SC MAGNETS: Fabrication & Test

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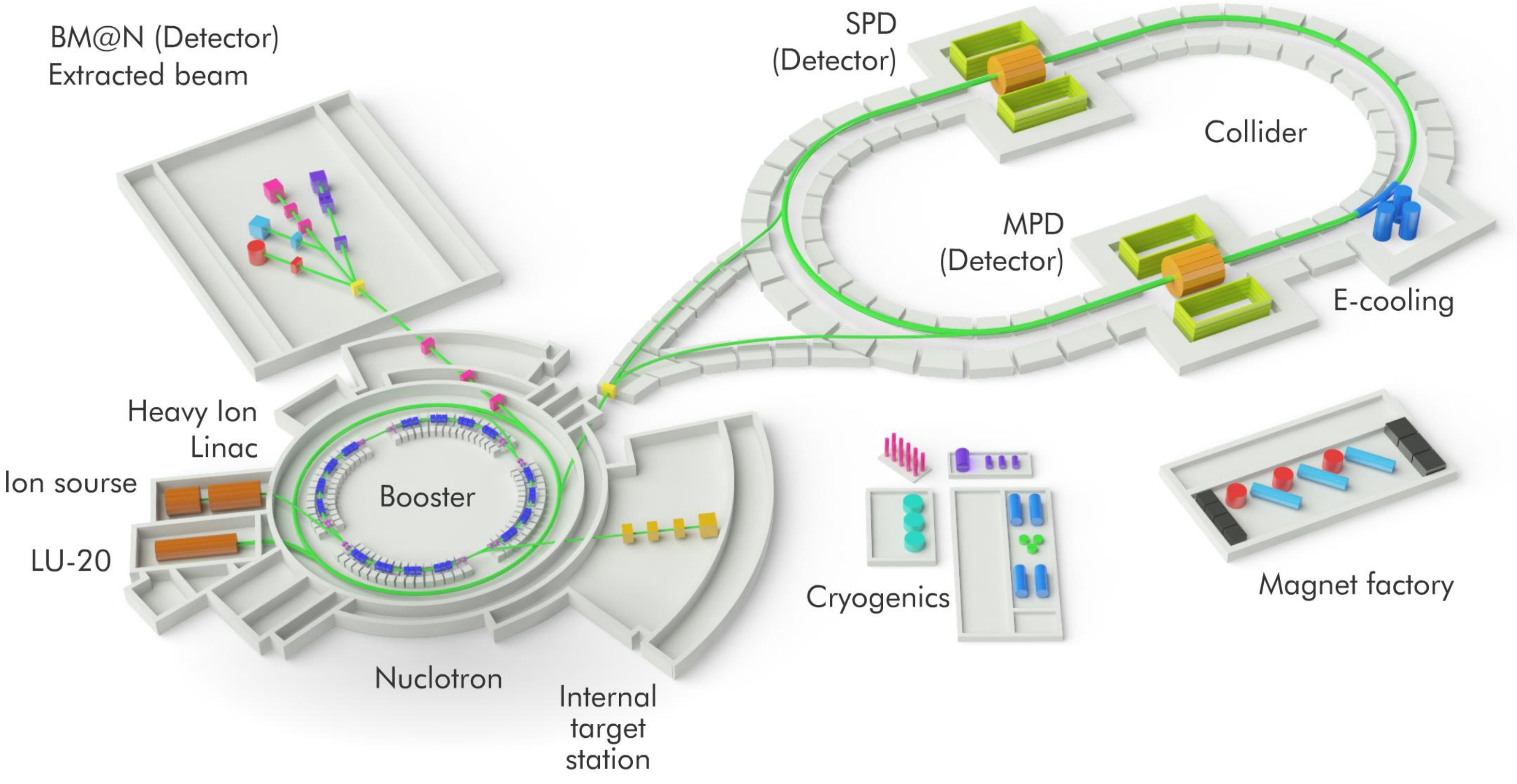
for the NICA team

Outline

- Introduction, SC magnets in NICA complex
- Design of the magnets
- Status of magnets manufacturing and test
- Facility for SC magnet assembling and cryogenic tests
- Conclusion

