MAGNETIC FIELD MAPPING AND INTEGRAL TRANSFER FUNCTION MATCHING OF THE PROTOTYPE DIPOLES FOR THE NSLS-II AT BNL*

P. He, A. Jain, R. Gupta, J. Skaritka, C. Spataro, P. Joshi, G. Ganetis, M. Anerella, P. Wanderer, Brookhaven National Laboratory, Upton, NY 11973, U.S.A.

Abstract

The National Synchrotron Light Source-II (NSLS-II) storage ring at Brookhaven National Laboratory (BNL) will be equipped with 54 dipole magnets having a gap of 35 mm, and 6 dipoles having a gap of 90 mm. Each dipole has a field of 0.4 T and provides 6 degrees of bending for a 3 GeV electron beam. The large aperture magnets are necessary to allow the extraction of long-wavelength light from the dipole magnet to serve a growing number of users of low energy radiation. The dipoles must not only have good field homogeneity (0.015% over a 40 mm x 20 mm region), but the integral transfer functions and integral end harmonics of the two types of magnets must also be matched. The 35 mm aperture dipole has a novel design where the yoke ends are extended up to the outside dimension of the coil using magnetic steel nose pieces. This design increases the effective length of the dipole without increasing the physical length. These nose pieces can be tailored to adjust the integral transfer function as well as the homogeneity of the integrated field. One prototype of each dipole type has been fabricated to validate the designs and to study matching of the two dipoles. A Hall probe mapping system has been built with three Group 3 Hall probes mounted on a 2-D translation stage. The probes are arranged with one probe in the midplane of the magnet and the others vertically offset by ±10 mm. The field is mapped around a nominal 25 m radius beam trajectory. The results of measurements in the as-received magnets, and with modifications made to the nose pieces, are presented.

INTRODUCTION

The National Synchrotron Light Source-II (NSLS-II) under construction at Brookhaven National Laboratory (BNL) will be a new state-of-the-art 3 Gev electron storage ring designed to deliver world-leading intensity and brightness. It will have an energy resolution of 0.1MeV and spatial resolution of 1nm. The NSLS-II storage ring has a circumference of 792 meters. It will be equipped with 60 dipole magnets of which 54 dipoles have a gap of 35mm and 6 dipoles have a gap of 90mm. Each dipole has a field of 0.4 T and provides 6 degrees of bending for a 3 GeV low emittance electron beam. The large aperture dipoles are necessary to service the IR community, but the cost constraints required that the majority of dipoles have a much smaller aperture. Thus, NSLS-II is unique in having two different aperture dipoles[1]. The dipole specifications are shown in Table 1. The 35 mm aperture dipole has a novel design where the yoke ends are extended up to the outside dimension of the coil using magnetic steel nose pieces. This design increases the effective length of the dipole without increasing the physical length[2]. These nose pieces provide a means to improve end and integrated field quality, with chamfered sector ends to match the field integrals of the two types of magnets.

Table 1: NSLS-II Dipole Parameters

Parameter	Unit	A	B
Quantity required	Each	54	6
Aperture(min.)	mm	35	90
Operating DC field	T	0.4	0.4
Magnetic length	m	2.62	2.62
Radius of beam axis	m	25.02	25.02
Operating current	A	360	360
Operating voltage(max)	V	11	32
Field homogeneity, X=±20mm, Y=±10mm, in magnet body	%	<0.015	<0.015
Total integral field homogeneity X=±20mm x Y=±10mm	%	<0.05	<0.05
Turns per pole		16	42
Power	kW	4	11.5
Yoke length, nominal	m	2.584	2.584

DIPOLE PROTOTYPE MAGNET PROGRAM

To obtain the required field quality within programmatic constraints, a development program was implemented. Reference designs were developed and optimized while advanced manufacturing methods were demonstrated by industry. The contractors had freedom to improve on the reference design and investigate advanced yet cost-effective manufacturing methods. The 35 mm dipole prototype was made at Buckley, New Zealand (Figure.1) and 90 mm dipole prototype was made at Stangenes, USA (Figure 2). Both of them were measured using Hall probe mapping system at BNL. The results of measurements in the as-received magnets, and with modifications made to the nose pieces are presented in this paper.

