Status of the Design and test of SC Magnets for the NICA Project

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Outline

- NICA/MPD project
- Design of the NICA magnets:
  - SC cable
  - booster magnets
  - collider magnets
- First results of the magnets test
- Conclusion

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NICA/MPD project

- The NICA/MPD project started at 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/MPD complex will consist of two injectors, a new SC booster synchrotron, the existing SC synchrotron – Nuclotron, and the new SC collider with two detectors.

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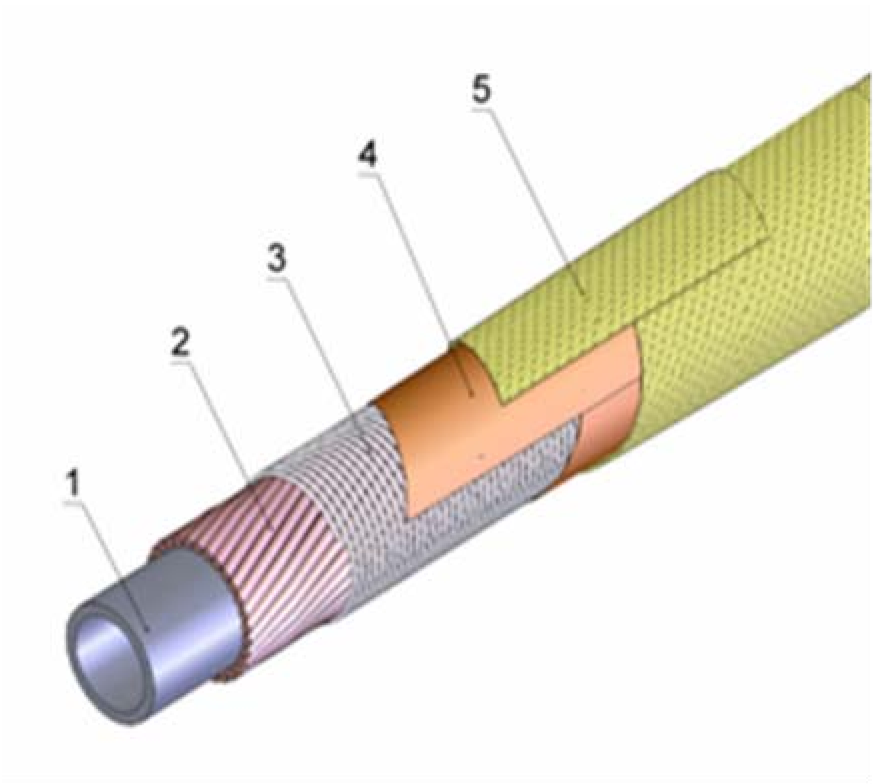
Design of the NICA magnets. *SC Cable*



1. CuNi -tube cooled by two-phase helium flow,
2. Superconducting strand,
3. NiCr-wire,
4. Kapton tape,
5. Glassfaber tape.