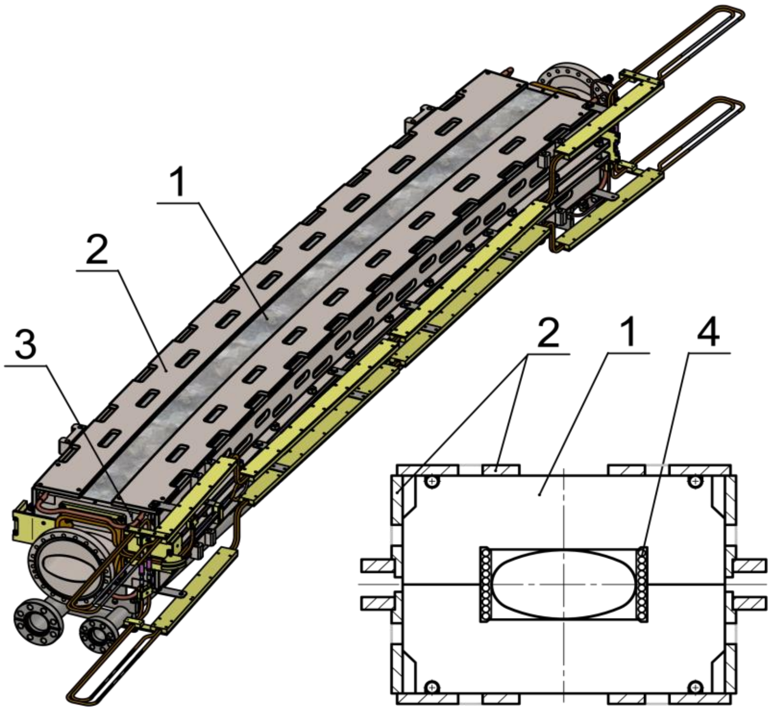
NICA accelerator complex

- two injector chains
- new 600 MeV/u SC booster synchrotron
- upgraded SC synchrotron Nuclotron
- SC collider 503 m in circumference with luminosity up to $1 \cdot 10^{27}$ cm^{-2} s^{-1} for Au^{79+}
- two interaction points with MPD and SPD detectors



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.



View of the dipole magnet. 1 – lamination, 2 - side plate, 3 - end plate, 4 – SC coil.

The iron yoke consists of two symmetric parts bolted together. The half-yokes are fabricated of laminated isotropic 0.65 mm thick electrical steel M 530. The laminations are compressed with specific pressure of 5 MPa in the direction of the longitudinal axis of the magnet. The side plates, 10 mm thick, are welded with laminations and 20 mm thick stainless steel end plates.

Design of the NICA booster magnets

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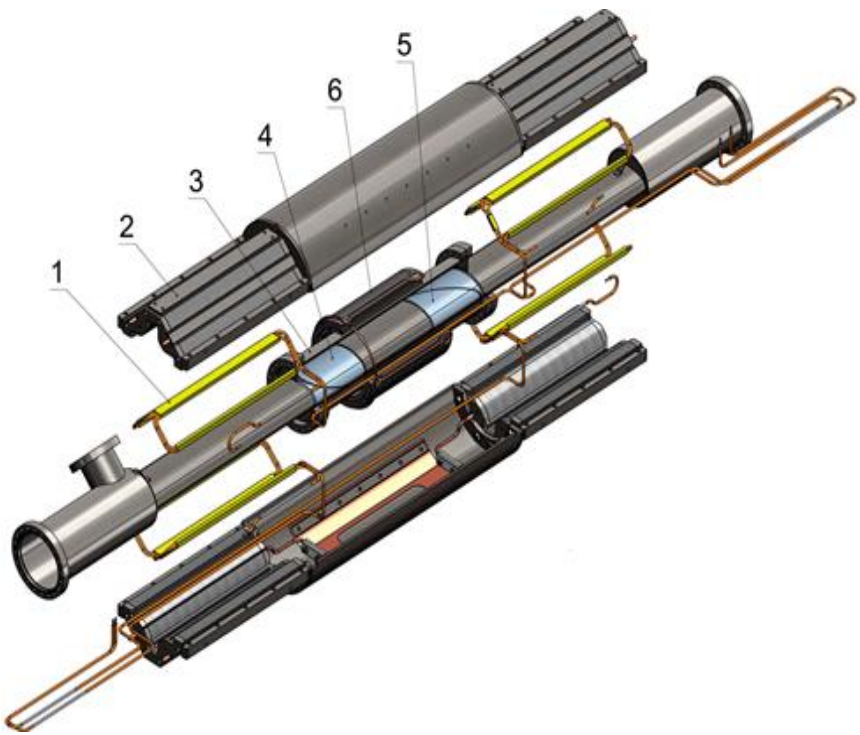
Two lattice lenses are connected together using the intermediate cylinder and form a doublet (see Fig. 1). The doublet of about 1.8 m length has a rigid mechanical design. It has a demountable construction that allows splitting the doublet into two horizontal parts to install the beam pipe. The doublet fixed in the cryostat by means of suspension rods and adjusted in space as one unit.



