MAGNETIC MEASUREMENT RESULTS OF THE NSLS-II BOOSTER DIPOLE MAGNETS*

S. Sinyatkin, G. Baranov, A. Batrakov, P. Burdin, D.Burenkov, S. Gurov, V. Kiselev, V. Kobets, E. Levichev, I. Okunev, A. Polyansky, Y. Pupkov, L. Serdakov, P. Vobly
BINP SB RAS, Novosibirsk, Russia

Abstract

Focusing and defocusing dipoles magnets of 3 GeV NSLS-II booster are designed, manufactured and tested at BINP, Russia. Magnetic measurements of 32 BD and 28 BF magnets are made by BINP. In this paper the results of magnetic measurements of dipole magnets in the field range 0.638 – 11.829 kGs for BD type and 0.260 - 4.829 kGs for BF type are presented. Analysis and comparison with magnetic field simulation are made.

INTRODUCTION

NSLS II - the synchrotron radiation source (SR) of the third generation is under construction in Brookhaven National Laboratory, USA [1,2]. The SR source includes the linear accelerator with energy up to 200 MeV, the booster synchrotron with energy up to 3 GeV and a 3 GeV storage ring.

Budker Institute of Nuclear Physics has carried out a full set of works on creation of the booster synchrotron for NSLS-II source. BD and BF dipole magnets were designed [3] and made at BINP. Basic parameters of the dipoles are given in Table 1.

Table 1: Dipoles Specification

Dipole parameters	BF	BD
Number	28	32
Effective magnetic length	1.24 m	1.30 m
Angle	3.2673°	8.3911°
Field injection	0.03068 T	0.07516 T
Field extraction	0.46021 T	1.12734 T
Quadrupole K1, extraction	0.82 m^{-2}	-0.55509 m^{-2}
Sextupole K2, extraction	3.6 m^{-3}	-4.3 m^{-3}
Good field region	±12 x ±20 mm	
Field quality in good integral field region, $\Delta B/B0$	$\pm 1\cdot10^{-3}$	

Magnetic measurements were carried out for quality test of the manufactured dipoles. BD and BF dipole magnets were measured with the Hall probes on the stand of magnetic measurements at BINP. The method of measurement is discussed in the article [4]. In this article the results of the magnetic measurements of dipole magnets are described. The alignment of the magnets in the booster ring is considered. The way of correction of integrated parameters of dipoles is presented.

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MAGNETIC MEASUREMENT

Two sets of special devices for BF and BD magnets were developed to test the quality of manufacture of the dipole magnets. Measurement of a magnetic field was carried out by means of the Hall probes. Two thermo stabilized carriages with 20 (BD) and 17 (BF) Hall probes were made. The carriage with the Hall probes moved with a 5 mm step in rectilinear guide by means of a stepper motor. The survey and alignment system was developed to connect a magnetic axis of dipoles with dipole fiducial marks precisely. The system consists of angular reflectors for laser tracker, laser tracker, fiducial marks on the dipole magnet and an additional network for alignment. Angular reflectors are located on the carriage with the Hall probes. Coordinates of probes are measured better than ±20 µm with respect to reflectors position. Five fiducials located on the dipole magnet provide connection between the geometrical axis of dipole and a position in the booster ring. Connection of position of angular reflectors and the fiducial marks located on basic surfaces of magnet is carried out by means of the laser tracker and an additional network of fiducial marks. Tolerance of position definition of the carriage with the Hall probes should be better than ±75 µm. The fiducial system allows measuring the position of the Hall probes at every step of the stepper motor. At processing of the magnetic measurements, the corrections of probes position with respect to a geometrical axis of dipole were made. It provides connection between the map of magnetic fields and the geometrical axis of the dipole.

Tracking of the particles was carried out using the corrected map of the magnetic field. Parameters of elements were determined taking into account the particle tracking. The alignment of dipoles was performed on the basis of the analysis of magnetic parameters. Correction of position was carried out at significant deviations of the integrated characteristics of the magnets.

