ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-WEPSC17

VIBRATING WIRE SYSTEM FOR FIDUCIALIZATION NICA BOOSTER SUPERCONDUCTING QUADRUPOLE MAGNETS

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Abstract

The NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex under construction at the Laboratory of High Energy Physics (LHEP) JINR. The facility includes two injector chains, two existing superconducting synchrotrons Nuclotron and a new Booster, under construction superconducting Collider, consisting of two rings. The lattice of the Booster includes 48 superconducting quadrupole magnets that combined in doublets. Each doublet must be fiducialized to the calculated trajectory of the beam. Alignment of the magnetic axis is necessary for properly install the magnets at the beam trajectory. The vibrating wire technique was applied to obtain the the magnetic axis position of quadrupoles. A new measurement system has been worked out and produced at the LHEP. The magnetic axis positions of the quadrupole doublets are determined at the ambient temperature. The paper describes design of the measurement system, measuring procedure and results of the magnetic axis position measurements.

INTRODUCTION

The NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex under construction at the Laboratory of High Energy Physics (LHEP) JINR [1]. The facility includes two injector chains, two existing superconducting synchrotrons Nuclotron and a new Booster, under construction superconducting Collider consisting of two rings. The Booster have been put into operation at 2020. Main goals of the Booster are accumulation of 2×10^9 Au^{31+} ions acceleration of the heavy ions up to energy required for effective stripping; forming of the required beam emittance with electron cooling system. It has 210.96 m circumference and includes 48 superconducting quadrupole magnets that combined in doublets. All superconducting magnets for the NICA Booster have been assembled and tested at the test facility at the Laboratory of High Energy Physics. According to the technical specifications [2], the magnetic axis position must be measured with an accuracy less than 0.1 mm.

The vibrating wire technique was applied to achieve the precision of measuring the magnetic axis position. The vibrating wire technique based on Lorentz forces between alternating current flowing through the taut wire and transverse magnetic field excite the mechanical wire vibrations. If the frequency of driving current is close to one of the wire resonance frequencies the effect will be especially strong. The wire position can be obtained by moving the wire across the magnet aperture and measuring the wire vibrating amplitude [3, 4].

DOUBLET OF QUADRUPOLE MAGNETS

The Booster quadrupole magnets are Nuclotron-type include cold iron yoke with hyperbolic poles, shaped the magnetic field and a coil made of a hollow superconductor. The doublet of quadrupole magnets is a single rigid mechanical construction of about 1.8 m length. It's consists of defocusing and focusing quadrupoles, cylinder for rigid mounting magnets with each other, as well as two beam position monitors within cylinder. The doublet has a removable design that allows splitting it into two parts for assembly-disassembly halves of yoke and coil [5].

The main parameters of the NICA Booster quadrupole magnets are shown in Table 1.

Table 1: The Main Parameters of the NICA Booster quadrupole Magnets

Parameter	Unit	Value
Number of magnets	pieces	48
Maximum field gradient	T/m	21.5
Effective magnetic length	m	0.47
Field error at R = 30 mm		6×10^{-4}
Beam pipe aperture (h/v)	mm	128/65
Pole radius	mm	47.5
Yoke width/height	m	0.226
Weight	kg	110

VIBRATING WIRE SYSTEM

The NICA Booster Vibrating Wire measurement system has been designed, produced and commissioned at the LHEP. The copper-beryllium wire 0.125 mm diameter and length about 5.3 m stretched through the mechanical center of the doublet aperture (see Fig. 1: 2 – defocusing, 3 – focusing magnets) and supported by two stages A and B (4 and 5). Each of them has horizontal and vertical Physik Instrumente linear stages 404.2PD to moving wire (1) across the aperture. The doublet and stages are installed on the balk 6 m along. The geometrical centers of defocusing and focusing magnets are placed at the 3/8 L_w and 5/8 L_w, where L_w – wire length. The wire is fixed on stages and stretched by 0.8 kg weight. Digital wave form generator Keithley 6221 was used to drive alternating current through the wire. Two orthogonal Sharp phototransistors GP1S094HCZ0F (6) were used to detect wire vibrations and National Instruments 24-bit PXIe-4464 module for signal registration from them.

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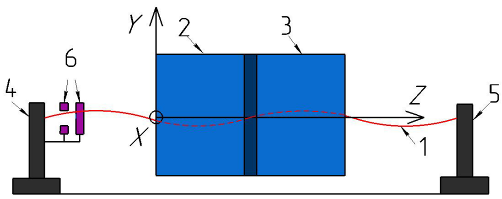

Figure 1: The scheme of the NICA Booster vibrating wire measurement system.