Fig. 1. View of the Nuclotron-type cable

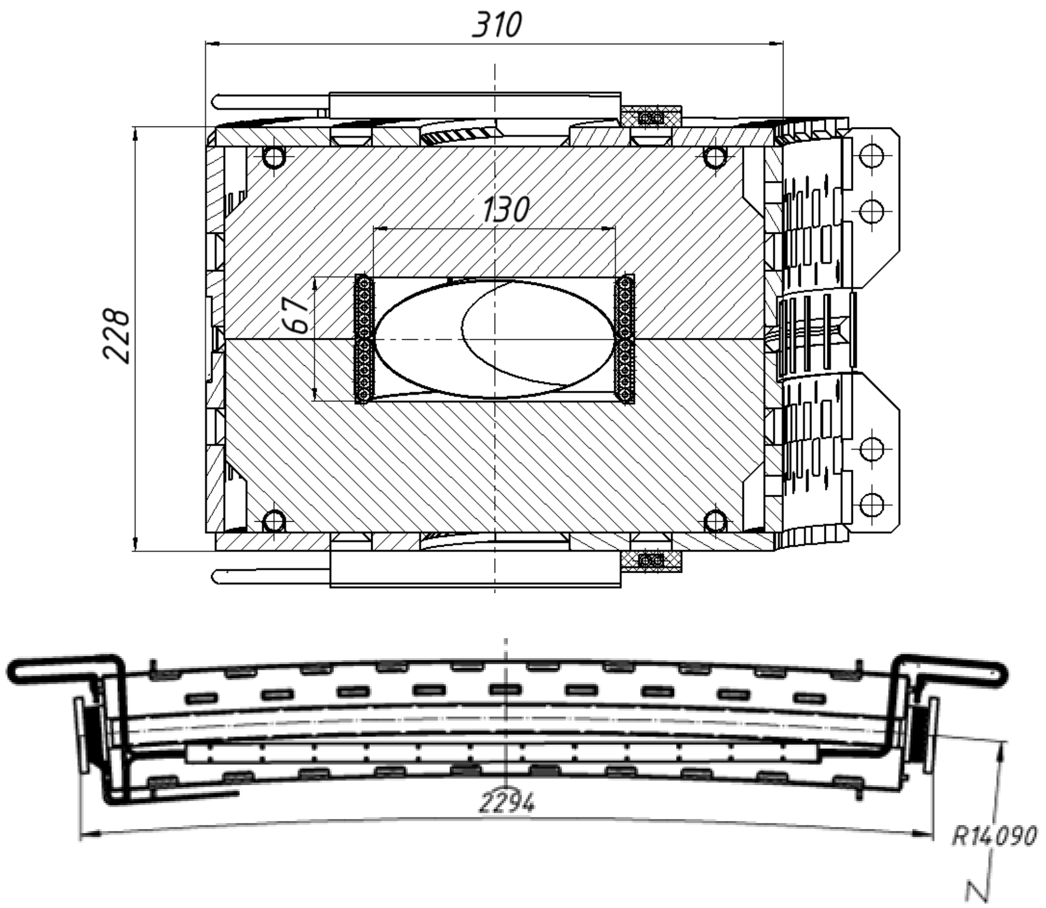
Design of the NICA magnets. *SC Cable*

Table 1. Main characteristics of the cable for the NICA magnets

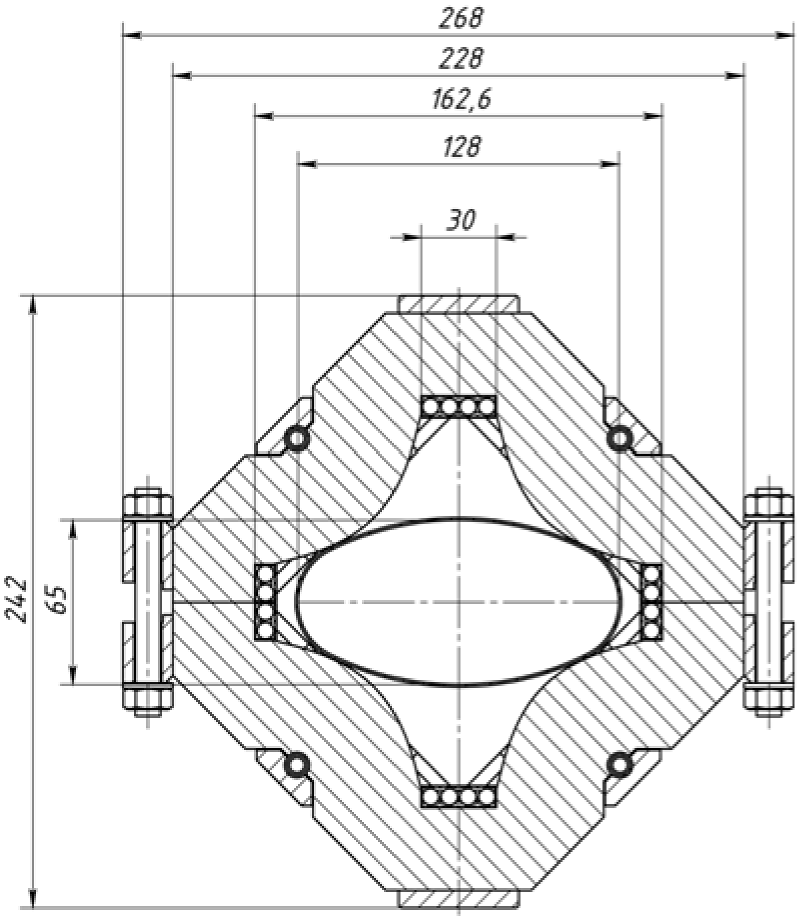
Characteristic	Booster	Collider
Cooling channel diameter, mm	3	3
Number of strands	18	16
SC strand diameter, mm	0.78	0.9
Superconductor	50% Nb – 50% Ti	
Cu/SC ratio	1.26 / 1	1.33 / 1
Diameter of SC filaments, μm	7	8
Twist pitch of filaments, mm	7	9
Cable outer diameter, mm	6.6	7.0
Operating current (1.8T, 4.65K), kA	9.68	10.4
Critical current (2.5T, 4.7K), kA	14.2	16.8

