ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL014

SERIAL MAGNETIC MEASUREMENTS FOR THE NICA QUADRUPOLE MAGNETS OF THE NICA BOOSTER SYNCHROTRON

A. Shemchuk, V. Borisov, A.Donyagin, S. Kostromin, O. Golubitsky, H.G. Khodzhibagiyan, M. Shandov, M. Omelyanenko, A. Bychkov LHEP, JINR,141980, Dubna, Moscow Region, Russia

Abstract

NICA is a new accelerator collider complex under construction at JINR, Dubna. More than 250 superconducting magnets are needed for the NICA booster and collider. The NICA Booster magnetic system includes 48 quadrupole superconducting magnets. The rotating coils probe developed for series magnetic measurements of booster quadrupoles doublets, as well as measuring methods are described. Results of magnetic measurements in cryogenic conditions for 12 doublets are presented and discussed.

INTRODUCTION

At the Laboratory of High Energy Physics (LHEP), serial assembly and testing of NICA Booster magnets were started at end of 2016 at the special facility [1]. The program of testing of magnets includes «warm» and «cold» magnetic measurements. It is necessary to assemble and test 48 quadrupole magnets for the NICA booster synchrotron. According to the specification, a magnetic measurement system, which is able to measure the effective length, magnetic field harmonics and magnetic axis in cold magnet inside the cryostat, is needed.

QUADRUPLE MAGNET FOR THE NICA BOOSTER

Table 1: Main Characteristics of the NICA Booster Quadrupole Magnets

Parameter	Unit	Value
Number of magnets		48
Field gradient (inj./max.)	T/m	1.3 /21.5
Effective magnetic length	m	0.47
Beam pipe aperture (h/v)	mm	128 /65
Operating current	kA	9.68
Ramp rate	T/(m·s)	14.3
Field error at R= 30 mm		$\leq 6\cdot10^{-4}$
Pole radius	mm	47.5

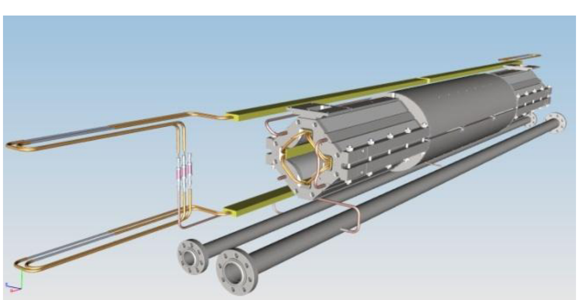

Figure 1: Booster doublet of quadrupole magnets.

The Nuclotron-type design [2],[3] based on a cold iron yoke and a saddle shaped SC coil have been chosen for booster quadrupole magnets. The doublet consists of a focusing and a defocusing lattice quadrupole magnets, which are connected with each other in a single rigid mechanical construction of about 1.8 m length (see Fig.1). The main parameters of the quadrupole magnets are presented in Table 1.

SPECIFICATION FOR MAGNETIC MEASUREMENTS

According to the specification, following parameters of a quadrupole magnet have to be measured with the required tolerances:

- Relative standard deviation of effective lengths

$$\delta L_{eff} = \frac{\Delta L_{eff}}{< L_{eff} >} \leq 5\cdot10^{-4}$$

$$L_{eff} = \frac{\int_{-\infty}^{\infty} B_2(s)\,ds}{B_2(0)}$$

- The magnetic axis with respect to magnets fiducials. $\sigma(\Delta x)$, $\sigma(\Delta y) \leq 0.1$ mm
- Relative integrated harmonics

b_2^*, a_2^*, a_3^*	$\leq 5\cdot10^{-4}$
b_3^*	$\leq 10^{-3}$
b_3^* at injection	$\leq 10^{-4}$
$b_n^*, a_n^*,\ n>3$	$\leq 10^{-4}$

