RAMPED MAGNETIC MEASUREMENT OF NSLS-II BOOSTER DIPOLES

I. Okunev, V. Kobets, A. M. Batrakov, A. Pavlenko, S. Sinyatkin, V.A. Kiselev,
G. Baranov, A. Erokhin, R. Vakhrushev, BINP SB RAS, Novosibirsk, Russia

Abstract

The magnetic system of NSLS II Booster is designed, manufactured and tested in BINP, Russia. The dipoles of the Booster have quadrupole and sextupole components and should create high quality of field of ± $2\cdot10^{-4}$ in region of ± 2 cm. The magnets should provide performance of the booster for energy from 170 MeV to 3.15 GeV with a 2 Hz frequency. This report considers ramping magnetic measurements of NSLS-II Booster Dipoles.

INTRODUCTION

The NSLS II is a third generation light source under construction at Brookhaven National Laboratory. The project includes a highly optimized 3 GeV electron storage ring, linac pre-injector and full-energy booster-synchrotron. Budker Institute of Nuclear Physics builds booster for NSLS-II. The booster should accelerate the electron beam continuously and reliably from minimal 170 MeV injection energy to maximal energy of 3.15 GeV and average beam current of 20 mA. The booster shall be capable of multi-bunch and single bunch operation.

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°
Vertical gap	±14 mm	±13 mm
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 field region, ΔB/B0	± $1\cdot10^{-3}$	

Booster operates at a frequency of 1 or 2 Hz. Parameters of the booster dipole magnets are shown in Table 1.

To create magnetic measurement stand (MMS) which allows to fully replace the measurement in the DC case and to ensure the accuracy required by the specifications is difficult and very expensive. Therefore, in addition to the MMS based on Hall sensor was fabricated rather "simple" stand allows to asses influence of vacuum chamber on dipole multipole components.

DESCRIPTION OF THE STAND

This stand was designed for the following requirements:

- sensitivity of the system should allows to measure multipole components for the first 50 ms of acceleration cycle,
- measurements must be performed outside and inside a vacuum chamber,
- measured area mast be more then ± 2cm,

Measuring sensor is a 5 coils located on the basis made from fiberglass. The distance between the centers of the coils 7 mm, coil width 4 mm length of the coil 1600 mm (see Figure 1, 2). In addition to all 5 coils special calibration bypass coil is installed. For measurements was used power supply, developed in BINP, with the characteristics similar to NSLS II booster dipole magnets power supply designed by DANFYSIK.

To assess the level of the signal induced in the coil we used the following approach:

- magnetic field consist of dipole, quadrupole and sextupole component.
- coil have 14 tunes, height is 2 mm
- effective magnetic length is 1300mm
- width of measuring coil is Δx = 4 mm.

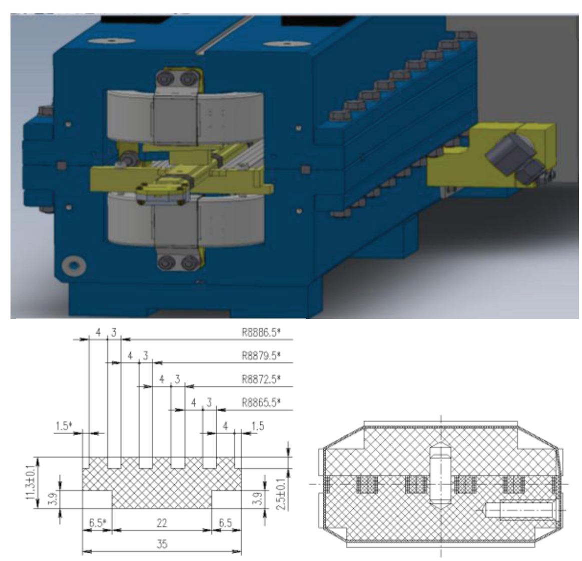

Figure 1: Booster dipole magnet with installed coils and cross section of the coils mandrel.

Then the EMF induced in the coil is determined by the formula:

$$\varepsilon(t,r) = \frac{d\Phi(t,r)}{dt},$$

were Φ(t,r) - the magnetic flux induced in the coil.

$$\Phi(t,r) = NLB\rho(t)\left(\frac{\Delta x}{\rho} + \frac{K_2 \Delta x^3}{24} + K_1 \Delta x r + \frac{K_2 \Delta x}{2} \cdot r^2\right)$$

Were N - the number of turns, L – length of the coils, Δx - coil width, ρ - the radius of the magnet, r - distance to the central coil, K_1 - quadrupole component, K_2 - sextupole component, Bρ(t) - the magnetic rigidity.

$B\rho(t) = \rho \cdot B_{ex} \cdot \sin(\omega t)$, where B_{ex} - field on the extraction, the calculated signals induced in the coil are in Table 2.