MEASURING PROCEDURE

To begin with, the wire position aligns to the doublet aperture geometrical center. The wire on the stages are adjusted relative to the doublet by Hexagon laser tracker AT402 with ±0.05 mm alignment tolerance. Then operating points are set on the wire position detectors – GP1S094HCZ0F. The output voltage of the phototransistors has a linear dependence on the amplitude of the wire vibrations with the X,Y positions in doublet aperture – $A \sim I_w \times |X, Y| \times L_w / \omega_n \times L_m$, where A – amplitude of the wire vibration, I_w – AC current through the wire, $L_{w,m}$ – wire and magnet length, ω_n – n harmonic of the wire natural frequency. The minimum of the wire vibration amplitude corresponds to the magnetic center position.

According to the position of the magnets, the fourth harmonic of the wire natural frequency is used to find the magnetic center position and also, at the fourth harmonic the wire is unsusceptible to external constant fields. Usually the fourth harmonic is about 104 Hz. The frequency of alternating current through the wire is close to the natural frequency of the wire. Furthermore, to maintain the correct S/N ratio, the wire vibration amplitude must be less than the working area of phototransistors. All measurement procedures are carried out by automatic program written in the LabVIEW programming environment.

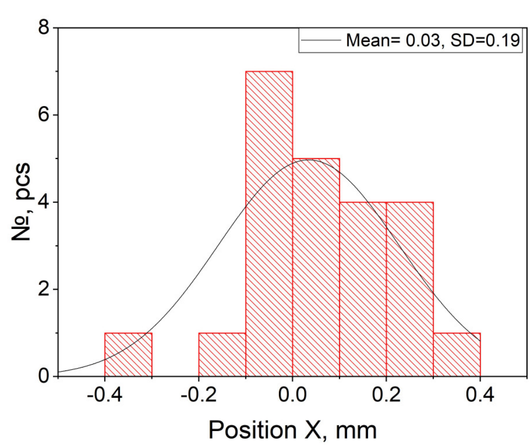

Figure 2: X position of the magnetic center of the defocusing quadrupole.

Initially, the position of the magnetic center determined for defocusing magnet. The wire vibrating amplitude at the detectors position is measured at 11 points on 1 mm length with step 0.1 mm (see Fig. 2, 3). The linear stages are moved in co-directional. The wire operating AC – 0.1 A and magnet DC – 35 A. In order to avoid the influence of the background fields, magnetic measurements were carried out with positive and negative operating currents trough the magnet coil. The mean value of the minimum wire vibration amplitude for negative and positive operating currents through the magnet coil corresponds to the magnetic axis position. The same measurements for the focusing magnet. Two points of the magnetic center for defocusing and focusing magnets defined the line – magnetic axis of the doublet. After magnetic measurements, the position of the magnetic axis was used to adjust the beam position monitors located between defocusing and focusing magnets.

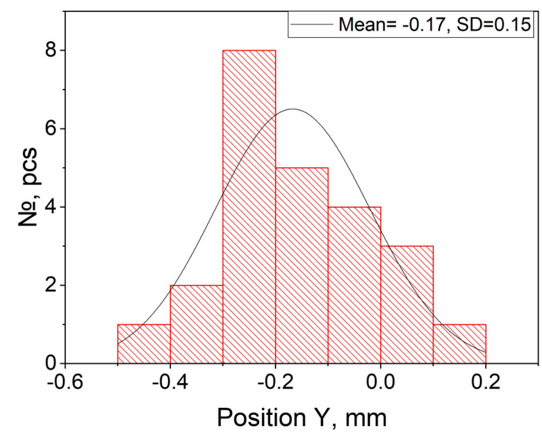

Figure 3: Y position of the magnetic center of the defocusing quadrupole.

MEASUREMENTS REPEATABILITY

With an eye to check out the wire measurement system and disassembly-assembly (D-A) of the doublets the repetitive measurements have been accomplished. The doublet was measured four times with a complete D-A of them. Disassembly involves the separation of the two parts of the doublet iron yoke and the dismantling of the coil. Magnet assembly carried out in reverse order. The results are shown in the Table 2. According to the results of four measurements (three D-A of the doublet) the standard deviation of the magnetic axis position is less than 0.04 mm.

Table 2: Deviation of the Magnetic Axis Positions

№ D-A	Defocusing X/Y mm	Focusing X/Y mm	Doublet X/Y mm
0	-0.02/-0.25	0.10/-0.26	0.04/-0.27
1	-0.07/-0.25	0.07/-0.26	0.00/-0.26
2	-0.03/-0.25	0.06/-0.32	0.02/-0.30
3	0.02/-0.22	0.11/-0.28	0.07/-0.26
mean	-0.03/-0.24	0.09/-0.28	0.03/-0.27
σ	0.04/0.02	0.02/0.03	0.03/0.02

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MEASUREMENT RESULTS

Magnetic axes fiducialization of the NICA Booster quadrupole magnets were successfully done. All measurements carried out at the ambient temperature. The typical tolerance of the magnetic axis position is determined below 0.07 mm. The positions of the magnetic axes for all magnets are shown at Fig. 4 and normal distributions of the magnetic axis positions are shown at Figs. 5-8.

