TESTING OF SUPERCONDUCTING MAGNETS FOR NICA BOOSTER SYNCHROTRON

S. Kostromin*, V. Borisov, O. Golubitsky, A. Donyagin, A. Galimov, B. Kondtatiev, S. Korovkin, H. Khodzhibagiyan, A. Kudashkin, G. Kuznetsov, D. Nikiforov, T. Serochkina, A. Shemchuk, A. Starikov, A. Tikhomirov, JINR, Dubna, Russia

Abstract

Serial tests of the SC-magnets of the NICA Booster (0.6 GeV/u, 211 m circumference superconducting booster synchrotron) started at the dedicated facility of LHEP JINR. Magnets' assembly and testing workflow are presented. First results of serial tests are presented and discussed.

INTRODUCTION

The Nuclotron-type design [1] based on a window frame iron yoke and SC coil has been chosen for the NICA booster and collider magnetic system [2] (Figure 1) as well as for the SIS100 synchrotron (FAIR project) [3]. Nuclotron-type magnets include a cold (4.5K) iron yoke and a winding made of a hollow NbTi composite SC cable cooled with a two-phase helium flow [4, 5].

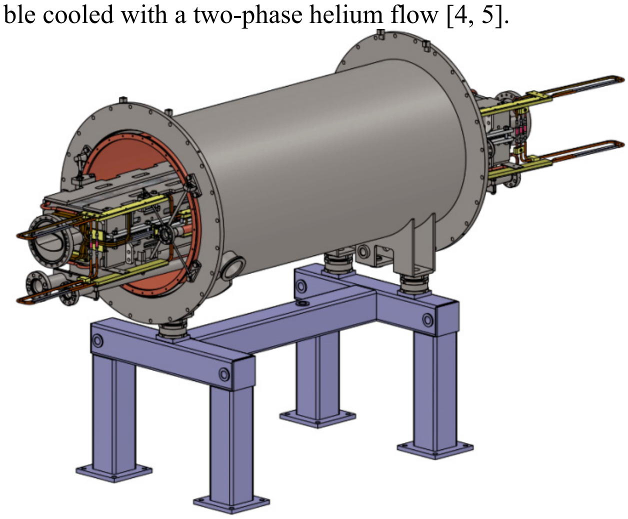

Figure 1: 3D-view of Nuclotron-type dipole magnet module for NICA booster.

MAGNET ASSEMBLY AND TESTING WORKFLOW

Serial assembly and testing of NICA Booster magnets started at end of 2016 at dedicated facility [6, 7]. Assembly and testing process of each sc-magnet at the facility consist of several key-steps: 1) sc-cable cable production; 2) sc-coil production; 3) mechanical assembly of the yoke and coil; 4) room-temperature magnetic measurements; 5) mounting of the yoke interface: cooling channels, insulators, bus-bars supports, helium supply headers; 6) magnet hydraulic resistance check, vacuum tightness check, electrical parameters check; 7) thermometers mounting and check; 8) mounting magnet into cryostat; 9) connecting sc-magnet unit to the feed-box at the cryogenic test hall; 10) cryogenic tests: cool-down, magnet training, magnetic measurements, static heat-leak measurements, dynamic heat release measurements, helium-tightness check, warm up 11) disassembling the magnet and installation of the beam pipe 12) assembling the magnet and storage before mounting in the accelerator ring.

During these operations 11 protocols are filled in. Main parameters of the magnet are checked to verify that exact magnet unit can be taken into accelerator ring assembly.

Magnet aperture geometry after coil and yoke assembly must be performed with accuracy of 50μm according to design drawings (some dimensions have tolerances 20 μm).

MAGNETIC MEASUREMENTS

Magnetic measurements at room temperature (*warm* magnetic measurements) are foreseen to check the magnet geometry and exclude further testing procedures for failed ones. Main magnetic field parameters are taken during *cold* (at 4.5 K temperature) measurements. Tolerances for the NICA booster synchrotron magnets main parameters [8] are shown in Table 1 below.

Table 1: Tolerances to the NICA Booster Magnets Field for B_{ref}= 1.8 T.

