferson Lab Stepper Stand Data Acquisition code developed using National Instruments Lab-Windows© software. The output files were then analyzed using Microsoft Excel©.

4.4 Results

Data for the 1st of the two pi-magnets was acquired and analyzed with little difficulty. There was some concern about the final effective length values (average deviation – 0.125%) and the end-field roll-off integral (K_1 deviation 13.80%), but proper accelerator setup rendered these values acceptable. Figure 4 displays the deviation of the field integral as a function of the radius of the core, while Figure 5 shows the longitudinal field uniformity for the 1st dipole.

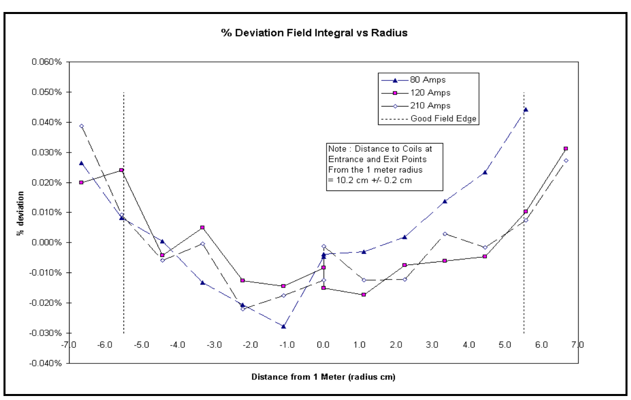

Figure 4: Deviation Field Integral vs Radius DY001

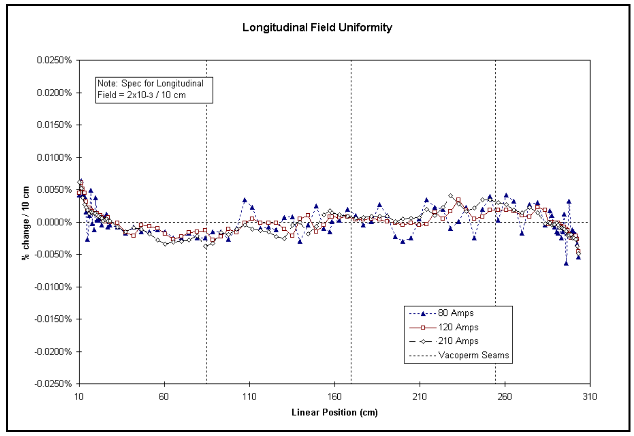

Figure 5: Longitudinal Field Uniformity DY001

The 2nd pi-magnet proved to be more cantankerous. As the data was being gathered and analyzed, problems became obvious. The calibration of the hall probes in the magnet center gave values that were similar to the first dipole, but once the longitudinal values were used as a check on this calibration, it appeared that there were large swings in the field strength, dependant upon location. As there were only 2 magnets in the sample, concerns arose as to the validity of the measurement method.

The magnet was disassembled to check for the source of the inconsistencies. The problem was traced to the installation of a brass layer between the poles and top layer of mumetal. The mumetal and brass layers had been added to the poles to improve field flatness[4]. These layers were reworked and the magnet reassembled. Measurements then continued and results similar to the first dipole were obtained.

5 CONCLUSIONS

The test stand design proved to be an efficient method to accurately map the pi-bend magnets. Results obtained by the mapping were used in conjunction with the optical steering of the beam to assist in the successful delivery of light at the IR-FEL facility.

REFERENCES

[1] F. Dylla and G. Neil, IR Demo Project Weekly Report for March 8-12,1999, Thomas Jefferson Accelerator Facility News Release, March 1999.

[2] D. R. Douglas, Lattice Design for a High-Power Infrared FEL, Proceeding of IEEE Particle Accelerator Conference, Vancouver, British Columbia, Canada, 1997.

[3] D. R. Douglas, Error Estimates for the IR FEL Transport System, Jefferson Lab Tech Note # 96-035, 1996.

[4] J. Karn, et al., Magnetic Measurement of the Prototype Dipole for the IR-FEL at the Thomas Jefferson National Accelerator Facility, Proceeding of IEEE Particle Accelerator Conference, Vancouver, British Columbia, Canada, 1997.