View of the doublet of the lenses. 1 – half-coil, 2 – half-yoke, 3 – beam pipe, 4, 5 – beam position monitors, corrector magnet

SC Cable

Main characteristics of the cable for the SC magnets

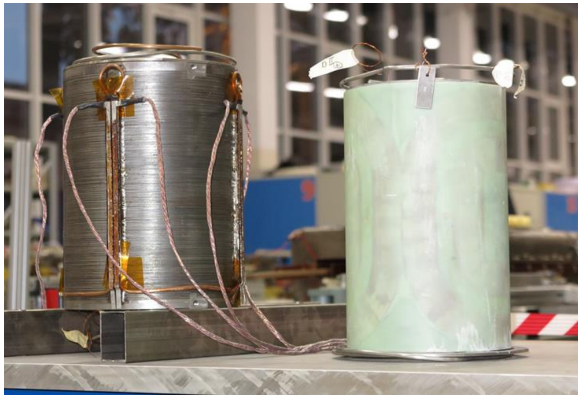
Parameter	Booster	Collider	SIS100 QP
Cooling channel diameter, mm	3	3	4.7
Number of strands	18	16	23
SC strand diameter, mm	0.78	0.9	0.8
Superconductor	Nb – Ti		
Cu/SC/CuMn ratio	1.26 / 1 / 0	1.33 / 1 / 0	2.2 / 2.3 / 1
Diameter of SC filaments, μm	7	8	3
Twist pitch of filaments, mm	7	9	7
Cable outer diameter, mm	6.6	7.0	8.38
Operating current (1.8T, 4.65K), kA	9.68	10.4	10.5
Critical current (2.5T, 4.7K), kA	14.2	16.8	21.0

Main Characteristics of the Magnetes for NICA Booster

Parameter	Dipole	Lens
Number of magnets	40	48
Max. magnetic field (gradient)	1.8 T	21.5 T/m
Effective magnetic length	2.2 m	0.47 m
Beam pipe aperture (h/v)	128 mm/ 65 mm	
Radius of curvature	14.09 m	-
Overall weight	1030 kg	110 kg

Status of Manufacturing the Magnets for NICA Booster

- Yoke of the Dipole Magnets – 36 or 90%
  Coil of the Dipole Magnets - 24 or 60%
- Yoke of the Quadrupole Magnets – 48 or 100%
  Coil of the Quadrupole Magnets - 38 or 79%
- Yoke of the Corrector Magnets – 26 or 80%
  Coil of the Corrector Magnets - 2 or 6%
- Cryostat for magnets – 71 or 100%