	Dipoles	Quads
Relative spread of L_{eff} [σ_{rms}]	± 5*10^{-4}	± 5*10^{-4}
Angle between the magnet median plane and its horizontal plane [mrad]	± 0.5	± 1
Transverse shift of the quad magnetic axis relative to the geometrical one [mm]	-	± 0.1
b_1 *	1	3*10^{-3}
a_1	5*10^{-4}	3*10^{-3}
b_2	5*10^{-4}	1
a_2	5*10^{-4}	10^{-3}
b_3 b_3 at injection field	10*10^{-4} 1*10^{-4}	10*10^{-4}
a_3	5*10^{-4}	10*10^{-4}

*Tolerances of the harmonics b_n, a_n are shown in the relative to the main component (b_1 – for dipoles, b_2 – for quadrupoles) units, measurement accuracy is 10^{-4} to this units. Reference radius is r_{ref}=30мм.

Rotating harmonic coils probes method used for magnetic measurements. Detailed description of the technique is presented in [9, 10]. Booster dipole is curved with radius ~14 m. Measurement probe consist of 5 identical sections with coils connected together by bellow couplings (see Figure 2 and Figure 3). Each section has inside three

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measuring coils made as single multilayered printed-circuit board.

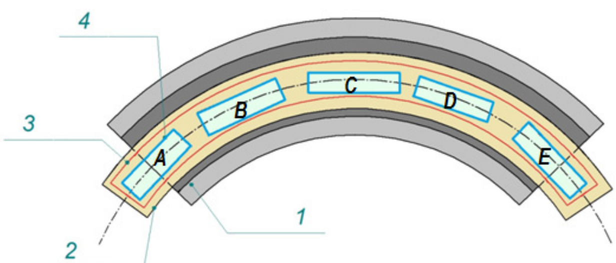

Figure 2: Dipoles' magnetic measurements system (MMS) probe scheme: 1- magnet yoke, 2 – probe support, 3 – additional coil, 4 – measurements sections with the harmonic coils.

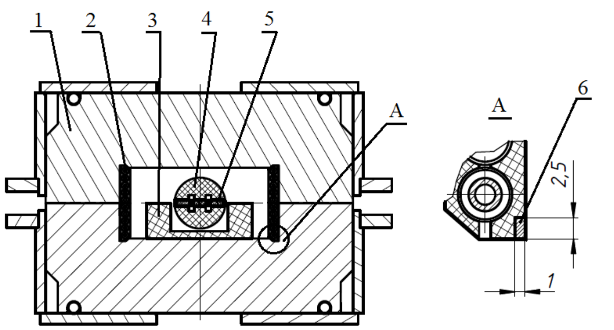

Figure 3: Cross-section of booster dipole with measurements probe inside: 1 – iron yoke, 2 – coil, 3- probe support, 4 – probe rotating part, 5 – rotating coils, 6 – reference coil.

Such a scheme with 5 sections with a straight coils ensures measurements with the relative accuracy 10^{-4}. Coils consist of 400 turns: 20 layers, each of 20 turns. Both type of magnetic measurements, "warm" and "cold", have been performed using same MMS. *Reference coil* consisting of 4 turns located in the corners of magnet yoke aperture used for measuring and calculating of phases of Fourier-harmonics of magnetic field. It is assumed that this coil produces dipole field directed along to geometrical middle plane of the yoke.

In described setup *integrated* harmonics are calculated (Figure 4):

$$a_n = a_{n\_A} + K * (a_{n\_B} + a_{n\_C} + a_{n\_D}) + a_{n\_E},$$

$$b_n = b_{n\_A} + K * (b_{n\_B} + b_{n\_C} + b_{n\_D}) + b_{n\_E},$$

$$L_{eff} = \frac{(b_{1\_A} + b_{1\_E}) \cdot l_к + K * (b_{1\_B} + b_{1\_C} + b_{1\_D}) \cdot l_к}{b_{1\_C}}$$

where $= \frac{3*l_k+4*\Delta l}{3*l_k}$, $l_к$ – length of the coils, Δl – longitudinal distance between coils.

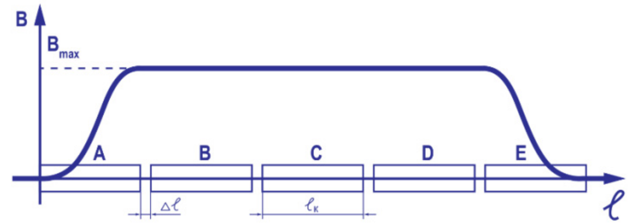

Figure 4: Schematic view of the probe measurement sections relative to the main component field profile.