Table 2: Estimations of EMF Signals and Tolerances for Signal Measurement

r, cm	dU_G, μV	V_G, μV·s	dU_S, μV	V_S, nV·s
0	0	0	0	0
0.7	12.6	0.32	10.71	0.27
1.4	25.2	0.65	42.83	1.07
2.1	37.9	0.97	96.38	2.47

dU_G and dU_S – estimated influence of vacuum chamber on the the quadrupole and sextupole component of dipole, signal [V].

V_G and V_S - estimated change of the signal in V·s of the quadrupole and sextupole components under the influence of the vacuum chamber.

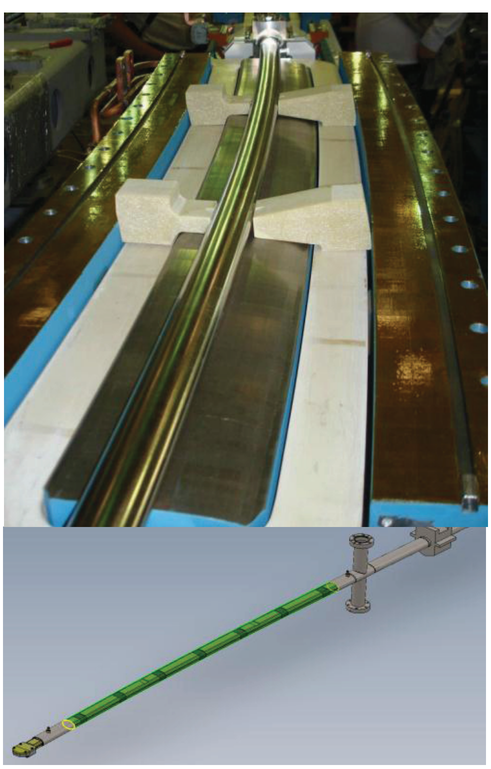

Figure 2: Half of the booster dipole magnet with installed vacuum chamber and vacuum chamber with installed mandrel.

To provide these measurements new type of the integrators with rigid triggering has been developed in Budker INP (Russia) [1]. These devices are based on the digital integration method which is providing high accuracy for integration of pulses even shorter than ADC sample interval.

Integrator VsDC2 is a 3U and 4HP Eurocard module equipped with two identical channels and CAN bus communication interface.

The set of four VsDCs is used in measurements of these dipole magnets. Parameters of the integrators are shown in Table 3.

Table 3: Parameters of the Integrators

	VsDC2 (CAN version)
# Chanles	2
Input ranges	±0.2V; ±0.5V; ±1V; ±2V; ±5V; ±10V
SNR at 1 ms at 1 s	10^{-6} $5\cdot10^{-7}$
Absolute error > 1 ms	$\sim10^{-5}$
Non-linearity	±20 ppm max
Gain error	±5 ppm max
Offset error	±0.5 ppm max
From factor	3U 4HP Eurocard

For the calibration of the coils between themselves used the following procedure:

Basis with coils without vacuum chamber are placed in the central position using special stand see Figure 1. Measurements of the magnetic field were carrying out using the 1 Hz ramp regime. Next basis with coils moved at a distance of 7 mm, at 2 steps, to the right and to the left from the center position making measurements of the magnetic field. Thus, each coil is set on the place of the other four. It is possible to make additional measurements to improve the accuracy of measurements, but one steel have some limitations due to height of the pole (14 cm) and coil cross section (Δx = 4mm).

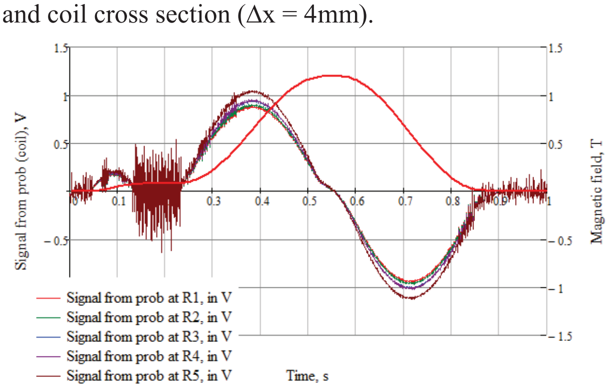

Figure 3: Signals in volts from the measuring coils and magnetic field in T.

ISBN 978-3-95450-122-9

This allows for each coil (including total coil) to measure the integrals of the magnetic field in five points and calculate the components of the field for each coil. Comparing all coils with for example central one it is possible to compare and calibrate each coil.

MAGNETIC MEASUREMENTS RESULTS

Signal from digital oscillograph made from VsDC2 shown on Figure 3. One can see that signal from coils has a big noise at the injection energy. This noise is connected with peculiarity of power supply (but it still meets the specifications), as well as the fact that the measured signal is the derivative of magnetic field (current).

