

STATUS OF THE DESIGN AND TEST OF SUPERCONDUCTING MAGNETS FOR THE NICA PROJECT

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Abstract

NICA is a new accelerator complex being under design and construction at the Joint Institute for Nuclear Research in Dubna. The actual design and the main characteristics of superconducting magnets for the NICA booster and collider are given. The magnets are based on a cold window frame iron yoke and a single-layered superconducting winding made from a hollow NbTi composite superconductor cable cooled with the forced two-phase helium flow. The first results of cryogenic tests of the magnets for the NICA project are presented.

INTRODUCTION

The NICA/MPD project [1] started at the Joint Institute for Nuclear Research (JINR) in Dubna in 2007. The goal of the project is to carry out experimental studies of the hot and dense strongly interacting quantum chromodynamics matter and light polarized ions. The NICA accelerator complex will consist of two injector chains, a new 600 MeV/u superconducting booster synchrotron, the existing superconducting synchrotron – Nuclotron [2], and the new superconducting collider having two rings each of about 503 m in circumference.

DESIGN AND MANUFACTURING OF THE PROTOTYPE MAGNETS

The Nuclotron-type design [3-5] based on a cold iron yoke and a saddle-shaped superconducting (SC) winding has been chosen for the booster and the collider magnet. The magnet includes a cold (4.5K) window frame iron yoke and a SC winding made of a hollow NbTi composite SC cable cooled with a two-phase helium flow. Lorentz forces in the winding are supported by the yoke. The main characteristics of the cable for the NICA magnets are given in Table 1. A cross-section view of the booster dipole and quadrupole magnets is shown in Figures 1 and 2, correspondingly. The main characteristics of the NICA booster and collider magnets are summarized in Tables 2 and 3, respectively. A full-scale curved model dipole magnet for the NICA booster was manufactured at the Laboratory of High Energy Physics (LHEP) JINR in April 2011. The magnet is 2.2 m long and has a radius of the curvature of 14 m.

The full-scale model quadrupole magnet for the NICA booster was manufactured by LHEP at the end of 2011.

Table 1: Main characteristics of the cable for the NICA booster and collider magnets

| Characteristic | Booster | Collider |
|---------------------------------|-----------------|-----------|
| Channel diameter | 3 mm | 3 mm |
| Number of strands | 18 | 16 |
| SC strand diameter | 0.78 mm | 0.9 mm |
| Superconductor | 50% Nb – 50% Ti | |
| Diameter of filaments | 7 μ m | 8 μ m |
| Cable outer diameter | 6.6 mm | 7.0 mm |
| Operating current (1.8T, 4.65K) | 9.68 kA | 10.4 kA |
| Critical current (2.5T, 4.7K) | 14.2 kA | 16.8 kA |

The Nuclotron-type design was chosen for the NICA collider. Two identical single-layer windings are located in the common straight iron yoke one over the other (see Fig. 3). Lorentz forces in the windings are supported by the yoke. The yoke consists of three parts made of laminated electrical steel. They are held together by longitudinal steel plates welded with laminations and frontal sheets. The magnets are cooled with the two-phase helium flow which in series passes from the supply header through the cooling channels of the bus bars, lower and upper windings, iron yoke and then - enters the return header. Each twin bore dipole or quadrupole magnet is connected in parallel to the supply and return helium headers.

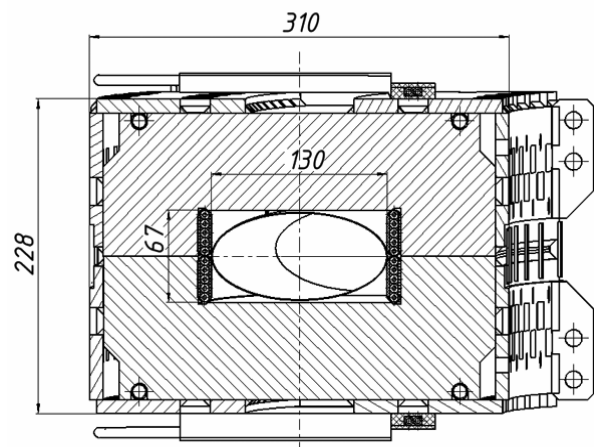


Figure 1: Cross-section view of the bent dipole magnet for the NICA booster.