EXPERIMENTAL SYSTEM AND PROCEDURES

The field mappings have been performed using Hall probe mapping system. This system has been built with three Group 3 Hall probes [3] mounted on a 2-D translation stage. The probes are arranged with one probe

*Work supported by US DOE Contract #DE-AC02-98CH10886
#phe@bnl.gov

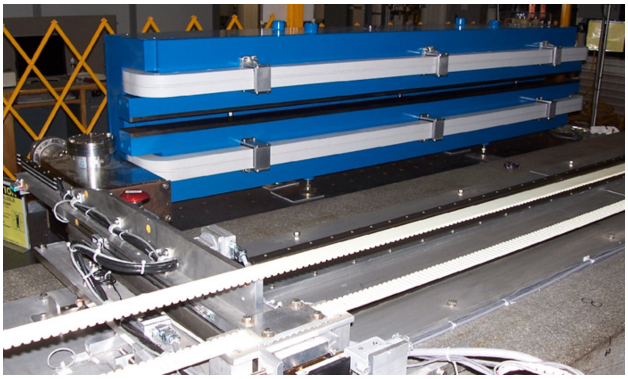

Figure 1: 35mm dipole prototype (Buckley).

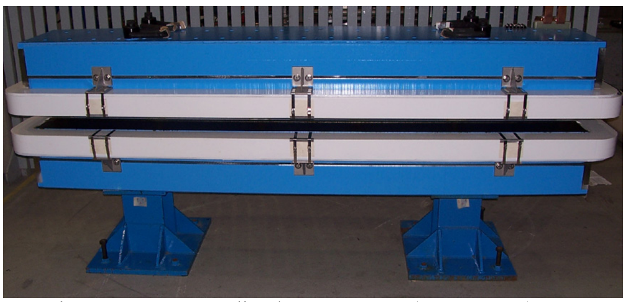

Figure 2: 90mm dipole prototype (Stangenes).

in the midplane of the magnet and the others vertically offset by ±10 mm (Figure 3). The 2-axis stage provides 4.28m axial motion using a belt drive and 0.33m of transverse motion using a screw drive. To align the Hall probes, a Faro laser tracker and 4 ft Faro CMM arm[4] was used, the Hall probes were run in both (X, Z) axis and tracked with the tracker and used as the working frame. Then the arm was brought into the job and used to find the center of the middle probe to establish the height center line. The dipole was placed onto the granite block and the center line of the upper and lower poles was set to the center line of the middle probe. Using the X&Z adjustment screws on the jack under the granite block, the X axis was set to be parallel to the track of the probe using the tracker and the outer corners of the dipole end poles. The field is mapped along a nominal 25 m radius

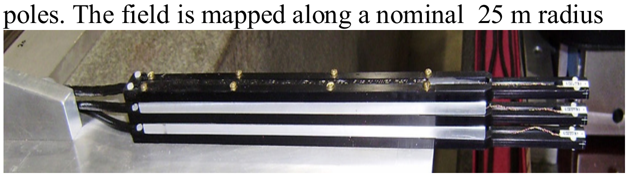

Figure 3: Three Hall probes_MPT-141.

beam trajectory (Figure 4). At a given longitudinal position, the Hall probes scan ±30 mm transversely. Linear encoders are used to obtain precise axial and transverse positions of the probe, and for the position feedback. Each probe was calibrated in the dipole field against NMR. A NMR probe will be added to the system for in-situ calibration checks of the Hall probes and to get more accurate absolute values of the integral transfer function. To obtain reproducibility of the hysteresis, the magnets were ramped to 380A and down to 0A three times and then ramped to 360A (3GeV); measurements were then made at this current.

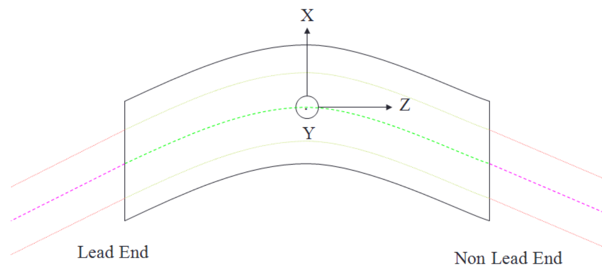

Figure 4. Curved C-dipole and particle trajectory

RESULTS AND DISCUSSION

Matching the field between the two kinds of dipoles (35mm and 90mm gap) includes matching of magnetic length, integral field and harmonic components. The "extended pole" design of 35mm dipole has the convenient adjustable nose feature. Geometric shaping of the nose piece along the beam axis can be used to adjust the field fall-off to obtain a better match between the end profiles of 35mm and 90mm aperture dipoles.