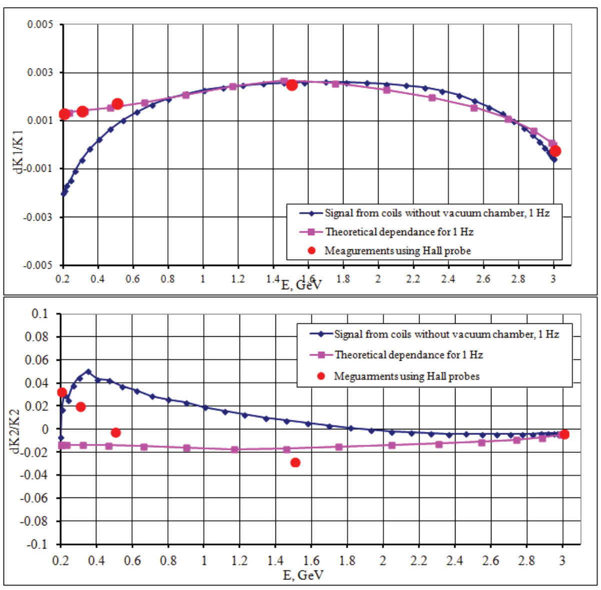

Figure 4: The results of magnetic measurements for BD magnet for the quadrupole and sextupole field components without a vacuum chamber.

Our attempts to correct the situation led to nothing, so we had to recruit more statistics and averaged the results. Figure 4 shows the results of the magnetic measurements without vacuum chamber compared with theoretical dependence and Hall probe measurements [3].

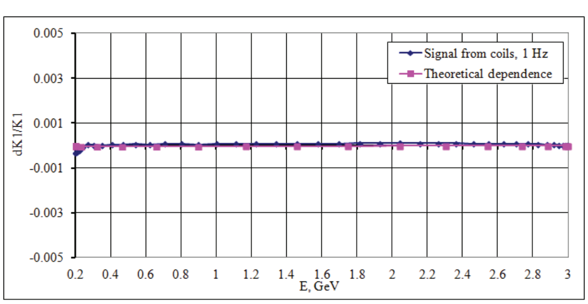

Figure 5: Influence of vacuum chamber on quadrupole component of the BD dipole.

Also were made experiments with vacuum chamber (see Figures 5,6). Figures show influence of the vacuum chamber on the dipole multipoles in the range of tolerances 5×10^{-3} for quadrupole and 5×10^{-2} for sextupole component.

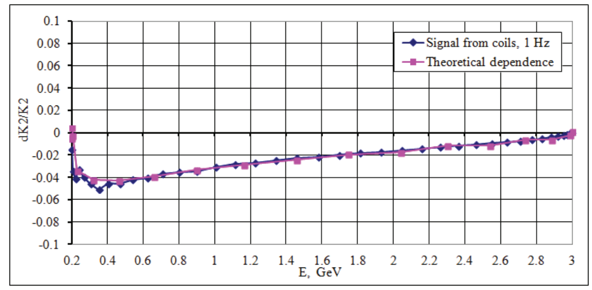

Figure 6: Influence of vacuum chamber on sexstupole component.

Currents on vacuum chamber were measured with help of proximity sensor for BF and BD magnets

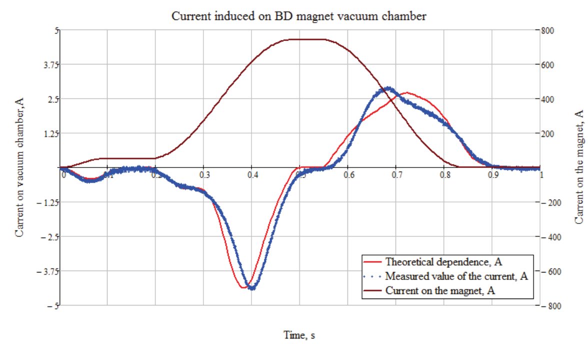

Figure 7: Current induced on BD magnet vacuum chamber.

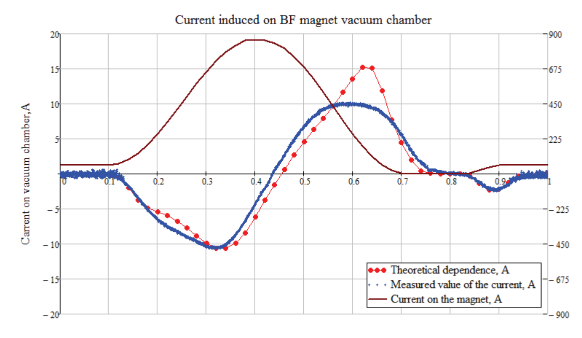

Figure 8: Current induced on BF magnet vacuum chamber.

REFERENCES

[1] A. Batrakov, A. Pavlenko, I.Ilyin, "Electronics for Precise Measurements of Accelerator Pulsed Magnets", THPEA033.

[2] A.Zhuravlev et al., "Pulsed Magnets for Injection and Extraction Sections of NSLS-II 3 GeV Booster", THPME033.

[3] S. Sinyatkin, et al., "Magnetic Measurement Results of NSLS-II Booster Dipole Magnets", THPME030.