Design of the NICA booster magnets

The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the NICA Booster.



Design of the NICA booster magnets



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

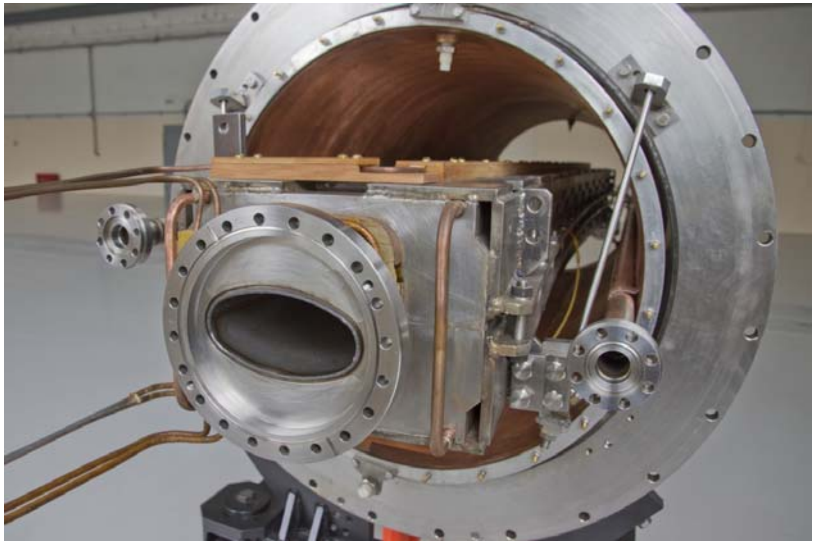
Design of the NICA booster magnet

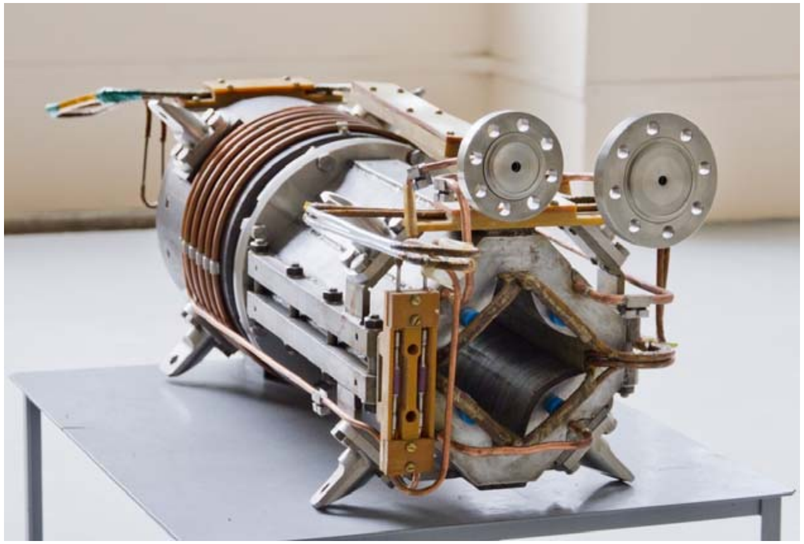
Table 2: Main parameters of the NICA booster magnets