The first set of measurement was taken on the 90mm dipole prototype. The axial field profile is shown in Fig.5. The magnetic length and integral field of 90mm dipole are 2.6214m and 1.049T·m respectively. The field uniformity is shown in Figure 6. The normal multipoles are derived from a polynomial fit. In the as-built 35mm

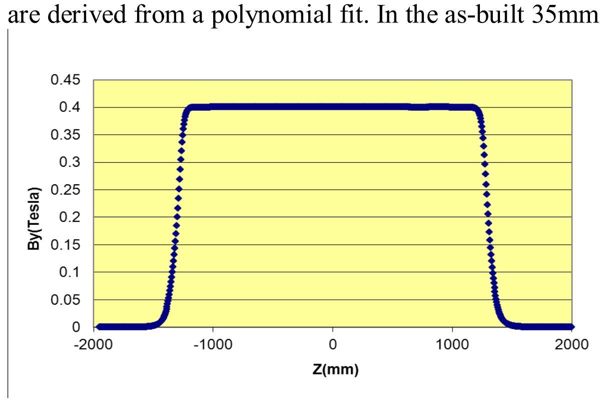

Figure 5: 90mm dipole axial field profile at 0.4 tesla.

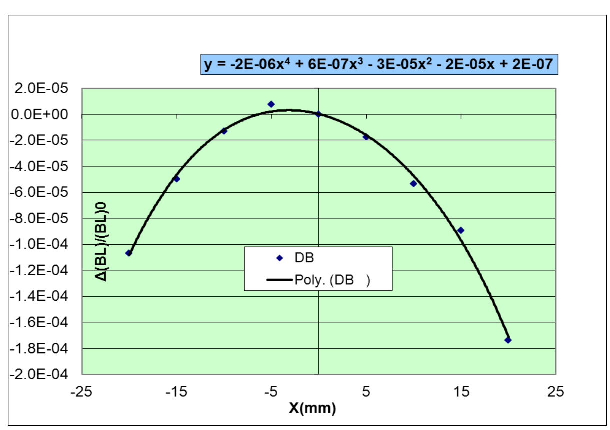

Figure 6: Field uniformity in 90mm dipole prototype.

dipole prototype, the results did not meet the specification and did not match the 90mm dipole. By chamfering the end nose piece of the 35mm dipole, we tried to match the field integrals and harmonic components of the two magnets. The transverse chamfer on the nose is used to match the sextupole component of the 90mm dipole. A typical value of the chamfer is 5~10mm. The angle of the chamfer is used to match the quadrupole term. The angle ranges from 1 to 3 degrees. We also compared two types of nose pieces: LNP-Laminated Nose Piece and SNP-Solid Nose Piece. The results (Figure 7) show that with SNP we gain about 0.5% in magnetic length.

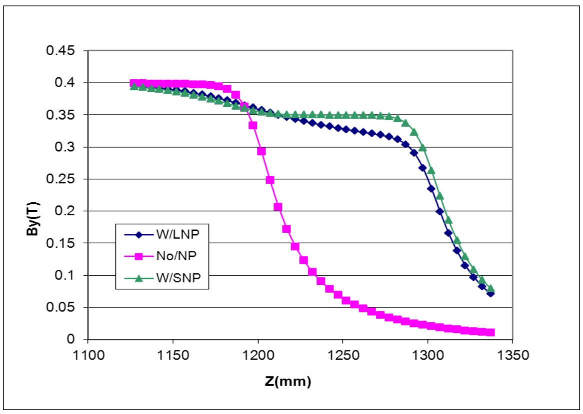

Figure 7: 35mm dipole end field profiles with LNP & SNP.

