THE PRESENT STATUS OF THE MAGNETIC MEASUREMENTS OF THE NICA COLLIDER TWIN-APERTURE DIPOLES

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Abstract

The lattice of the NICA collider includes 80 twin-aperture superconducting dipole magnets. Serial production and testing of these magnets have been started at the Veksler and Baldin Laboratory of High Energy Physics of the Joint Institute for Nuclear Research (VBLHEP JINR) in Dubna, Russia. The measurement of the magnetic field parameters is needed to be conducted for both apertures of each collider magnet at the ambient and LHe temperature. Pre-series magnet with two different configurations of coils was successfully tested. This paper describes the present status and results of dipole magnets magnetic measurements and comparison of the results with calculations.

INTRODUCTION

The lattice of the NICA collider includes 80 twin-aperture superconducting (SC) dipole and 86 quadrupole magnets [1]. The collider operating modes are energies of 1.0, 3.0, and 4.5 GeV/u, which correspond to the constant operating fields of dipole magnets 0.4, 1.2 and 1.8 T. The Superconducting Magnets and Technologies (SCM&T) Department and the 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 JINR in Dubna, Russia. The measurement of the magnetic field parameters is needed to be conducted for both apertures of each collider magnet at the ambient and LHe temperatures. The design and main characteristics of magnets for the NICA collider are given in [3, 4]. Serial production and testing of these magnets have been started at JINR. Pre-series magnet with two different configurations of coils (pre-serial and serial) was successfully tested. According to the specification, the following parameters of collider dipole magnets have to be measured:

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

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

- 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 7th.

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 (1) that are mounted on the lodgment (2) which is installed inside the measuring shaft (3). Each section is resembled by sets of three measuring coils made as a printed-circuit board (PCB). Each coil is formed by 20 layers of the PCB - each layer contains 20 turns, in total – 400 turns.

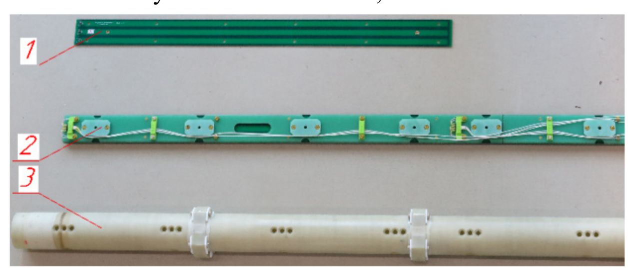

Figure 1: Main part of the MMS: 1. Section of three measuring coils (PCB); 2. Lodgment; 3. Measuring shaft.

The MMS construction is updated (see Fig. 2). In the centre of the magnet, the Hall probe (1) is installed on the central PCB for high resolution measurements of the magnetic field. Thermal contraction of the PCB is needed to be taken into account to compare results between magnets. For this task, special thermos-sensors PT100 (2) are mounted on the surface of each PCB. Special plates for inclinometer installation are included in the design of the serial MMS. The inclinometer with the system accuracy less than one arcsec [6] will be used to determine the frame of the measuring coil median planes relative to gravity.

MM are carried out at the ambient 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 of 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

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full cycle. Both types of MM have been performed using the same MMS. The detailed description of the MMS and methods was presented in paper [7].

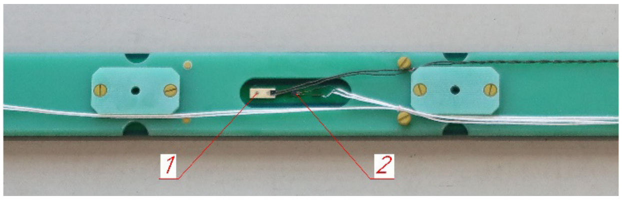

Figure 2: The Hall probe (1) and thermos-sensor PT100 (2) mounted on PCB.

FIRST RESULTS

The pre-series dipole magnet with pre-series and series coils was undergone all the tests, including "warm" and "cold" MM in the RC and DC modes. The results for top (blue) and bottom (red) apertures, for pre-series (dash), and series (solid) coils and calculation values are shown in Figs. 3-7. As it could be seen in Fig. 3, the saturation of iron yoke starts at the operating current of 9 kA.