MAGNETIC MEASUREMENT RESULTS

The measurements were performed by means of the WinHall code developed at BINP [1]. Magnetic measurements were carried out for 11 current levels of the prototype magnets and for 6 levels of serial samples. The factor of the field changes is 15. Integrated distribution of fields for one of a serial BF (a) and BD (b) magnets for various levels of fields is shown in Figure 1. Optimization of a pole profile and end chamfer was carried out for a

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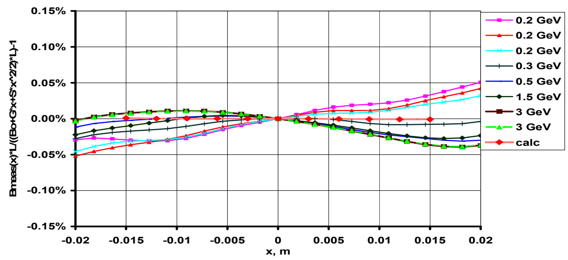
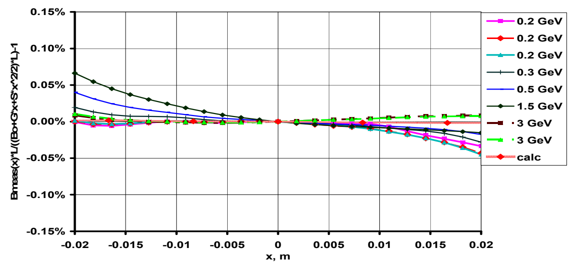
3-GeV energy [3]. Due to difference of nonlinear properties of steel used at modeling and due to the residual fields, the measured data have small deviation from the calculated curve (calc) corresponding to a 3-GeV energy.



a)



b)

Figure 1: Integrated field distribution of BF (a) and BD (b) magnets vs. levels of the ring energy; “calc” curve – computation curve for 3 GeV.

For booster performance the optimal cycle of demagnetization was determined. The original mode of the booster operation included change of currents from the values corresponding to the injection energy up to the fields corresponding to the extraction (Fig. 2, " old cycle " curves). For this mode, a strong nonlinearity of the dipole parameters in the area of small fields is observed (Fig. 2,3,4). The value of residual fields in the centre of dipoles was 18 Gs for BF and 26 Gs for BD. The new cycle of demagnetization includes the decrease of the current in the elements down to a zero value. In case of a 2-Hz mode operation of the booster, the additional correction of ramp is necessary. For a new mode of operation the maximal nonlinearity of magnetic field integral from the current is 1.8 % for BF magnets and 0.7 % for BD.

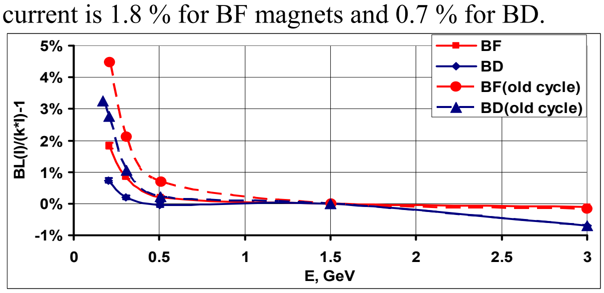


Figure 2: Nonlinearity of magnetic field integral of BF and BD dipoles vs. the booster energy.

In comparison with an “old cycle” of demagnetization the new cycle creates a smaller nonlinearity of a gradient and sextupole component of the field in the area of small fields (see Fig. 3,4). For BF dipoles the mistake of integrated parameters due to residual fields makes: for a gradient - 0.4 %, for sextupole component of the field - 3.3 %. In case of BD magnet dK1/K1 = 0.6 % and dK2/K2 = 5.1 % for quadrupole and sextupole components of the field, respectively.