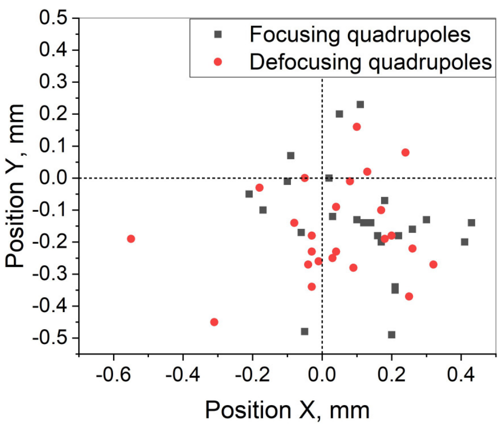

Figure 4: The magnetic axis positions of the NICA Booster quadrupole magnets.

The large spread of deviations of the magnetic axis positions is explained by the choice of the coordinate system of the doublet. Due to the fact that the coordinate system is set at the beginning of the defocusing magnet and the magnetic center is located significantly further along the length of the doublet. If there is a small angle between the defocusing and focusing magnets, this leads to large deviations of the magnetic axis positions.

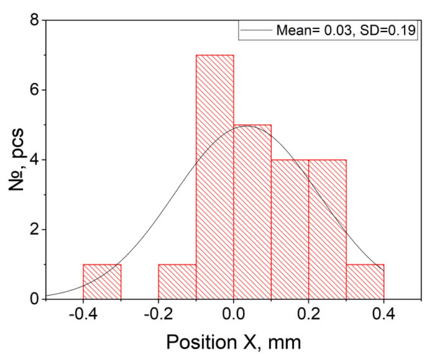

Figure 5: The defocusing quadrupoles normal distribution of the X positions of the magnetic center.

CONCLUSIONS

Vibrating wire technique is high accuracy technique to determine magnetic axis position of the magnet. It can be applied not only for one magnet but also for several magnets at the same time. It was shown that using vibrating wire technique, it's possible to fiducialize the doublet of the magnets at the beam trajectory. An accuracy of the determining magnetic axis below 0.07 mm and repeatability of the results after disassembly-assembly – 0.04 mm. The system also allows to take into account the influence of background fields. The developed vibrating wire system meets the technical requirements for the production of the superconductive magnets for the NICA project. Optimization, improvement, studies of the vibrating wire system and techniques should be continued at the LHEP.

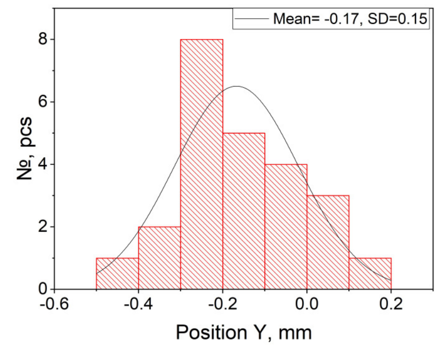

Figure 6: The defocusing quadrupoles normal distribution of the Y positions of the magnetic center.

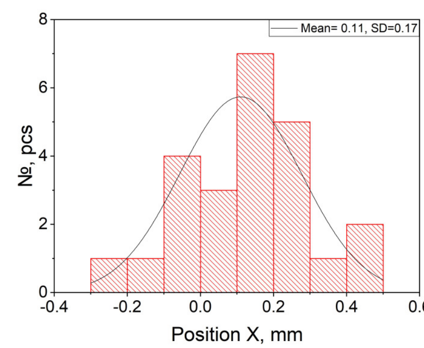

Figure 7: The focusing quadrupoles normal distribution of the X positions of the magnetic center.

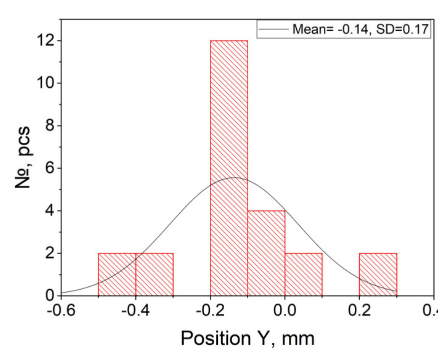

Figure 8: The focusing quadrupoles normal distribution of the Y positions of the magnetic center.

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