Status of Manufacturing the Magnets for NICA Booster

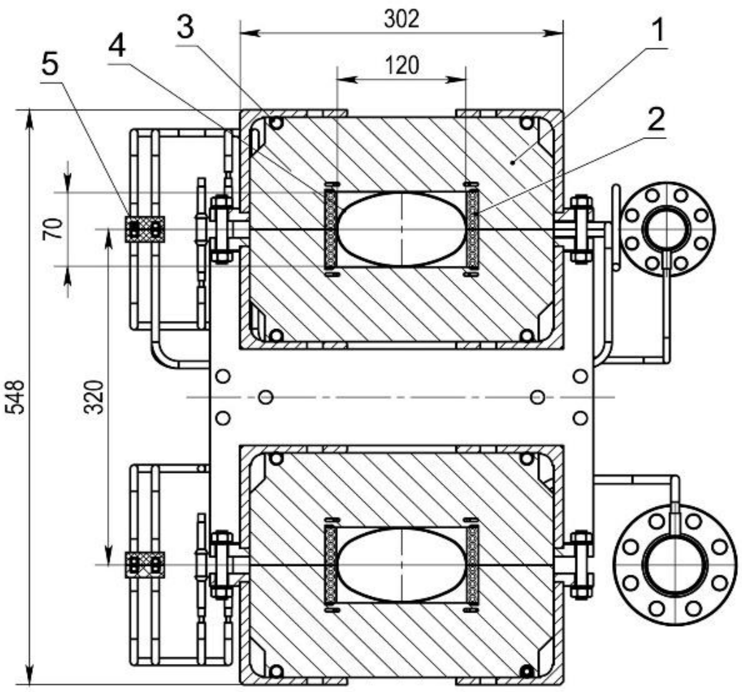
- Supports for the magnets – 71 or 100%
- Bellows for cryostats – 142 or 100%
- HTSC current leads on 10 kA – 10 or 100%
- Beam pipe for dipole magnets – 0%, pilot batch of 6 pcs.

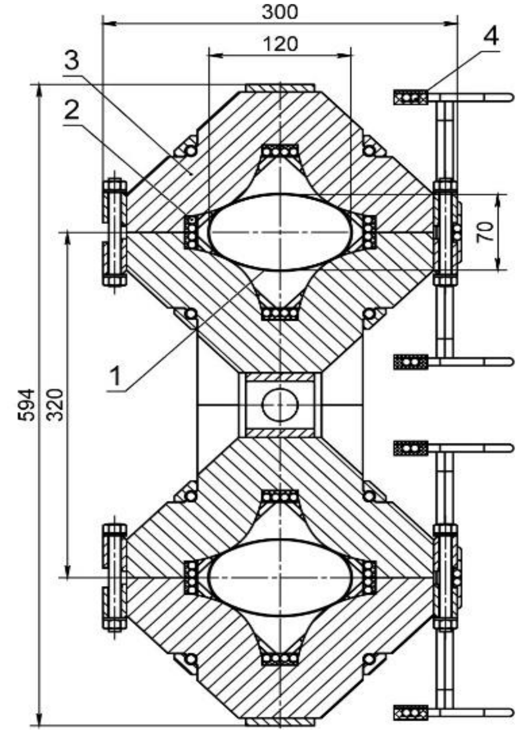
Beam pipe for doublets - 0%, in manufacturing stage

- Beam position monitor – 0%, in manufacturing stage

Design of the NICA Collider 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 Collider.





Cross-section of the collider magnets: Dipole magnet (left): 1 – lamination, 2 – SC coil, 3 – tube for cooling the yoke, 4 – beam pipe, 5 – bus bars; Quadrupole lens (right): 1 – beam pipe, 2 – half-yoke, 3 – lamination, 4 – bus bars. All dimensions in mm.

Main Characteristics of the NICA Collider Magnets

Parameter	Dipole	Lens
Number of magnets	80+8*	86+12**
Max. magnetic field (gradient)	1.8 T	23.1 T/m
Effective magnetic length	1.94 m	0.47 m
Beam pipe aperture (h/v)	120 mm / 70 mm	
Distance between beams	320 mm	
Overall weight	1670 kg	240 kg

*- the final focus lens;

**- the magnet for the vertical movement of the beams

Production of the NICA Collider Magnets

- The cryogenic test of pre-serial dipole magnet and the start of series production of the SC magnets for the NICA collider are scheduled for mid of 2017.
- A pilot batch of six cryostats for dipole magnets was manufactured.
- The completion of manufacturing of 350 bellows for cryostats is scheduled for 2017.
- The delivery 300 km of SC wire for the NICA collider magnets is nearing to completion.
- 380 tons of electrical steel for the magnet yokes were ordered.