THE MAGNETIC MEASUREMENT SYSTEM

The Design of Probe

Mechanical Design. The probe design is based on long fiberglass tube as a rigid frame, which holds two PCBs with harmonic coils arrays in proper positions (Fig. 2).The PCBs are not rigid and they require rigid holding plates. The plates design allows adjusting their positions in both transverse coordinates. After adjustment, plates are joined with the frame by 10 pins. Each of the PCBs covers measured magnetic field volumes of the quadrupole magnets "F" and "D". The probe is held inside yokes by four sliding bearings. Frames of bearings lean on yokes. Four bearings are used to minimize the sag of probe. The bearing design consists of a fiberglass ring, four holding anchors, four supports for sliding elements. Sliding elements are made of PTFE. The tube in bearings positions has a treated and prepared surface with antifriction coating.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL014

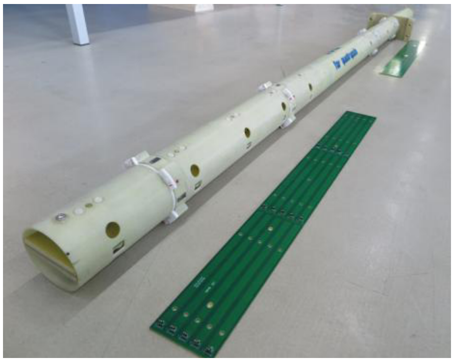

Figure 2: The view of the probe and PCBs.

There are variants for bearings sizes to accommodate the variation in the size of the yoke bore. To hold probe in the longitudinal position there is a bracket with the thrust sliding bearing. Rotation is carried out by the attached shaft. Signals go out through the slip rings. Fig.3 shows the 3D probe model.

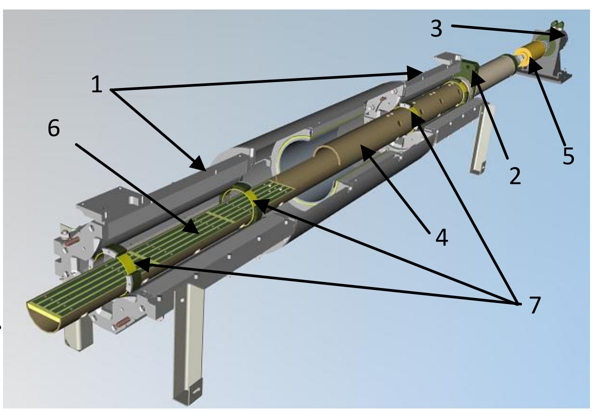

Figure 3:3D model of the probe installed in the magnet: 1 - Quadrupoles doublet, 2 –Thrusting bearing,3– Servomotor, 4-Tubular fiberglass frame, 5 - Slip rings, 6-PCB, 7 – Bearings.

Cryogenic Magnetic Measurements

If a doublet successfully passes warm magnetic measurements, as well as vacuum tests, it is installed into the cryostat. For cryogenic measurements one of six test benches is used, each of which is connected to the feed box and the satellite refrigerator (see Fig 4).

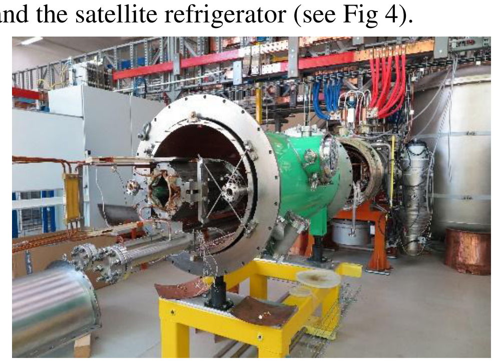

Figure 4: The doublet of the quadrupoles in the cryostat is in preparation for cryogenic measurements.

MAGNETIC MEASUREMENTS RESULTS

At the moment, 17 out of 28 doublets are measured at room temperature, and 7 out of 28 doublets have undergone cryogenic measurements.