At the moment 13 dipole magnets, are assembled and have passed all tests, including "warm" and "cold" magnetic measurements. Results are presented below. Relative standard deviation of effective length is shown in Fig. 5 as a function of the magnet excitation.

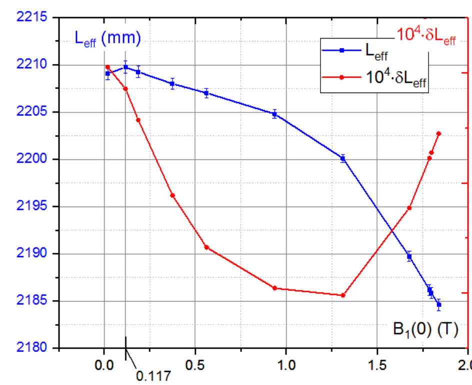

Figure 5: Relative standard deviation of effective lengths vs. the magnetic field intensity in the center.

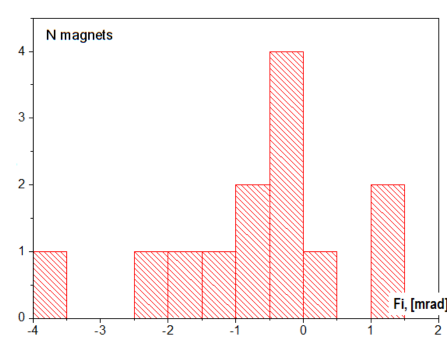

Figure 6: Angle between the magnet median plane and its mechanical horizontal plane.

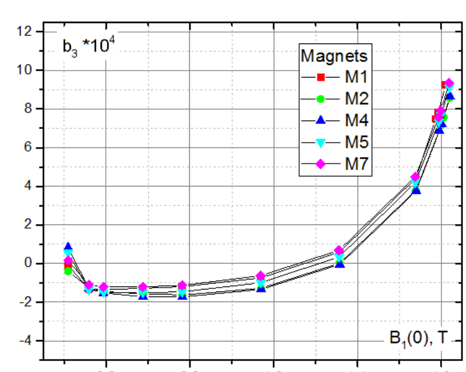

Figure 7: b_3 harmonic vs. the magnetic field in the center for several magnets.

Magnetic measurements program just fulfilled for 2 doublets of NICA booster quadrupoles. The obtained results are under processing. MMS probe for quadrupoles design is based on the harmonic coils rotating within the pipe supporting the magnet poles (see Figure 8).

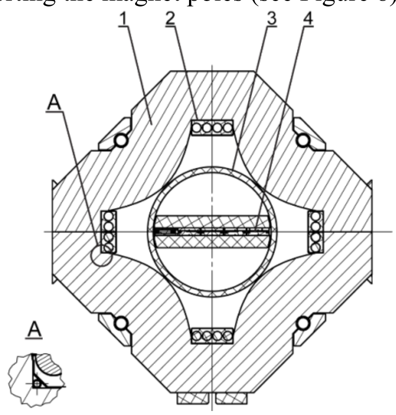

Figure 8: Cross-section of booster quadrupole magnet with measurements probe inside: 1 – iron yoke, 2 – coil, 3- probe coils rotating support, 4 – rotating coils.

CRYOGENIC TESTS

Hall for cryogenic tests of the magnets with 3 helium satellite refrigerators (HSR) [11], equipped with 6 feed boxes with 12 HTS current leads on 18 kA pulse operation. It is intended to provide cold tests of SC magnets simultaneously at 6 benches and is planned to be used for testing of NICA (booster, collider) and FAIR (SIS100 synchrotron) SC magnets. Each of three HSR provides two test benches with liquid helium alternately.

Static heat leaks and dynamic heat releases are measured during cryogenic tests for the each magnet unit. The calculated values are 4.4 and 8.4 W for dipole magnet [4] correspondingly and 4.0 and 0.8 – for quadrupole magnet correspondingly. Measured values are in the agreement with the calculated ones.

CONCLUSIONS

Full testing program is fulfilled for 13 dipoles for NICA booster synchrotron. Values of the magnets effective lengths, field harmonics, static heat releases and dynamic heat leaks are in the agreement with the predicted values and fulfill the technical specification.

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