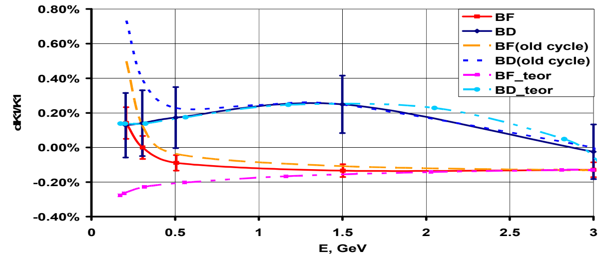


Figure 3: A deviation of a gradient of the field integral from nominal parameter of BD and BF magnets; "Old cycle" – curves of an original cycle; "teor" - a curve of modeling.

Change of a gradient of the field integral from the energy of the booster ring is presented in Fig. 3. Theoretical dependences of the integrated gradient of the field (see "teor" - Fig. 3) is in a good agreement with the measured data corresponding to the new cycle of the elements demagnetization. The estimation of the relative RMS measurement accuracy of integral of the gradient at a 3-GeV energy is $\pm 7\cdot 10^{-5}$ for BF magnet, $\pm 5\cdot 10^{-5}$ for BD magnet. The relative accuracy of measurement of the gradient for the injection energy is 15 times worse. The relative accuracy of reproduction of the gradient integral determined by the quality of dipole manufacturing is $\pm 4\cdot 10^{-4}$ for BF magnet, $\pm 1.6\cdot 10^{-3}$ for BD magnet.

Change of the integral of sextupole component of the field is shown in Fig. 4. Calculated dependences of sextupole component of the field is in a good agreement with the measurements at a large value of the field. In the area of a small field the deviation of the sextupole component of the field is determined by the residual field.

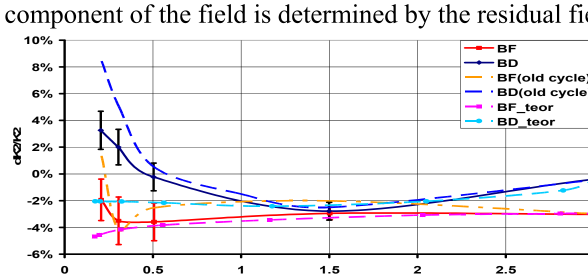


Figure 4: A deviation of sextupole components of the integrated field from the nominal parameter of BD and BF magnets; " Old cycle " - curves of an original cycle; "teor" - a curve of modeling.

The relative RMS measurement accuracy of the integral of sextupole component at a 3-GeV energy is $\pm 8\cdot 10^{-4}$ for BF, $\pm 6\cdot 10^{-4}$ for BD. Mistake of the integral of the sextupole component due to the manufacture accuracy is $\pm 4\cdot 10^{-3}$ for BF, $\pm 5\cdot 10^{-3}$ for BD.

The deviation of magnetic effective length for various levels of the ring energy is shown in Fig. 5. Change of the effective magnetic length is insignificant. The greatest deviation for the dipole BD due to iron saturation is $4\cdot 10^{4}$.

Relative accuracy of manufacturing of the longitudinal dimension are $\pm 2\cdot 10^{-4}$ for BF magnet and $\pm 1\cdot 10^{-4}$ for BD.

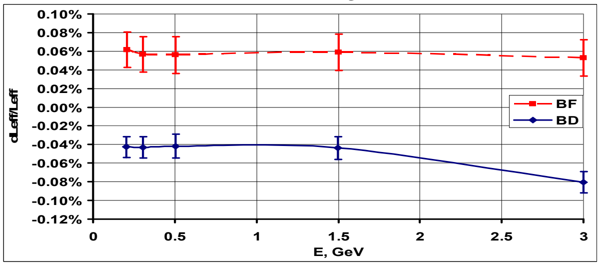


Figure 5: Change of effective magnetic length vs. energy of the booster ring.