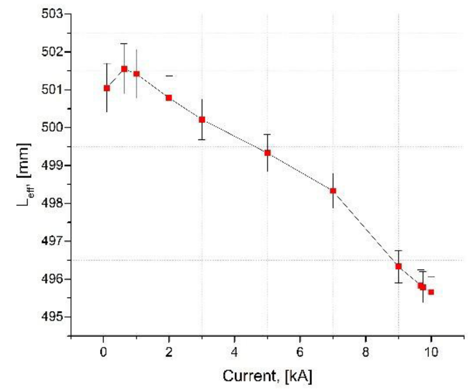

Figure 5: Mean value and relative standard deviation of effective lengths vs. current.

Figure 5 shows the dependence of the effective length on the current obtained in cryogenic tests.

Effective Length

To calculate the relative variation of quadrupole effective lengths (see Fig. 6), the value approximately equal to the effective length was calculated:

$$L_{eff} = \frac{1}{b_2(0)}\left[\sum_{i=1}^{3} B_{2,i} \cdot s_i\right]$$

i - section number, B1, i - main field harmonic measured by i section, si – part of integration path going through i.

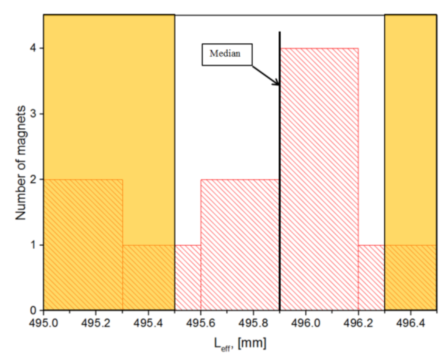

Figure 6: Distribution of effective lengths of a doublet.

Magnetic Axis

Figure 7 shows the magnetic axes in the design coordinate system, at the current of 9745 A. When calculating the magnetic axis, the displacement of the rotational axis of the sensor is taken into account.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL014

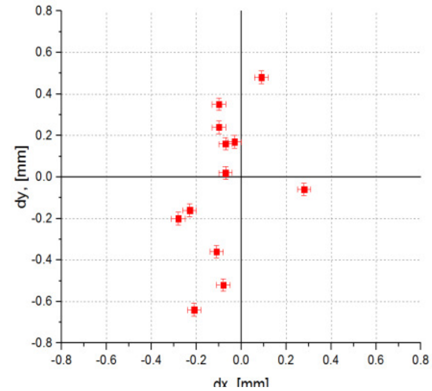

Figure 7: The positions of the magnetic axes at the current 9745 A.

Relative Integrated Harmonics

We use analog compensation for harmonics measurement. The compensation ratio for various sections is in range 1600-21000. Such high values of compensation ratio are possible due to the very precise geometry of the coils made as PCBs.

Figure 8 shows the dependences of the harmonics b_6 as a function of current. Almost for all quadrupoles, this harmonic is in tolerance.

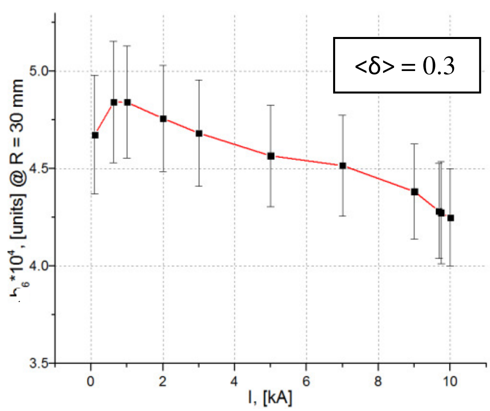

Figure 8: b_6 vs. current for 12 quadrupoles.

Figure 9 shows mmultipoles at the current = 9745 A. Calculation in the Opera, and in the future and experiment have shown that the harmonic a_3 appears due to the displacement of the SC-coils in the yoke.

