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FIRST SERIAL MAGNETIC MEASUREMENTS of the NICA COLLIDER TWIN-APERTURE DIPOLES

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Abstract

NICA is a new accelerator complex under construction at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, to study properties of hot and dense baryonic matter. Magnetic system of the NICA collider includes 80 twin-aperture dipole and 86 quadrupole superconducting magnets. The collider twin-aperture magnet is 1.94 m long, 120 mm/70 mm (h/v) aperture with window-frame design similar to the Nuclotron magnet. The measurement of the magnetic field parameters is supported to be conducted for both apertures of each collider magnet. This paper describes magnetic measurements methods and the development of the dedicated system for serial dipole magnets of the NICA collider.

INTRODUCTION

The NICA (Nuclotron-based Ion Collider fAcility) [1] accelerator complex will consist of two injector chains, the 600 MeV/u superconducting (SC) booster synchrotron, the existing SC synchrotron (Nuclotron), and the new SC collider that has two storage rings each with the circumference of about 503 m. The storage ring includes two arcs, two straight sections, and two interaction points. The main elements of the NICA collider magnetic system are 80 twin-aperture dipole and 86 quadrupole SC magnets. The Superconducting Magnets and Technologies (SCM&T) Department and special technical complex [2] for assembly and testing of SC magnets for the NICA and FAIR projects were established at the Veksler and Baldin Laboratory of High Energy Physics (VBLHEP) JINR. At the moment, pre-series dipole magnet has been manufactured and fully tested. The serial yokes are made in proceeding. The design and main characteristics of the magnets for the NICA collider are given in [3, 4]. The collider magnets operating modes are the constant fields of 0.4, 1.2 and 1.8 T, which corresponds with energies 1.0, 3.0, and 4.5 GeV/u. According to specification, the following parameters of collider dipole magnets have to be measured:

- main field component;
- effective magnetic length and relative standard deviation

$$L_{\mathrm{eff}} = \frac{\int_{-\infty}^{\infty} B_y ds}{B_y(0)};\ \delta L_{\mathrm{eff}} = \frac{\Delta L_{\mathrm{eff}}}{< L_{\mathrm{eff}} >};$$

- magnetic field direction (dipole angle), angle between the magnetic and mechanical median plane:

$$\alpha_1 = -arctg\left(\frac{A_1^*}{B_1^*}\right),$$

$*$ – integrated harmonics;

- relative integrated harmonics up to the 5th.

PROCEDURE OF MAGNETIC MEASUREMENTS

The magnetic measurements (MM) procedure is based on the rotating coils method [5]. The magnetic measurement system (MMS) (see. Fig. 1) consists of three identical sections that are mounted on the lodgment which is installed inside the measuring shaft (4). Each section is resembled by sets of three measuring coils made as printed-circuit board (PCB). Each coil is formed by 20 layers of the PCB - each layer contains 20 turns, in total – 400 turns.

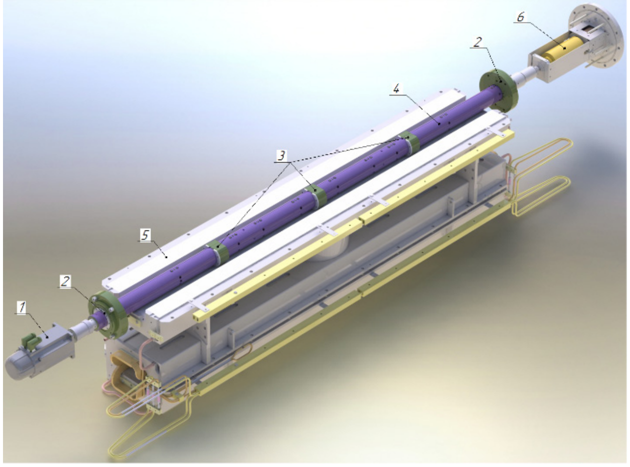

Figure 1: 3D model of an equipment for MM: 1. Servomotor, 2 Outer bearings, 3. Inner bearings, 4. Measuring shaft, 5. Yoke, 6. Slip rings and angle encoder.

MM are carried out at the environment temperature with the operating current of 100 A ("warm" measurements) and at the temperature of 4.5 K with the maximum operating current of 10.8 kA ("cold" measurements). The step-by-step method of measurement with fast ramped magnetic field with 0.9 T/s (RC mode) and the constant velocity rotating method with the constant magnetic field (DC mode) were used. At least one full revolution has to be conducted for a full cycle. Both types of MM have been performed using the same MMS. The detailed description of the MMS and methods was performed in paper [6].

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FIRST RESULTS

The pre-series dipole magnet passed all the tests, including "warm" and "cold" MM in the RC and DC modes. The results for up (blue) and bottom (red) apertures are shown in Fig. 2-8 and in Table 1. As it could be seen in Fig. 2, the saturation of iron yoke is began on the operating current 9 kA.