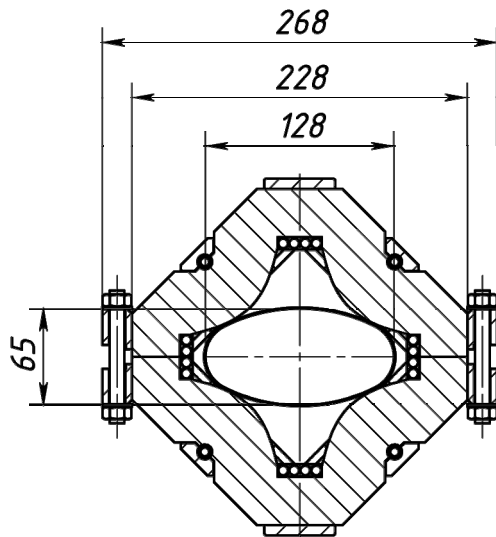


Figure 2: Cross-section view of the quadrupole magnet for the NICA booster.

Table 2: Main parameters of the NICA booster magnets

| Parameter | Dipole | Lens |
|-----------------------------------------|------------------------|--------------|
| Number of magnets | 40 | 48 |
| Maximum magnetic field (field gradient) | 1.8 T | 20.2 T/m |
| Effective magnetic length | 2.2 m | 0.55 m |
| Ramp rate | 1.2 T/s | 13.5 T/(m·s) |
| Field error at R= 30 mm | $\leq 6 \cdot 10^{-4}$ | |
| Beam pipe aperture (h/v) | 128 mm/65 mm | |
| Radius of curvature | 14.01m | - |
| Overall weight | 1020 kg | 110 kg |
| Operating current | 9.68 kA | |

Table 3: Main parameters of the NICA collider magnets

| Parameter | Dipole | Lens |
|-----------------------------------------|--------------------------------------|-----------|
| Number of magnets | 80 | 86 (+12*) |
| Maximum magnetic field (field gradient) | 1.8 T | 23 T/m |
| Effective magnetic length | 1.94 m | 0.46 m |
| Ramp rate | ≤ 0.5 T/s | - |
| Field error at R= 30 mm | $\leq 2 \cdot 10^{-4}$ | |
| Beam pipe aperture (h/v) | 120 mm/70 mm (\varnothing 180*mm) | |
| Distance between the beams | 0.32 m | |
| Overall weight | 1680 kg | 300 kg |
| Operating current | 10.4 kA | |

* - the final focus lens

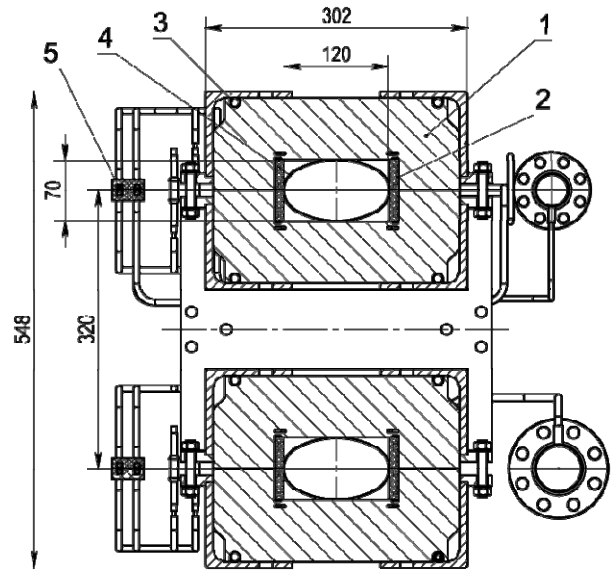


Figure 3: Cross-section view of the twin aperture dipole magnet for the NICA collider: 1 – iron yoke, 2 - SC coil, 3 – tube for cooling the yoke, 4 – beam pipe, 5 - bus - bars.

A twin aperture model dipole magnet for the NICA collider was manufactured at LHEP JINR in August 2011. Production of the model collider twin-bore quadrupole lens with hyperbolic poles (see Fig. 4) has been completed in September this year.

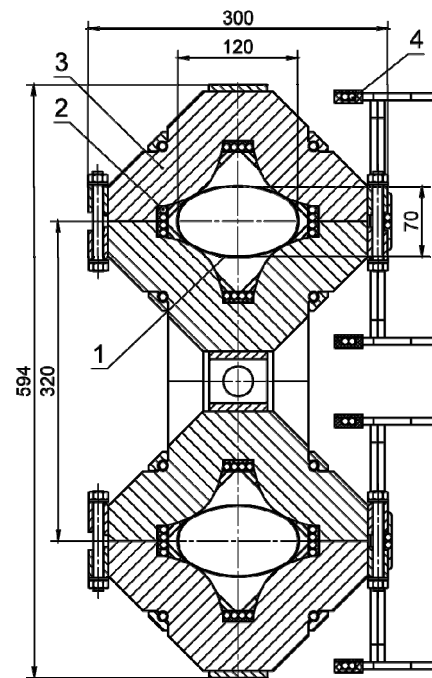


Figure 4: Cross-section view of the quadrupole magnet for the NICA collider: 1 – beam pipe, 2 - SC coil, 3 – iron yoke, 4 – bus - bars.