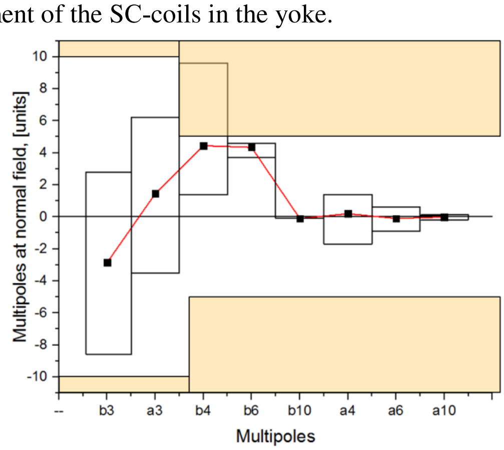

Figure 9: Multipoles at the current = 9745 A (n=3,4,6,10).

The large value of the harmonic b_4 is caused by large geometric deviations of the hyperbolic poles (see Fig. 10). Magnetostatic simulation in the 2-d OPERA (TOSCA) with using real geometry confirms this. The geometry is measured with a portable CMM.

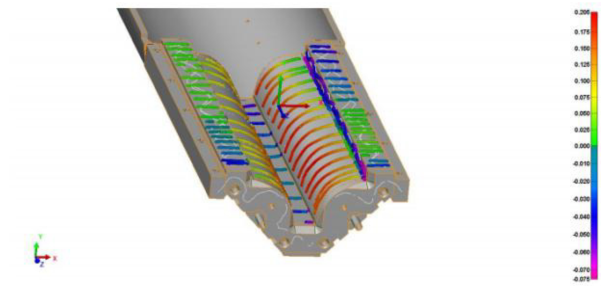

Figure 10: Map of the color deviations of one of quadrupoles with a large b_4 .

Using data on measurements of the geometry of the hyperbolic profile, the dependence of the deviation of the profile vs. harmonic b4 in Fig. 11 is shown.

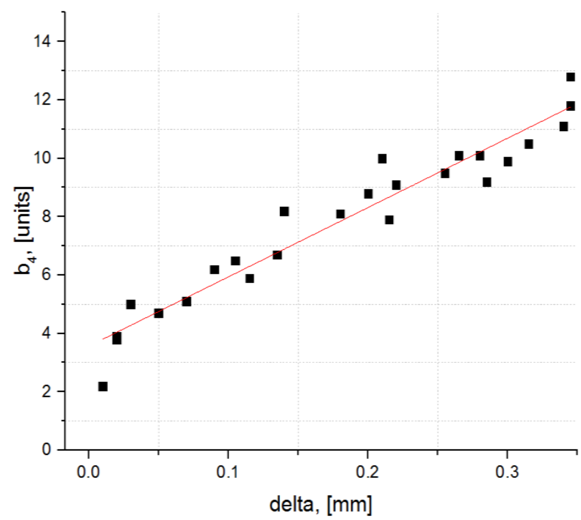

Figure 11: b_4 vs. deviation of hyperbolic profile.

CONCLUSION

27 % of the doublet of quadrupoles for the NICA booster synchrotron was successfully passed cryogenic test and can be installed in the tunnel of the accelerator. Magnetic measurements have showed good correspondence of the magnetic field parameters of magnets to the requirements of the specification.

ACKNOWLEDGMENT

Authors would like to thank those who support our tests at JINR, especially the staff of the SCM&T Department of LHEP. Also thanks to Anna Bogomolova for proofreading the paper.

ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-THPAL014

REFERENCES

[1] Khodzhibagiyan H. et al., Facility for Superconducting Magnet Assembling and Serial Testing, Proc. of the 13th Cryogenics, Prague, (April 2014).

[2] H. Khodzhibagiyan et al., "Development of fast-cycling superconducting magnets at JINR", Proc. of ICIC21, CRYOPrague 06, vol. 1, pp. 113-116, 2006.

[3] H. Khodzhibagiyan et al., "Superconducting Magnets for the NICA Accelerator Collider Project", IEEE Trans. Appl. Supercond., vol.26, N3, June 2016.