Parameter	**Dipole**	**Lens**
Number of magnets	40	48
Maximum magnetic field	1.8 T	
(field gradient)		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	14.01 m	-
Overall weight	1020 kg	110 kg
Operating current	9.68 kA	

Design of the NICA booster magnet

The prototype dipole magnet with bent single-layer winding was built in April 2011. A full-scale model quadrupole magnet for the NICA booster was manufactured at the LHEP in December 2011.

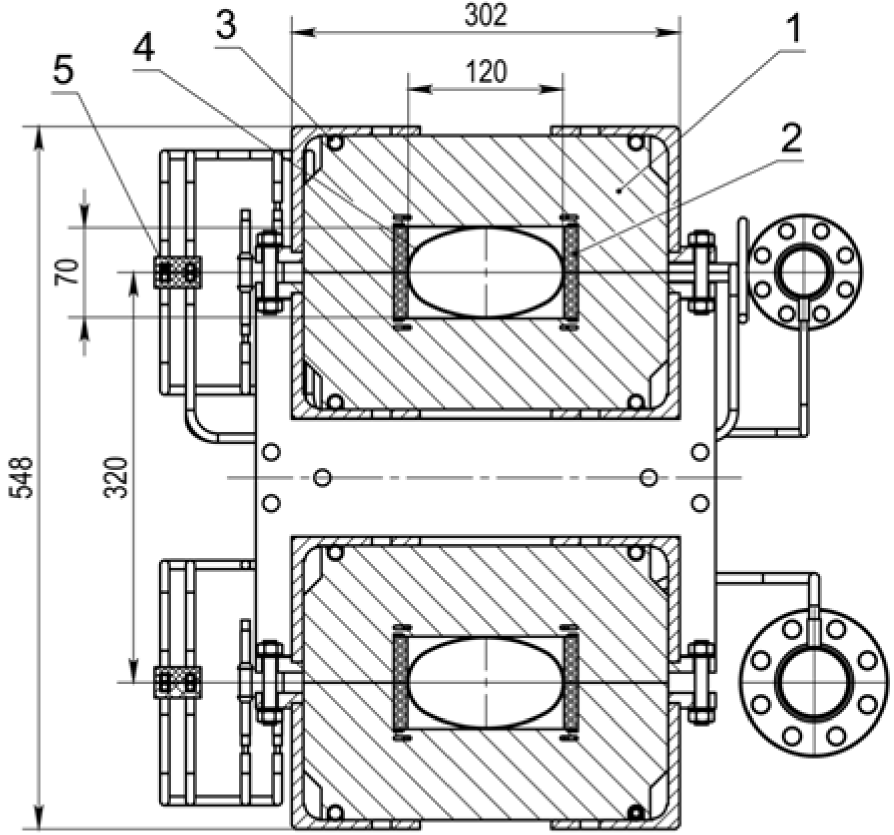




The NICA booster magnets: Installation of the cryostat with the dipole magnet on the bench for the cryogenic test (left) and quadrupole lens before mounting in the cryostat (right).

Design of the NICA collider magnets

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. Lorentz forces in the windings are supported by the yoke.