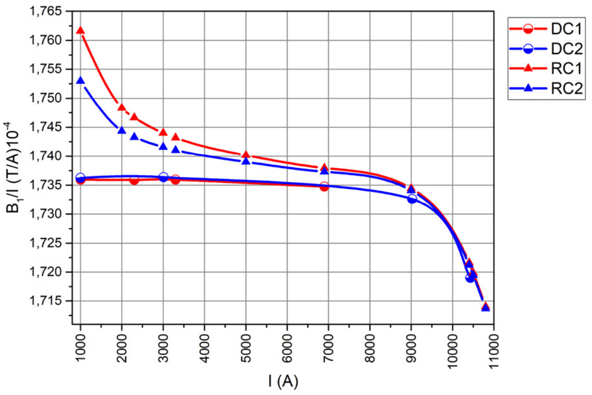

Figure 2: The functional dependence of the main field on the operating currents.

Dipole Angle

The special reference magnetic field created by the additional point is like windings so, the fact that it is parallel to the surface of poles was used to create a reference point for field direction measurements [5, 6]. Phases of the main harmonics of the reference field were measured and used as initial angles of coils rotation. High accuracy and the resolution of the servomotor are used to reproduce initial angles with the required accuracy.

The technique for DC mode was not fully debugged. This explains the large deviation between DC and RC modes (see Table 1).

Effective Length

The relative variations of dipoles effective length is approximately equal to the effective length that was calculated as [7, 8]:

$$L_{\text{eff}} = \frac{1}{B_1(0)}\left[\sum_{i=1}^{3} B_{1,i}\cdot s_i\right],$$

where i – section number; $B_{1,i}$ – main field harmonic is measured by i section; s_i – part of integration path going through i section; $B_1(0) = B_{1,2}$. Sections 1 and 3 are covered by the fringe field regions $s_1 = s_3 = l_{coil}$. Section 2 is covered by the central field region and part of integration path (s_2) included gaps between coils 1 and 3. Values of effective lengths for the bottom and up apertures are shown in Fig. 3 as a function of the magnet excitation.

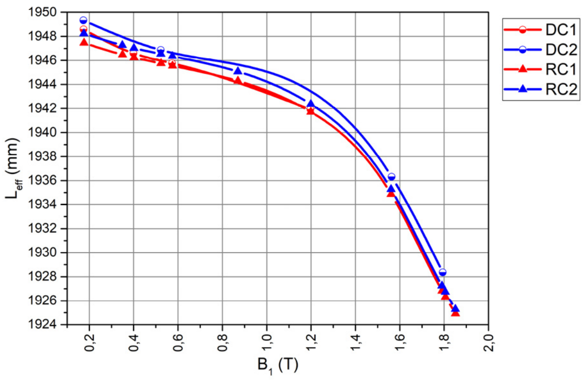

Figure 3: Mean value of the effective length vs. the magnetic field in centre.

Multipole Errors

The analog compensation for harmonics measurements was used. As it could be seen in Fig. 4, sensitivity up to the 10th harmonic (amplitude (d_n), normal (b_n) and skew (a_n) components) [6] has been provided by the MMS.

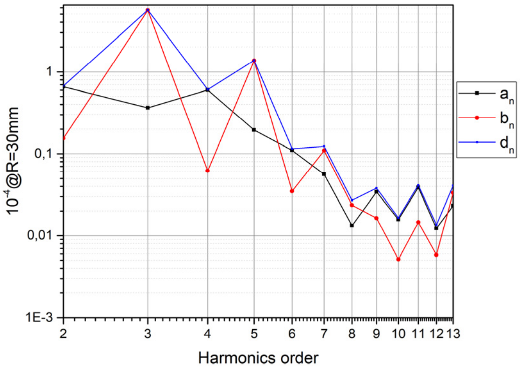

Figure 4: Sensitivity for harmonics of the MMS.

The collider dipole, as well as in magnets of this type in the Nuclotron and the Booster [6], was obtained the value of b_3=8-10*10^{-4} (Fig. 5) that significantly affects the dynamics of the beam in the storage rings.

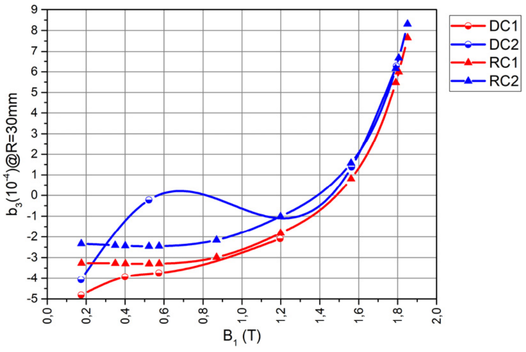

Figure 5: The value of b_3 vs. the magnetic field in centre.