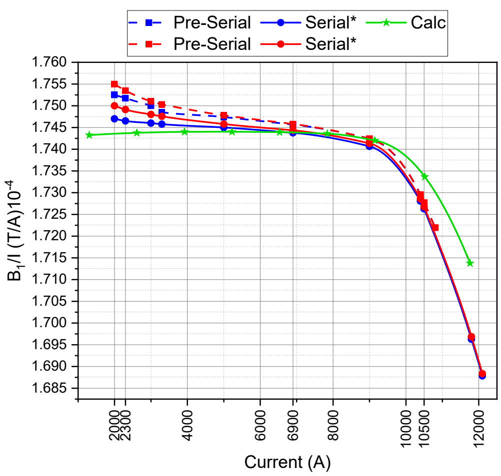

Figure 3: The functional dependence of the main field on the operating currents.

Dipole Angle

The special reference magnetic field created by the additional wires in corners of coil. The fact that it is parallel to the surface of poles was used to create a reference point for field direction measurements [7, 8]. Phases of the main harmonics of the reference field were measured and used as the initial angles of coils rotation. High accuracy and resolution of the servomotor are used to reproduce the initial angles with the required accuracy.

Effective Length

Relative variations of the dipoles effective length is approximately equal to the effective length that was calculated in [9, 10]:

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

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 a part of integration path (s_2) including gaps between coils 1 and 3. Values of effective lengths for the bottom and up apertures are shown in Fig. 4 as a function of the magnet excitation.

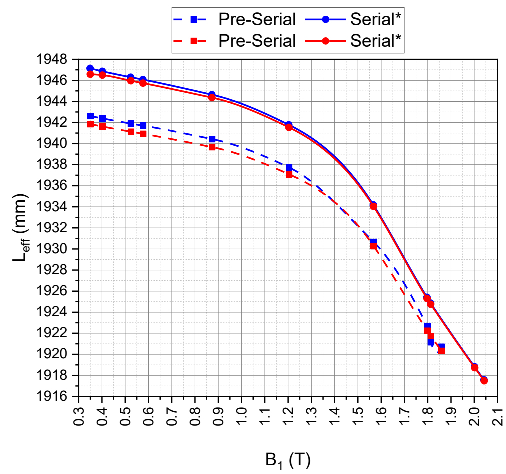

Figure 4: Mean value of the effective length vs. the magnetic field in centre.

Multipole Errors

The analog compensation for harmonics measurements was used. As it shown in [7, 10] sensitivity up to the 10th harmonic has been provided by the MMS.

The collider dipole, as well as in magnets of this type in the Nuclotron and the Booster [7], obtained the value of b_3=8-10*10^{-4} (see Fig. 5) for pre-serial coils at the operating field 1.8 T that significantly affects the dynamics of the beam in the storage rings. For the serial coils the value of b_3=4-5*10^{-4} was obtained at the operating field of 1.8 T and b_3=-(4-5*10^{-4}) at the operating field of 0.4 T.

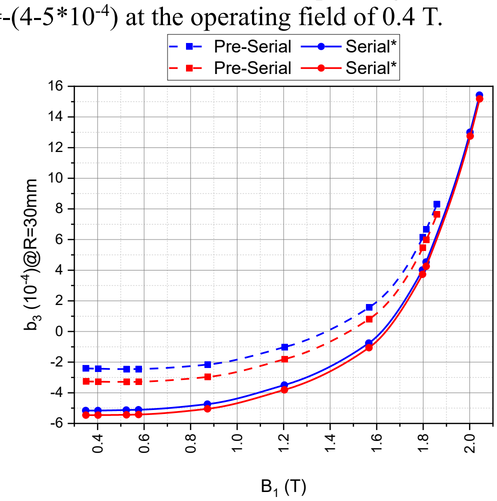

Figure 5: The value of b3 vs. the magnetic field in centre.

In addition, as it is shown in Fig. 6 and 7 the values of b_5 (see Fig. 6) and b_7 (see Fig. 7) had the functional dependencies on the magnetic field, but didn't exceed the value 10^{-4}.

