MAGNETIC MEASUREMENT SYSTEM FOR THE NICA QUADRUPOLE MAGNETS

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Abstract

NICA is a new accelerator collider Nuclear Research (JINR) in Dubna. More than 250 superconducting magnets need for the NICA booster and collider. These magnets will be assembled and tested at the new test facility in the Laboratory of High Energy Physics JINR. A method of measuring of the quality of the magnetic field in the aperture of the quadrupole magnet for the booster synchrotron is described. Commissioning of equipment for magnetic measurements in the aperture of the doublet of quadrupole lenses is described.

INTRODUCTION

At the Laboratory of High Energy Physics (LHEP) creation of the first stage of technical complex [1] for assembly and testing of SC magnets for the NICA and FAIR project is finished. 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. For measurement of characteristics of the quadrupole magnets two main sensors are used.

QUADRUPLE MAGNET FOR THE NICA BOOSTER

The quadrupole magnet consists of the focusing and defocusing lenses which are rigidly connected among themselves. The parameters of the quadrupole magnet are presented in [2] and Table 1. 3D view of the magnet shown in Figure 1.

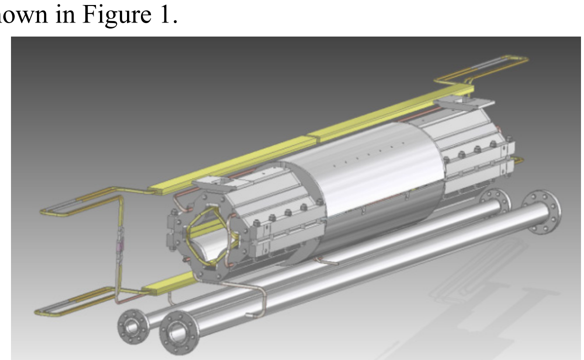

Figure 1: 3D view of the quadrupole magnet.

REQUIREMENTS FOR COMPOSITION OF MAGNETIC MEASUREMENTS

Requirements

- ✓ For all quadrupole lenses before the magnetic test in a superconducting mode, it is necessary to make measurements at normal (room) temperature. Thus, there is no need for magnetic measurements in the lenses with obviously unacceptable characteristics at 4.5 K temperature.
- ✓ The parameters of the harmonic coils must provide measurement accuracy according to specifications (see Table 1) during tests at 4.5 K.
- ✓ Both cold and warm serial measurements of the magnets are carried out without the vacuum chamber of the beam.
- ✓ For the 3-5 quadrupole lenses serial measurements should be supplemented by studies not included in a standard set of procedures:
  - ○ The study of the effects (both static and dynamic) distortion values of the harmonics of the magnetic field associated with the presence of the vacuum chamber
  - ○ Study of hysteresis effects
  - ○ To study the influence of Assembly/disassembly of the lens on the measured parameters
  - ○ The study of the dependence of field harmonics from the current. In particular, the necessary measurement of harmonics with a maximum field installation, field injection and 5-7 intermediate values. This task necessarily involves the need to accurately determine the values of the current in the main windings corresponding to three values of the fields.

Values which are Necessary to Measure

Based on the requirements for the creation of the measuring bench formulated the table 1. It contains both relative and absolute error.

It is necessary to measure the next parameter, quadrupole magnet:

- The gradient in the center of the magnet
- Integral gradient
- The effective length
- The offsets of the magnetic axis of the magnet, with respect to the geometric axis.
- The angle of rotation of the magnetic field relative to the yoke
- The relative Central and integral harmonics, to 6 inclusive

METHODS AND IMPLEMENTATION OF MEASUREMENTS

In accordance with the requirements specified in Table 1 was chosen 2 methods of measurement. The first method of harmonic coils [4], the second method of tangential coils.

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Table 1: Relative Errors of the Parameters of the Magnet

Value	Precision
The gradient in the center of the magnet, G0	
Integrated gradient, GL	0.01%
The effective length, Leff	0.01%
The offset of the axis of the magnet, Δx	0.1 mm
The offset of the axis of the magnet, Δy	mm
The angle of rotation	rad
Higher harmonics	

For all quadrupole lenses were developed two sensors, corresponding to these two methods in front of the magnetic test of a superconducting mode, it is necessary to take measurements at normal (room) temperature. Thus, there is no need for magnetic measurements in the lenses with obviously unacceptable characteristics in a much more difficult technical conditions (cryogenic temperatures).

The Design of the Measuring System

Reference Magnetic Field. It is necessary to measure the orientation of all the sections of the sensor relative to each other. For the realization of this problem in measured magnets the reference magnetic field [3] from an additional winding (see Fig. 2) consisting of 4 conductors located in corners of the magnet yoke was used. This winding generates a magnetic field directed parallel to the magnet poles. The direction of this magnetic field, due to small sizes of a winding, is defined by the accuracy of fabrication of the magnet yoke. In view of the high mechanical accuracy of manufacturing of a yoke, it is possible to consider that a reference magnetic field is parallel to magnet poles. We will notice that this additional reference winding can be used also, as the detector of the quench in a SC magnet.

