MAGNETIC MEASUREMENT SYSTEM FOR THE NICA QUADRUPOLE MAGNETS

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Abstract

NICA is a new accelerator collider complex under construction at the JINR in Dubna. More than 250 superconducting magnets need 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. First results of magnetic measurements in normal conditions (“warm”) are presented and discussed.

INTRODUCTION

At the Laboratory of High Energy Physics (LHEP), serial assembly and testing of NICA Booster magnets started at end of 2016 at 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 NICA booster synchrotron. According to specification a magnetic measurement system able to measure effective length, magnetic field harmonics and magnetic axis in cold magnet inside cryostat is needed.

QUADRUPLE MAGNET FOR THE NICA BOOSTER

Table 1: Main characteristics of the NICA Booster 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

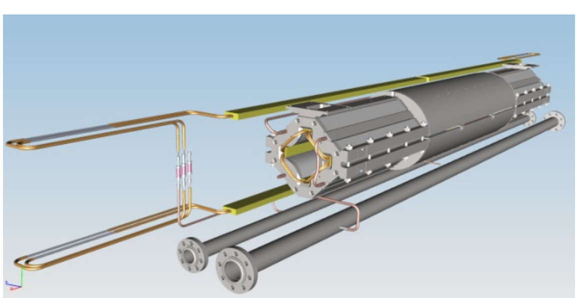

Figure 1: Booster quadrupole magnet.

The Nuclotron-type design [2, 3] based on a cold iron yoke and a saddle-shaped SC coil has been chosen for the booster quadrupole magnet. The quadrupole magnet consists of the focusing and defocusing quadrupole magnet, which are connected to 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 quadrupole magnet have to be measured with required tolerances:

- Relative standard deviation of effective lengths

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

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

- 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^*	$\leq10^{-3}$
b_3^* at injection	$\leq10^{-4}$
b_n^* , a_n^* , $n>3$	$\leq10^{-4}$

THE MEASURING MEASUREMENT SYSTEM

The successful experience with prototype probe for a quadrupole magnets [4] based on fiberglass tube design allowed us to develop the new full-size probe for series magnetic measurements of quadrupoles doublets. This probe as our probe for dipole magnets is based on radial harmonic coils arrays made as single multilayer PCB.

The Design of Probe

Mechanical Design The probe design is based on a long fiberglass tube as a rigid frame, which holds in proper positions two PCBs with harmonic coils arrays (Fig. 2, 3, 4). The PCBs are not rigid and they require rigid holding plates. Design of plates allow adjust their positions in both transverse coordinates. After adjustment, plates joint with the frame by 10 pins. Each of the PCBs covers measured magnetic field volumes of the quadrupole magnets "F" and "D". The probe holds inside yokes by four sliding bearings. Frames of bearings lean on yokes. Four bearings is used to minimize 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.

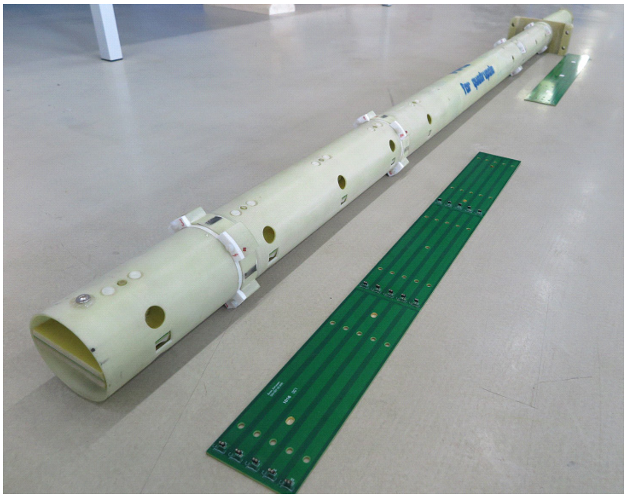

Figure 2: The view of the probe and PCBs.