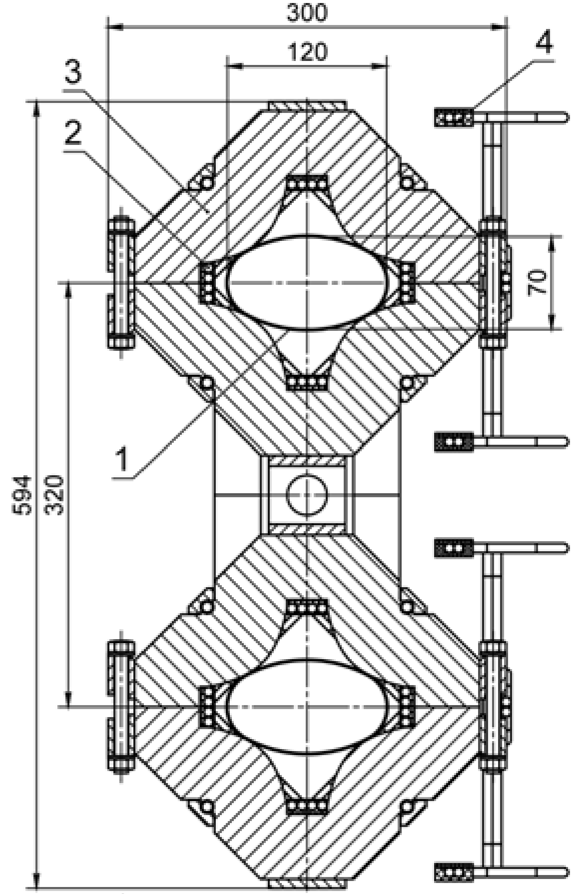


1 – iron yoke,
2 - SC coil,
3 – cooling tube,
4 – beam pipe,
5 - bus – bars.

Cross-section view of the dipole magnet for the NICA collider.

Design of the NICA collider magnets

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 a two-phase helium flow.



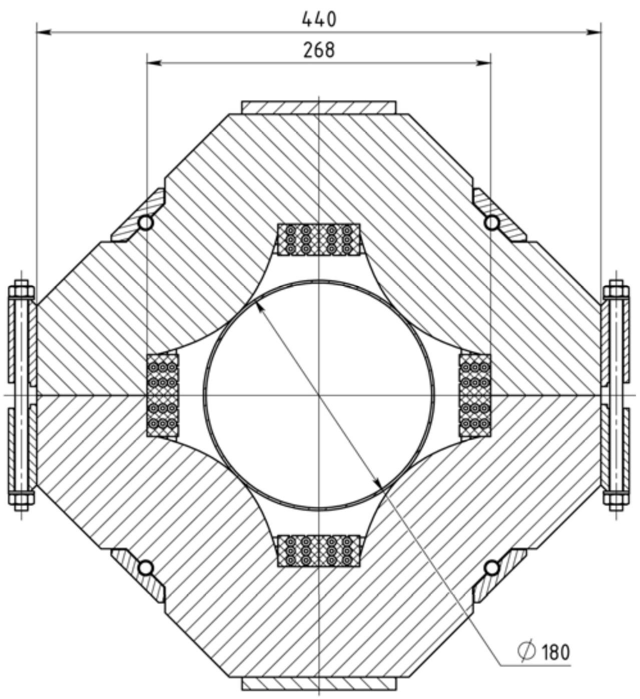
1 – beam pipe,
2 - SC coil,
3 – iron yoke,
4 – bus - bars.

Cross-section view of the quadrupole magnet for the NICA collider.

Design of the NICA collider magnets

Design of the final focus lens should be completed in late 2012.

Production of the first model lens is scheduled for the second half of 2013.



Field gradient G = 19 T/m.

Operating current I = 10.3 kA.

Number of turns per pole – 6.

Pole radius R = 90 mm.

Cross-section view of the final focus quadrupole magnet for the NICA collider.