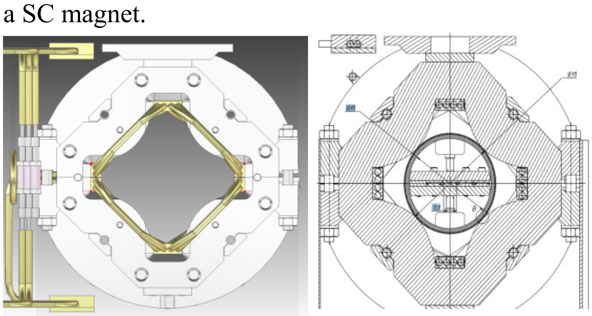

Figure 2: The location of the reference winding (left). In the lens F, and D, the magnetic field vector has opposite direction. The cross section of the quadrupole magnet is installed the harmonic sensor (right).

Mechanical Design. For measuring quadrupole magnet uses two types of sensors:

- With Tangential Coil (further TC)
- With Harmonic Coil (further HC)

In a tangential sensor used two sections (in the lens F and D, respectively) connected by two bellows couplings, and a common hollow shaft. Sections (see Fig. 3 pos.5) are made of fiberglass , after the processing - stoving varnish, in order to avoid adsorption pores of the fiberglass with water. Each section contains two ceramic bearing, which, in turn, planted in glass fibre laminate holders. The assembled structure is mounted in a long box, whose ends are reference plane. After the introduction of TC in the quadrupole magnet, the box is fixed with brackets (see Fig. 3 pos.4) to reference plates (see Fig. 3 pos.3) of the magnet. In each section, in a special way, set for 8 coils with different geometrical dimensions.

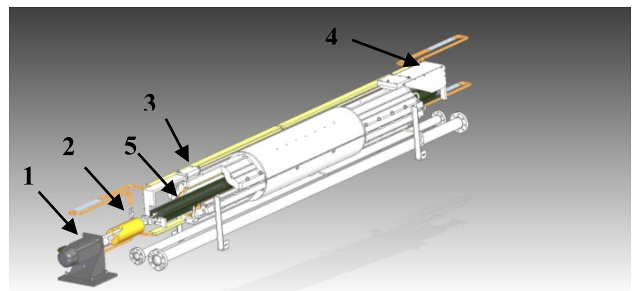

Figure 3: Quadrupole magnet with installed tangential sensor. In the front section made the cut.

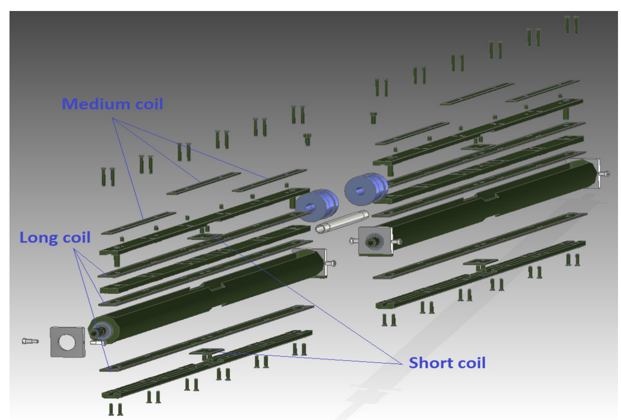

Figure 4: The composite tangential sensor elements.

For accurate assembly of the sensor used measurement arm that allows accurately set the coils according to the model. The sensor uses three types of coils (Fig. 4): 1, Long; 2 - Short; 3 - Medium.

In order to measure the specified value, the coil is included as a counter and sequentially. To measure the displacement of the magnetic axis using the center of a long coil (see Fig. 5, pos. 1). To measure the effective length and gradient fields are applied "quadrupole" long coil (see Fig. 5, pos. 2,3) plus a short coil in the center. To measure higher harmonics are used all the long coil (Fig. 5, pos 1,2,3), and all medium coil (Fig. 5, pos. 6,7,8).

In the prototype harmonic of the sensor, use a hollow tube of fiberglass, in which, on the adjustment screws to set the plate. On the plate are attached to the prototype coil with 193 turns. Figure 6 shows the assembled prototype of

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the future sensor. The prototype is half working sensor, other words, it is possible to measure only the lens F or D.