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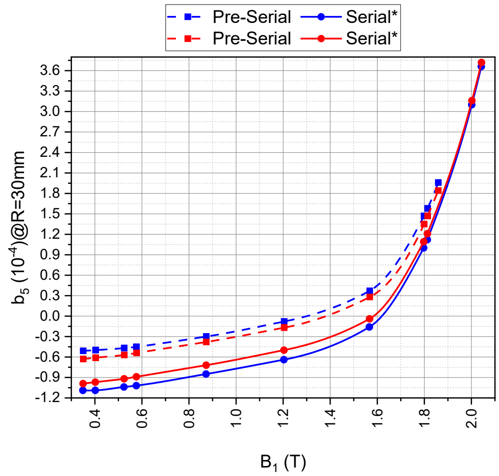

Figure 6: The value of b5 vs. the magnetic field in centre.

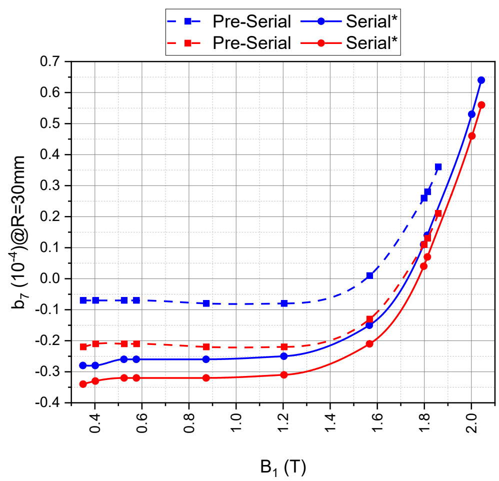

Figure 7: The value of b7 vs. the magnetic field in centre.

Integral values of the harmonics at the operating field 1.8 T for bottom and top series coils are shown in Fig. 8.

Comparison of the results in the RC and DC modes were done in [10].

CONCLUSION

At the moment the development of MMS and MM of the pre-series collider dipole with two different configurations of coils has been finished. Good correlation between calculations and measurement results are shown. The first serial MMS was produced. The previous experience in the establishing and operating of MMS for pre-series magnet was taken into account in the development of the MMS. Production of two serial MMS for simultaneous measurement two apertures of magnet is in progress. Development of the MMS for the NICA collider quadrupole is planned for future. Serial production and testing of these magnets have been started at JINR.

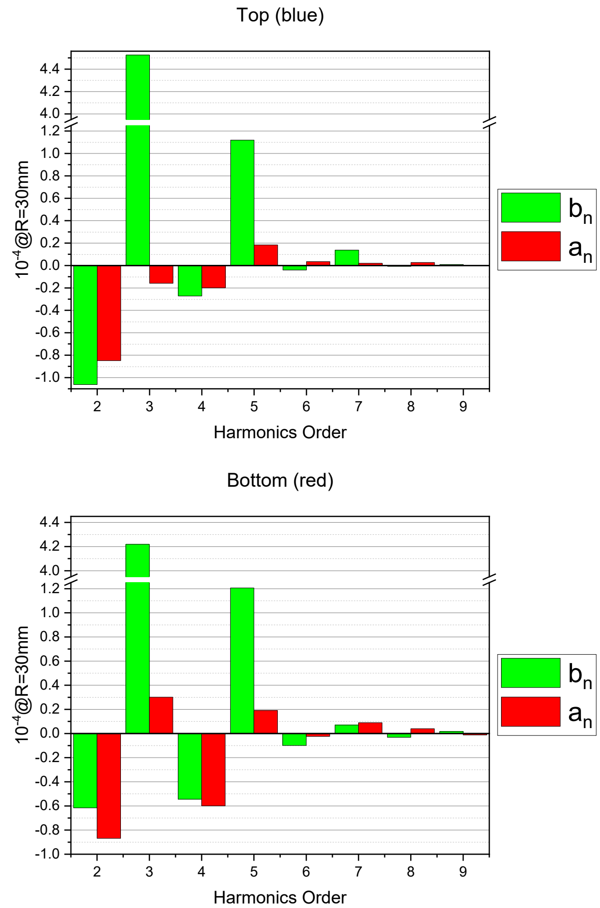

Figure 8: Integral values of the harmonics at the operating field 1.8 T for top (up) and bottom (down) series coils.

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