After chamfer of the SNP (Figure 8), the magnetic length and integral field are 2.585m and 1.046T·m respectively. The 35mm dipole field uniformity and harmonic components derived from a polynomial fit before and after chamfer are shown in Figures 9 and 10. Integral field measurements of the 90mm dipole prototype and 35mm dipole prototype (before and after chamfer) are listed in Table 2.

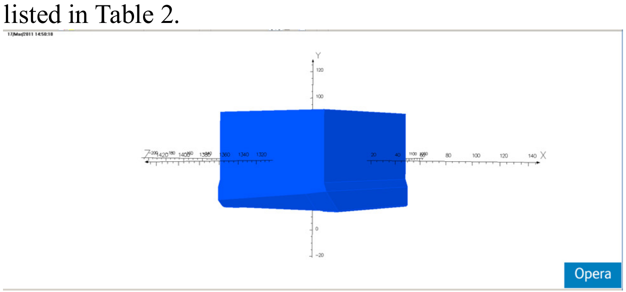

Figure 8: Chamfered SNP.

CONCLUSIONS

The two NSLS-II ring dipole prototypes (35 mm and 90 mm gap) have been measured and found to meet the field quality tolerances. The novel extended pole design of 35 mm dipole provides the possibility of matching the field between the 90mm and 35mm dipoles. With chamfered the nose piece, the harmonic components of 35mm dipole can match the 90 mm dipole, but the magnetic length is shorter than 90mm dipole, so we may need to adjust the nose piece for better matching.

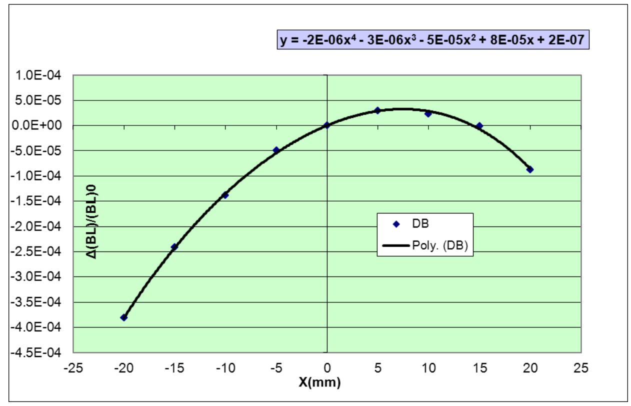

Figure 9. 35mm dipole field uniformity before SNP chamfer.

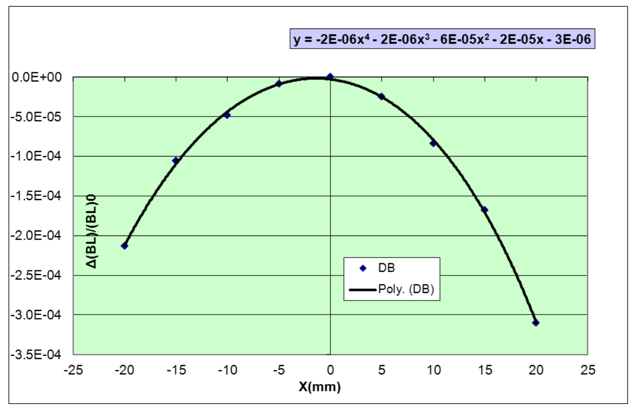

Figure 10: 35mm dipole field uniformity after SNP chamfer.

Table 2: Summary of Measurements of 90mm and 35mm Dipole Prototypes (Before and After Chamfer)

	90 mm Dipole	35 mm Dipole (B)	35 mm Dipole(A)
Integral Field(T·m)	1.049	1.048	1.046
Magnetic Length(m)	2.621	2.589	2.585
Quadrupole Component(%) at 1cm	0.002	0.008	0.002
Sextupole Component(%) at 1cm	0.003	0.005	0.006

(B)-before chamfer, (A)-after chamfer

ACKNOWLEDGEMENTS

The authors would like to thank S. Sharma and F. Willeke for their help and insight. We thank D. Sullivan for setting up and survey the measurement system.

REFERENCES

[1] J. Skaritka et al., MO6PFP008A, PAC'09.
[2] R. Gupta et al., TU1RAI01, PAC'09.
[3] Group 3 Technology Ltd, MPT-141spec.doc
[4] http://www.faro.com