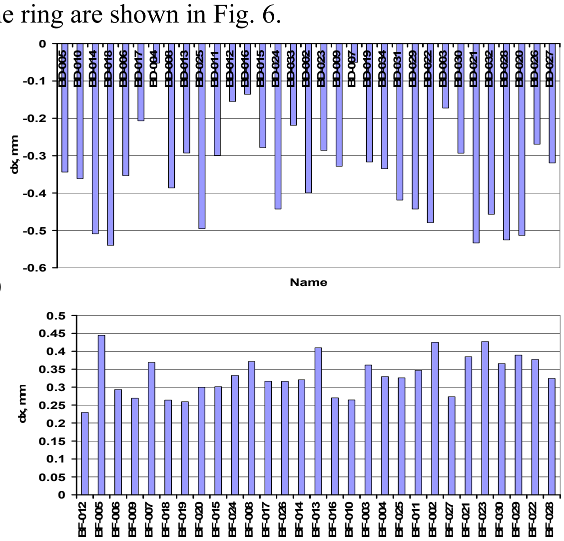
ALIGNMENT OF DIPOLES

Due to the combined magnetic properties of the dipole magnets, the exact alignment of the dipoles in the booster ring is necessary. The fiducial system was developed to connect the magnetic axis of dipoles with the dipole fiducial marks. The alignment of dipoles was carried out taking into account the results of magnetic measurements at the nominal fields corresponding to the extraction energy. Transverse position is determined by a condition of the required integral of the magnetic field on equilibrium orbit (1):

$$dB\cdot L=(G\cdot dx+S\cdot dx^2/2)\cdot L$$
$$dx=-(G-\sqrt{G^2+2\cdot S\cdot dB})/S\approx dB\cdot L/(G\cdot L) \quad (1)$$

Here $dB\cdot L$ - a deviation of integral of the magnetic field from the required value; dx - necessary correction of the dipole position in a transverse direction for an alignment in the ring. Final corrections of the dipole alignment in the ring are shown in Fig. 6.

a)



b)

Figure 6: Alignment correction of BD (a) and BF (b) dipoles in the ring.

CORRECTION OF PARAMETERS

High quality of the field integral and gradient is required taking into account the analysis of optic sensitivity to the mistakes of elements. The integral of the field is corrected by an alignment of the dipoles in the booster ring. To correct integral of the field gradient, two parameters were used: change of gap between the poles of the dipole and correction of alignment in the ring. The design of the dipole provides change of the gap between the poles via change of the thickness of kapton tape located between the top and bottom parts of the dipole. Initial thickness of the tape is 50 μm. The change of the gap between the poles and alignment of the dipole are determined by the condition of a constancy of the field integral on an equilibrium orbit and the required correction *dG* of the integral of the field gradient.

Field dependence on change of the gap, mistake of the field, gradient of the field and transfer displacement looks like (2). Expressions for correction of the gap between the poles and alignment of the dipole are (3):

$$B_y(x)=Bo\cdot(1+dh/h)+dB+$$
$$+\left(Go\cdot(1+dh/h)+dG\right)\cdot(x+dx)+\frac{So}{2}\cdot(x+dx)^2 \quad (2)$$

$$dx\approx\left(Bo\cdot dG-Go\cdot dB\right)/\left(Go^2-Bo\cdot S\right)$$
$$dh/h\approx\left(Go\cdot dG-So\cdot dB\right)/\left(Go^2-Bo\cdot S\right) \quad (3)$$

At possible mistakes in the field dB/B = $-3\cdot 10^{-3}$ and dG/G = $-1.5\cdot 10^{-3}$ corrections of dh/h gap are: - 30 μm - for BF magnet, +60 μm - for BD dipole. Correction of an alignment dx: + 110 μm for BF dipole; -120 μm for BD dipole. At manufacturing of the serial dipoles correction was made for 6 BD magnets and 2 BF magnets.

CONCLUSION

Parameters of the serial magnets manufactured at BINP meet the requirements of the field quality. To increase the accuracy of dipoles alignment in the ring the fiducial system was developed. Numerous magnetic measurements of dipoles have shown high accuracy of connection between the magnetic axis and the fiducial marks of the magnets.

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