Design of the NICA collider magnets

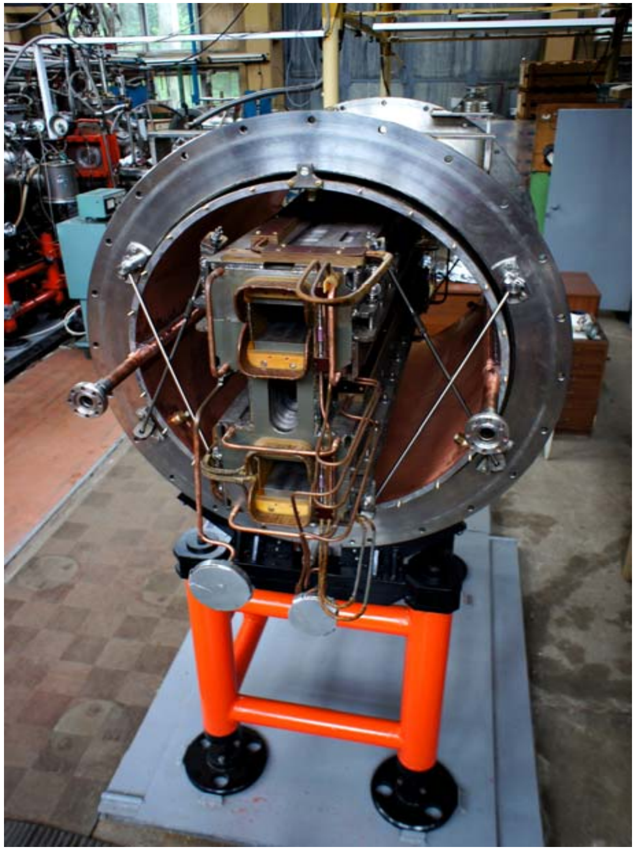
Main parameters of the NICA collider magnets

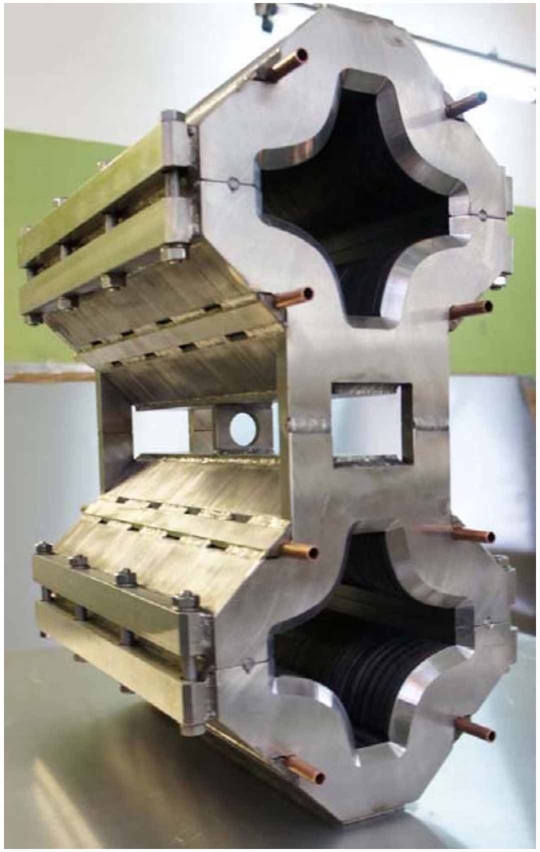
Parameter	Dipole	Lens
Number of magnets	80	86 (+12*)
Maximum magnetic field (field gradient)	1.8 T	 23 T/m
Effective magnetic length	1.94 m	0.46 m
Ramp rate	≤ 0.5 T/s	-
Field error at R= 30 mm	$\leq 2 \cdot 10^{-4}$	
Beam pipe aperture (h/v)	120 mm/70 mm (Ø 180*mm)	
Distance between the beams	0.32 m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

* - the final focus lens

Design of the NICA collider magnets

A twin aperture model dipole magnet for the NICA collider was manufactured at LHEP JINR in August 2011. Manufacturing of the model collider twin-bore quadrupole lens with hyperbolic poles was completed in September this year.





The first NICA collider twin-bore dipole magnet in own cryostat (left) and iron yoke of the quadrupole lens (right).