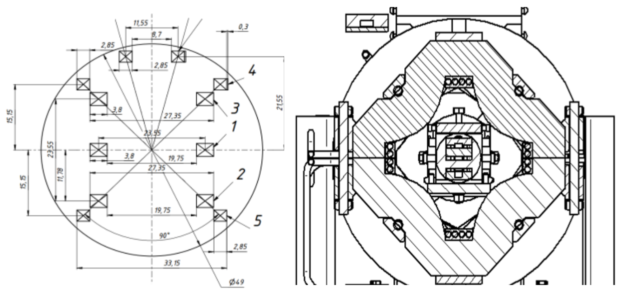

Figure 5: Scheme of the cross section of the measuring section (left). The cross section of the quadrupole magnet is installed the tangential sensor (right).

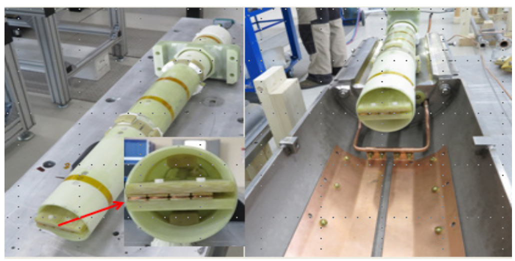

Figure 6: The prototype harmonic sensor.

In contrast to tangential - in a harmonic gauge is used sliding bearings (see Fig. 7, right). On the hollow pipe, in place of the slip applied epoxy resin, subsequently treated on a lathe. The bearing has a PTFE liners that provide the best glide.The advantage of such complex structures is the lack of deflection of the sensor along the entire length. Figure 7 left presents the 3D model of the harmonic full-size sensor. The numbers indicate the following elements: 1 - Doublet quadrupole lenses; 2 - Bracket for mounting the sensor magnet; 3 - Multipole corrector; 4 - Motor; 5 - Lens F; 6 - D Lens; 7 - glass fibre laminate tube; 8 - Slip rings; 9,10 - Sets tangentially coils.

Both sensors are driven by servo motors, with the parameter of the encoder is 2^{20} pulses per revolution. The signals from the coils and in that and in other case transmitted via a sliding contact. For more precise control of the position of the coils relative to the magnet, encoder mounted at the end of the sensor is used. This decision will allow to track possible backlash in the mechanics of the sensor.

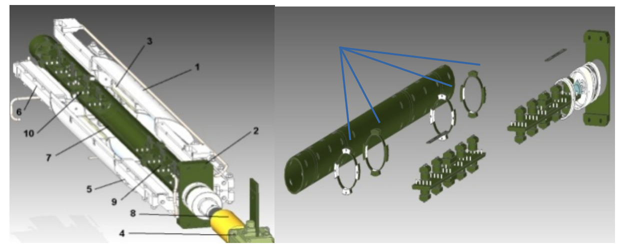

Figure 7: 3D model of a tangential sensor installed in the magnet (left) and its constituent elements (right).

Structure of harmonic and tangential coil. Tangential coils are made as the multilayered printed-circuit board (PCB). Coils consist of 400 turns created from 20 layers, each of which contains 20 turns. Production of PCB was ordered in China. The sample of PCB was tested cyclically by cooling down to the LN2 temperature. The sample wasn't destruction.

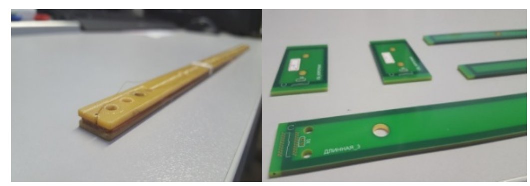

Figure 8: The measuring coil of tangential (right) and prototype of harmonic sensors (left).

Prototypes of harmonic coils(see Figure 8, left) are made from two bonded between a glass fibre laminate conductors to which a coil to a coil wound around a thin conduit with polyamide insulation. In operating the sensor, will be used coils made on PCB technology.

RESULTS AND FUTURE PLANS

Started mass measurements quadrupole magnets. At the moment, held the "warm" test, made a tangential sensor. The results of the measurements are presented in Table 2. The plans in the near future is to build the full harmonic sensor, as well as the launch of the stand string methods to determine the magnetic axis of quadrupole magnets.

Table 2: The Results of the Warm Measurements of the Tangential Sensor

№ of series		L_{eff} [mm]		G [mm]		ΔX [mm]		ΔY [mm]	
		F	D	F	D	F	D	F	D
1		490.106	491.18	0.21538	0.21866	-0.412	-0.4051	5.92E-4	-4.38E-4
	σ	0.009	0.01	6E-6	7E-6	4E-4	5E-4	6E-6	7E-6
2		491,20	490,058	0,21859	0,21532	-0,337	-0.327	-6.5E-4	2,08
	σ	0.02	0.007	3E-5	3E-5	0.001	0.002	4E-5	0.01
Average		490.65	490.62	0.21699	0.21699	-0.375	-0.366	-2,9E-5	1,040
	σ	0.02	0.01	3E-5	3E-5	0.001	0.002	3.3E-5	0.007

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