FIRST NICA MAGNETS TEST RESULTS

A cryogenic test of the first dipole magnet for the NICA booster synchrotron was carried out in May 2011. The first quench occurred at 7705 A. After the 13th quench the current reaches the nominal value of 9690A that corresponds to the magnetic field induction in the gap of 1.8 T. Further training was stopped because of the power supply and current leads limitation.

The measured static (at zero current) heat flow to the magnet was 5.8 W. AC losses of 12 W were measured by means of the calorimetric method while the magnet was operating in the triangular cycle with the magnetic field ramp rate of 1.2 T/s without a pause. This value agrees well with the calculation and confirms the correct choice of steel for the magnet yoke. The pressure drop of the helium flow in the cooling channel of the magnet was 47 kPa during the operation in the indicated mode. Hydraulic resistance of the cooling channel was 2 times higher than the calculated value due to the fact that the cooling channel of the cable has a diameter of 2.6 mm instead of the designed one equal to 3 mm. The new winding of the cable with a cooling channel of 3 mm in diameter was fabricated and installed in the yoke of the magnet in spring 2012. Cryogenic tests of the magnet with the new winding were performed in May 2012. Training for new winding consisted of a single quench at 9475 A. The maximum current in the magnet of 11299 A was determined by quench in the current lead. Measurements of the harmonics of the magnetic field in the aperture of dipole magnet have been done by means of the equipment used for the Nuclotron magnets. Sextupole harmonic of the field in the Booster magnet was about 10 times less than in the Nuclotron magnet. The higher harmonics of the field with the specified equipment was not observed. We are currently developing methods and manufacturing of new equipment for magnetic measurements in the NICA magnets with much higher requirements for the quality of the field in comparison with the Nuclotron magnets. The first phase of the new equipment is scheduled to start operation in mid-2013.

Experimental studies of the booster quadrupole magnet were carried out in spring 2012 after upgrading the power supply on the test bench. The current reached the nominal value of 9690 A after the 4th quench. The measured static heat flow to the quadrupole magnet was 3.3 W. AC losses of 4.4 W were measured by using the calorimetric method while the magnet was operating in the triangular cycle with the following parameters: amplitude of the magnetic field gradient of 20.3 T/m, and ramp rate of 20.3 T/(m·s) without a pause. AC losses as a function of the magnetic field gradient ramp rate are shown in Fig. 5. The pressure drop of the two-phase helium flow in the cooling channel of the lense was 7 kPa during the operation in the indicated mode.

At the moment the construction of the new test facility for cryogenic testing of superconducting magnets is performed at LHEP. Premises with an area of 2,600 m²

were prepared to install the equipment. The manufacturing of a power supply on 15 kA and HTSC current leads are in the final stage. Contracts for the cryogenic and vacuum equipment for the new test facility for parallel testing of the SC magnets on 6 benches are in preparation. Commissioning of the first stage of the new test facility is scheduled for 2013.

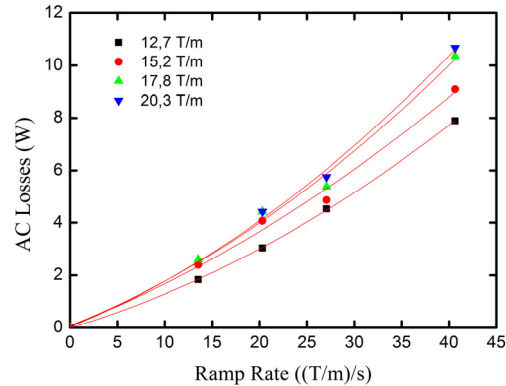


Figure 5: AC losses as a function of the magnetic field gradient ramp rate in the aperture during the operation in the triangular cycle for the NICA booster quadrupole magnet.

CONCLUSIONS

The full-scale Nuclotron-type superconducting model dipole and quadrupole magnets for the NICA booster and collider were manufactured at LHEP JINR. First dipole and quadrupole magnets for the NICA booster have successfully passed the cryogenic test on the bench. The nominal current of 9.7 kA was reached after short training. The magnets were successfully tested in the pulsed mode with a magnetic field ramp rate of up to 4 T/s. The estimated value of the sextupole harmonic of the field in the Booster dipole magnet is about 10 times less than in the Nuclotron magnet. Tests of the model magnet and lense for the collider are scheduled for the autumn of this year. The construction of the new test facility for cryogenic testing of superconducting magnets is in progress.

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