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

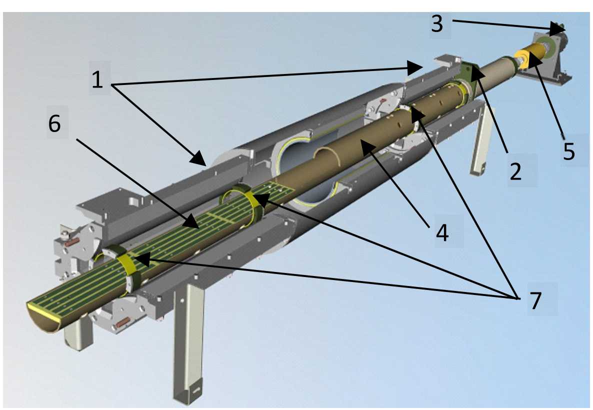

Figure 3: 3D model of the probe installed in the magnet. 1 - Quadrupoles doublet, 2 - Thrusting bracket, 3 - Motor, 4 - Tubular fiberglass frame, 5 - Slip rings, 6 - PCB, 7 - Bearings

Harmonic Coils Array The probe uses two multilayer PCBs with radial harmonic coils arrays. Each PCB contains three arrays by five coils (See Figs. 2 and 4). Three arrays of coils cover measured magnetic field volume divide it on three equal parts: center - with plateau in field longitudinal distribution, and two on edges with fringe field. Coils consist of 400 turns created from 20 layers each of which contains 20 turns. Three central coils in each array are connected between them to prepare signal, which is used to compensate main, and dipole harmonics, fifth coil is reserve.

The Probe Assembly Procedure Precision assembly was carried out under the control of the the ROMER Absolute Arm Compact Model 7512 [8]. The most difficult task is adjustment harmonic coils in proper transvers positions relative to the rotation axis. To hold PCBs at proper positions relative to the rotation axis, sector inserts with holes for the pins were used. PCBs also have holes for the pins. The position of the inserts was adjusted under the control of the measuring arm.

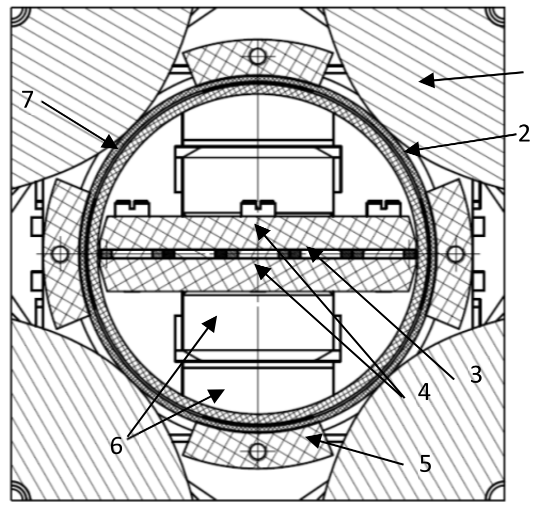

Figure 4: Section view of probe with slide bearing inside yoke. 1 - Yoke, 2 - Bearing frame, 3 - PCB, 4 - Holding plates, 5 - Anchor, 6 - Adjusting inserts, 7 - Probe frame.

The rotation axis of the probe is determined by numerous measurements of point target fixed on surface of probe, which rotate stepwise with probe. Center of circle trajectory of target is measured by measuring arm inside Polyworks software [9].

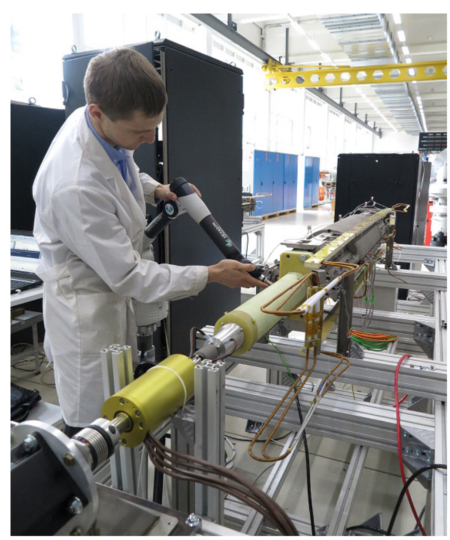

Figure 5: The measurement coordinates of the rotation axis.