Table 1: The First Results of the "Cold" Measurements

I [A]	Measurement type	B_1 [T]	L_{eff} [mm]	α_1 [mrad]	Relative harmonics, 10^{-4}						
					b_2	b_3	b_4	b_5	a_2	a_3	a_4
2300	RC1 (bottom)	0.40173	1946.24	-1.65	-1.1	-3.3	-0.2	-0.6	0.2	-1.0	0.0
	DC1 (bottom)	0.39954	1946.59	-2.06	-1.1	-3.9	-0.2	-0.6	0.3	-1.1	0.0
	RC2 (up)	0.40096	1947.03	-0.67	0.1	-2.4	-0.3	-0.5	0.4	0.2	0.0
	DC2 (up)	—	—	—	—	—	—	—	—	—	—
6900	RC1 (bottom)	1.19919	1941.71	-1.35	-1.0	-1.8	-0.1	-0.2	0.3	-0.9	0.1
	DC1 (bottom)	1.19681	1941.92	-1.94	-1.0	-2.1	-0.1	-0.2	0.4	-1.0	0.0
	RC2 (up)	1.19874	1942.35	-0.67	0.1	-2.4	-0.3	-0.1	0.4	0.2	0.0
	DC2 (up)	—	—	—	—	—	—	—	—	—	—
10400	RC1 (bottom)	1.79046	1926.83	-1.10	-1.1	5.5	-0.1	1.4	-0.5	-0.9	-0.5
	DC1 (bottom)	—	—	—	—	—	—	—	—	—	—
	RC2 (up)	1.79006	1927.25	-0.55	0.1	6.2	-0.2	1.5	0.7	0.2	0.1
	DC2 (up)	1.79349	1928.35	5.35	0.0	6.3	-0.2	1.5	0.7	0.1	0.1

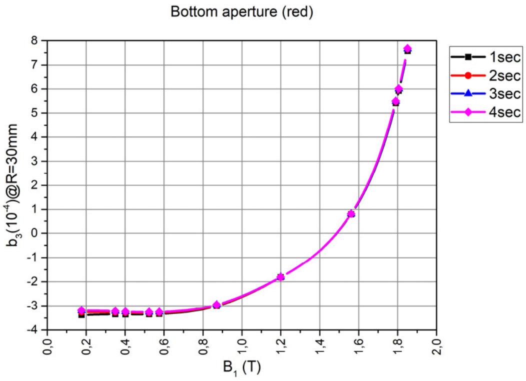

Figure 6: The functional dependence of b_3 from different ramp rates of operating currents (bottom aperture).

In addition, as it is shown in Fig. 6 the value of b_3 does not depend on the ramp rate of the operating current (10.8 kA per 1, 2, 3 and 4 seconds).

Figure 7 shows that the value of b_5 also as b_3 had obtained a functional dependences on the main field in center. Other harmonics had not obtained functional dependences (average values are shown in Fig. 8).

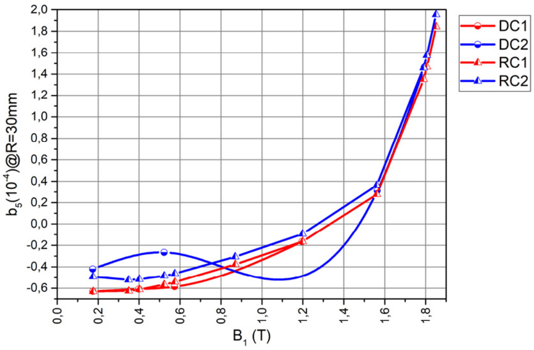

Figure 7: The value of b_5 vs. the magnetic field in centre.

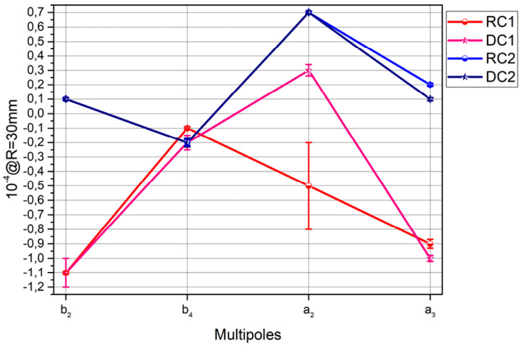

Figure 8: Multipole errors (values less 10^{-4} not shown).

As it could be seen, RC and DC modes show good correlation. Harmonics less 10^{-4} not presented.

CONCLUSION

At the moment the development of MMS and first MM of the collider dipole has been finished. The procedure of data analysis was completed for RC mode and not fully for DC mode (the accuracy of dipole angle measurement was not satisfactory). Following the measurements at DC mode, production of two serial MMS (for simultaneous measurement two apertures of magnet) and development of the MMS for NICA collider quadrupole magnets will be carried out.

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