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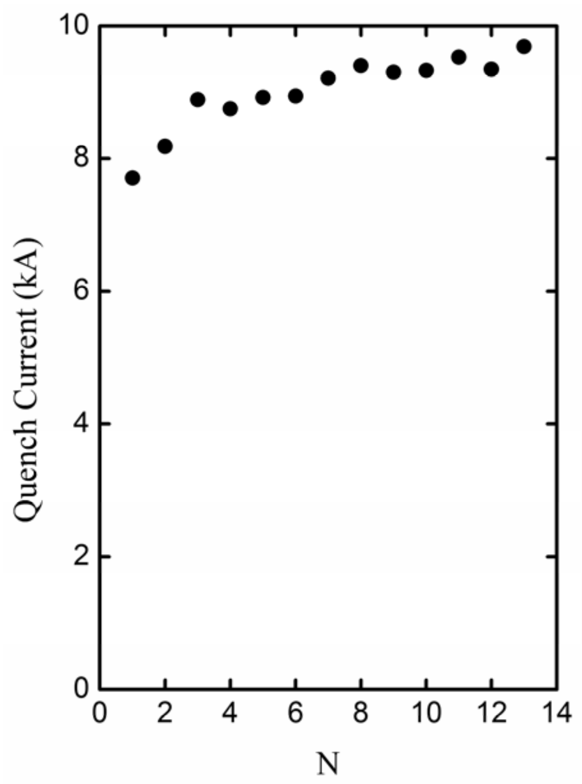
First results of the magnets test.

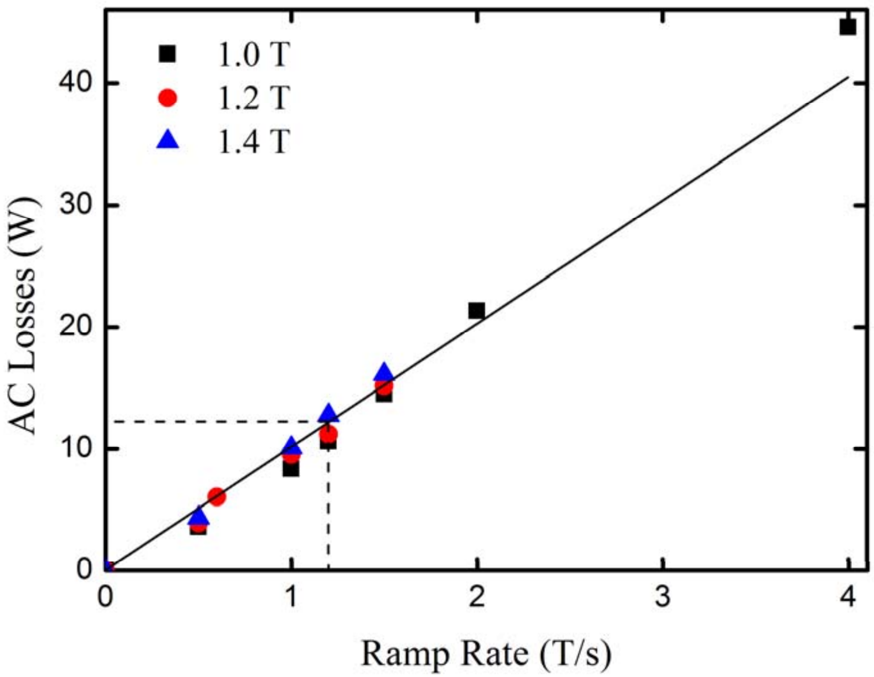
Dipole magnet for the NICA booster

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 9690 A. This corresponds to the magnetic field induction in the gap of 1.8 T. Further training was stopped because of the power supply limitation.



First results of the magnets test.

Dipole magnet for the NICA booster



The measured static 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 a magnetic field ramp rate of 1.2 T/s without a pause. This value agrees well with the calorimetric calculation and confirms the correct choice of steel for the magnet yoke.

First results of the magnets test.

Dipole for the NICA booster with the new coil

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.