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This procedure is used also to measure coordinates of probe rotation axis in reference frame of doublets, which defined by fiducials holes on references areas on yokes upsides (see Fig. 5)

The Measurement Methods

The step-by-step method [6, 7] with fast-ramped field gradient with ramp rate 14.3 T/(m*s) was used. Angular magnetic flux dependence is measured sequentially at N (64) equally spaced azimuthal coil positions. Voltage signals inducted in coils by magnetic field ramp are digitized at each angular position. After that, the signals are integrated offline. Well-known Fourier analysis procedures is used to achieve harmonics content of measured magnetic field. Two measurement are made, uncompensated and compensated.

Data Acquisition and Controls

DAQ same with used in magnetic measurement of booster dipole magnets is used. NI PXI measurement electronics are used: PXI 4462 DSA modules (24 bits, 204,8 kS/s, Δ-Σ ADC) for signals digitizing, CompactRIO controller as master for EtherCAT to control servo drive . All software created in LabVIEW environment. High accuracy Kollmorgen AKM DB-series servomotor and AKD-P servo drive are used to rotate probe precisely.

Magnet Current Source and its Control Low-noise pulsed current source [10] is used to excite magnet. The current source is controlled by the external analog signal generated by PXI-6238 galvanic isolated module. The triangular shape of pulse with parabolic smoothing of inflection points is used.

Current Measurement The power supply current is measured by the current sensor LEM's ITZ 600-SBPR FLEX ULTRASTAB, adjusted to the range of currents up to 100 A. The output signal is digitized by NI PXI 4462 DSA block synchronously with coils signals.

RESULTS

Dependence of all measured harmonics on harmonics number is shown in Fig. 6. Values are mean value by five measurements. We can see that noise floor is 0.0002 unit, at reference radius 30 mm.

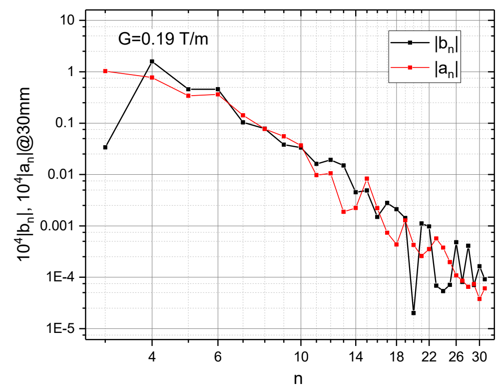

Figure 6: Harmonics vs harmonic number.

The results of the magnetic measurements of the quadrupoles doublet are presented in Table 2. Magnetic axis displacements were measured relative to the rotation axis. The values of the integral harmonics are presented in Table 3.

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Table 2: Results of the Magnetic Measurements

L_{eff} [mm]		G [T/m]		ΔX [mm]		ΔY [mm]	
F	D	F	D	F	D	F	D
505.3	504.8	0.1863	0.1867	-0.76	-0.29	-0.04	-0.67

Table 3: The values of the integral harmonics * 10^{-4}

№ of harmonic	3		4		6		10	
	F	D	F	D	F	D	F	D
b_{int}	6,44	-0,2	0,28	0,78	0,80	0,15	0,04	-0,003
a_{int}	1,30	5,1	0,02	-1,8	0,16	-4,9	0,03	0,10

REFERENCES

[1] H. Khodzhibagiyan *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.

[4] A. Shemchuk *et al.*, "Magnetic Measurement System for NICA Quadrupole Magnets", Proceedings of RuPAC2017, St. Petersburg, Russia (2017).

[5] V. Borisov *et al.*, "Magnetic Measurement System for the NICA Booster Magnets", Proceedings of IPAC2014, Dresden, Germany (2014).

[6] S.A. Kostromin, V.V. Borisov, A.V. Bichkov *et al.*, Phys. Part. Nuclei Lett. (2016) 13: 855. doi:10.1134/S1547477116070323

[7] M. Shandov *et al.*, "Measurements of Magnetic Field Parameters of NICA Collider Dual Magnet", Proceedings of RuPAC2017, St. Petersburg, Russia (2017).

[8] `http://www.hexagonmi.com/products/portable-measuring-arms/romer-absolute-arm-compact`

[9] `http://www.innovmetric.com/en/products/polyworks-inspector`

[10] M.M. Omelyanenko, V.V. Borisov, A.M. Donyagin, H.G. Khodzhibagiyan, S.A. Kostromin, A.A. Makarov, and A.V. Shemchuk, Phys. Particl. Nucl. Lett., 2017, vol. 14, no. 1, pp. 219–226.

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