Cryogenic test facility of superconducting magnets for the accelerator complex NICA

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Abstract. The new accelerator complex NICA is being constructed on the basis of the existing superconducting synchrotron Nuclotron at JINR. NICA will consist of 3 rings of superconducting magnets: the Nuclotron, a booster synchrotron and a two-aperture collider ring. Superconducting dipole and quadrupole magnets for the NICA complex will be manufactured and tested at the new test facility. All the magnets contain a cold iron yoke and saddle-shaped superconducting windings made of the hollow NbTi composite superconducting cable refrigerated by two-phase helium flow at 4.5 K. The cryogenic system of the new facility is based on helium refrigerators with excess return flow. The scheme of the cryogenic testing area of the test facility is presented. A mathematical model of the cooling-down processes of the magnets was developed based on the experimental data for the prototypes of the booster and collider superconducting magnets. The calculated parameters allow us having a shorter time of cooling-down and warming-up of the magnets, thus reaching the necessary productivity of the facility.

1. Introduction
A superconducting accelerator Nuclotron has been operated at the Joint Institute for Nuclear Research (JINR) since 1993 up to now. The project of the new superconducting accelerator complex NICA (Nuclotron-based Ion Collider fAcility) is being developed on the basis of the Nuclotron and planned to have been built by 2017 at the Veksler and Baldin Laboratory of High Energy Physics (LHEP) of JINR [1]. To create this project it is necessary to produce and to test 266 superconducting magnets. The new test bench will be created for these purposes.

2. New test facility
The main purpose of the new test bench is to organize the conveyer production of the quadrupole and dipole superconducting magnets for booster and collider accelerator rings. The magnet design allows having a high rate of cooling and a relatively small distribution of temperature gradient in the magnet yoke. The first dipole magnets for the NICA booster was manufactured and tested in 2011. These magnets are 2.2 m long, weight 1020 kilogram and have a radius of curvature of about 14 m. A full-scale model of the quadrupole magnet for the NICA booster was manufactured at the LHEP in December 2011 [2]. The cryogenic tests of the twin-aperture dipole magnet for the NICA collider were successful performed in June 2013.
The new test facility consists of the following sections: assembling section, warm magnetic test section, vacuum test section and cryogenic test section (see Figure 1.) The first section is intended for assembling iron yoke with superconducting coils. The cooling tubes are soldered to the yoke workpiece. The yoke workpieces of the magnets undergo warm magnetic measurements at the next section. The main goal of the “warm” magnetic measurements is the assessment of the quality of the magnetic field in the gape of the magnet. At the vacuum section the magnet is inserted into the vacuum shell and the mentioned assembly is vacuum – checked. In addition, during the vacuum tests the hydraulic resistance of the cooling channels is tested. After the magnet has been tested, it goes to the cryogenic section. These tests are carried out at the operating temperature and the maximum currents of the superconducting magnet.

3. Cryogenic test bench

The cryogenic system of the new test stand should provide high reliability of production and uninterrupted operation and implement the necessary performance of the stand. The system was developed based on satellite helium refrigerators for the low-temperature tests of the superconducting magnets. The throttle-type satellite helium refrigerator is one of the most reliable cryogenic plants [3]. Therefore, they have been selected for the cryogenic system of the new test facility. The low-temperature test bench includes: satellite helium refrigerator (1), compressed helium pipeline (5), return helium pipeline (6), liquid nitrogen pipeline from the cryogenic storage tank (7), liquid helium pipeline from the Dewar vessel (2), current leads cryostats (3), and superconducting magnet cryostat (4) (see Figure2. ).
The satellite helium refrigerator cools down the superconducting magnet from 300 K to 4.5 K, provides refrigerating at the operating temperature of about 4.5 K and warms up from 4.5 K to 310 K. The cooling capacity of satellite helium refrigerator is 100 W. The cooling of superconducting magnet proceeds in two stages. The first stage is cooling of the magnet by helium flow at the temperature of 80 K. At the first stage the cooling capacity is provided by the nitrogen bath of the satellite. The nitrogen bath is fueled with liquid nitrogen from a cryogenic storage tank. The second stage begins when the output temperature of the helium from the magnet is 120 K. At this stage of the magnet cooling the helium flow temperature is 4.5 K. The second stage of cooling is continued until the temperature of the iron yoke is 4.5 K. Cryostatting is to ensure a constant temperature of the magnet at different heat loads during operation. After the test, the magnet should be warmed up to a temperature of about 310 K.

The new test bench will use high temperature superconducting (HTS) current leads. These HTS current leads can be operated at high intensity current up to 18 kA. They will be operated in pulsed mode. HTS current leads have three cooling stages. The top of the HTS current lead is cooled with water. This is to maintain the positive temperature of the top of the HTS current lead. The middle of the current lead is cooled by liquid nitrogen from the satellite helium refrigerator. The cold gaseous nitrogen flowing to the top heats up and its temperature reaches about 290 K. The lower part of the HTS current lead is cooled by liquid helium.

4. Mathematical model
The mathematical model simulated the thermo-physical processes occurring during the cooling of the superconducting magnets from 300 K to 4.5 K. For modeling, it is necessary to know the design and materials of the magnet and thermo-physical properties of the coolant. As a result, we obtain the evolution of the coolant and material magnet temperatures in each cross-section with a time interval of one second.
The superconducting dipole magnet of the booster was tested. This magnet is 2.2 m long and has a radius of curvature 14 m and weighs about 1 ton. The experimental temperatures of helium in the three main points during the cooling of the dipole magnet are shown in Figure 3. (points). The simulated processes are shown by lines.

![Figure 3. Cooling process of the dipole magnet booster](image)

While modeling for the new cryogenic test bench the cooling period of the booster dipole magnet was 18 hours. According to calculations productivity of the new test bench will be 3 magnets weekly.

5. Conclusions
The full-scale Nuclotron–type superconducting model dipole and quadrupole magnets for the NICA booster and collider were manufactured at LHEP JINR. In the near future cryogenic testing of the all four types of the superconducting magnets prototypes will be performed. The use of mathematical models were projected pace and timing of the production of superconducting magnets for the accelerator complex NICA. The manufacturing and testing of 266 superconducting magnets on the new test bench will take about two years. The commissioning of new test facility is scheduled at end of 2013.

6. References
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