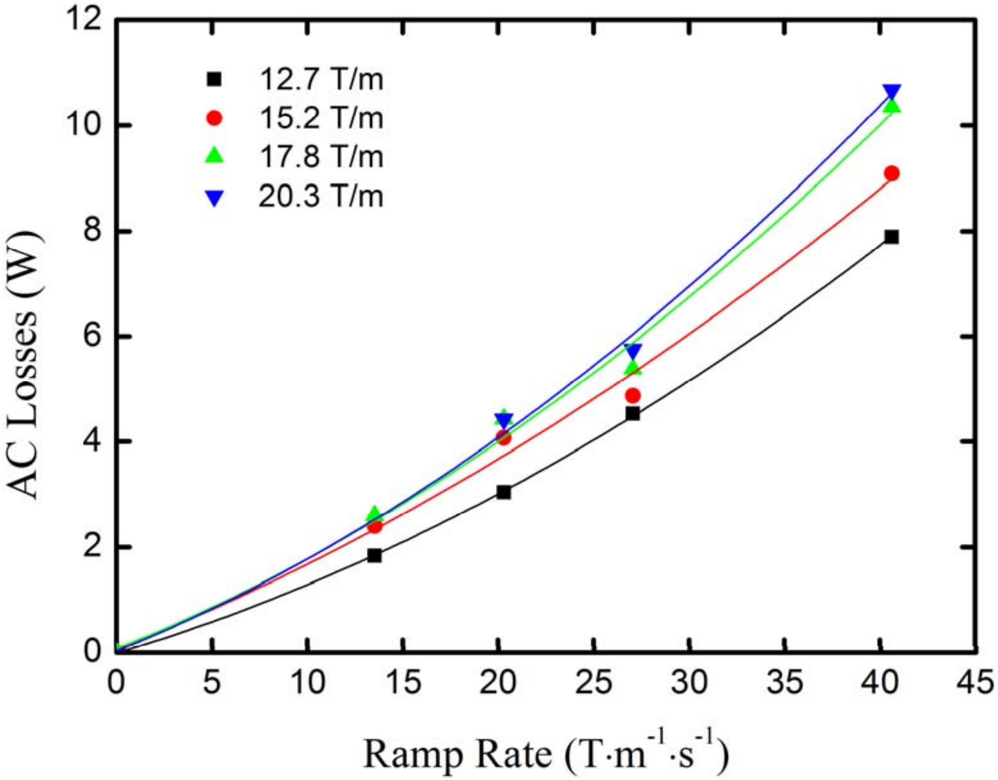
The new coil of the cable with a cooling channel of 3 mm in diameter was fabricated and installed in the yoke of the magnet. Cryogenic tests of the magnet with the new winding was carried out in May 2012. Training for new winding consisted of a single quench at 9475 A. The maximum current in the magnet of 11 299 A was determined by quench in the current lead. Measurement of the harmonics of the magnetic field in the aperture of dipole magnet has been done with the help of equipment that was 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 is not observed.

First results of the magnets test.

Quadrupole magnet for the NICA booster

- 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 4^{th} 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.
- The pressure drop of the two-phase helium flow in the cooling channel of the lens was 7 kPa during the operation in the indicated mode.

First results of the magnets test.
Quadrupole magnet for the NICA booster



AC losses as a function of the magnetic field gradient ramp rate in the aperture for the NICA quadrupole magnet.

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New test facility for SC magnets

- Premises with an area of over 2,600 m^2 prepared for installation of equipment.
- Supply of HTSC current leads and power supply of 15 kA are scheduled for early October 2012 and Spring 2013, correspondingly.

New test facility for SC magnets

- Contracts for the cryogenic and vacuum equipment for the new test bench, there are 6 terminals for parallel testing of the SC magnets, are in preparation.
- Commissioning of the first stage of the new stand is scheduled for 2013.

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Conclusion

- 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 measured values of AC losses and the pressure drop of the helium flow in the cooling channel agrees well with the calculation.
- Tests of the model magnet and lens for the collider are scheduled for autumn of this year.
- New facility for testing the SC magnets is under installation of technological equipment.

Thank you for your attention