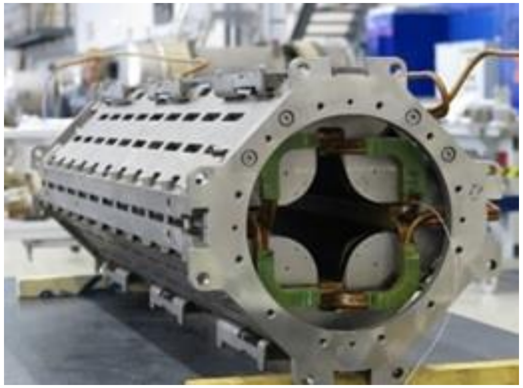
Magnets for the SIS100 Synchrotron

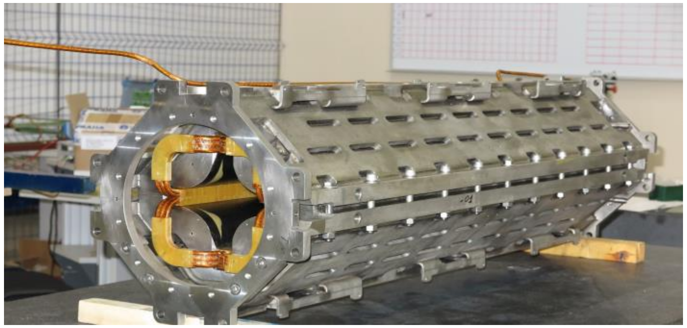
All SIS100 lattice quadrupole and corrector magnets have to be made in JINR, Dubna. The Nuclotron-type design based on a cold, window-frame iron yoke and a winding of the hollow superconductor was chosen for the SIS100 magnets.

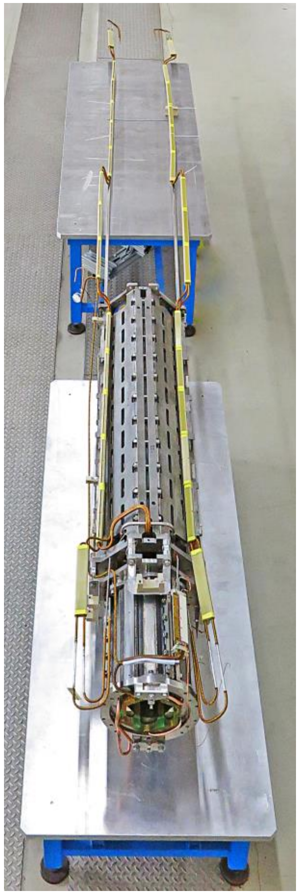
Characteristics of the SIS100 magnets

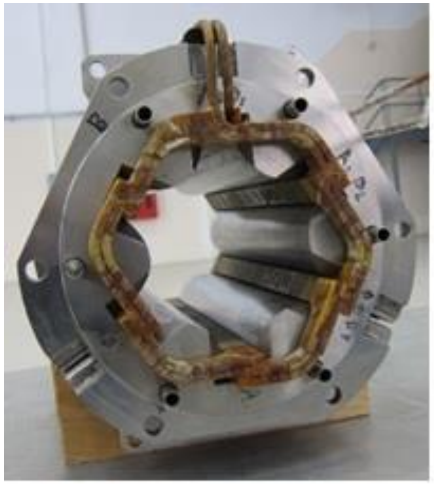
Parameter	Lattice Quadrupole	Corrector magnet		
		Multipole (Q/S/O)	Steerer	Chrom. Sextupole
Number of magnets	166	12	84	42
Max. field strength, T/m^{n-1}	27.77	0.75/25/333,3	0.37	232
Effective magnetic length, m	1.264	0.75	0.403/0.41	0.383
Aperture diameter, mm	100	150	135	120
Operation current	10512	250/246/240	245/241	252
Magnet weight, kg	850	200	120	145

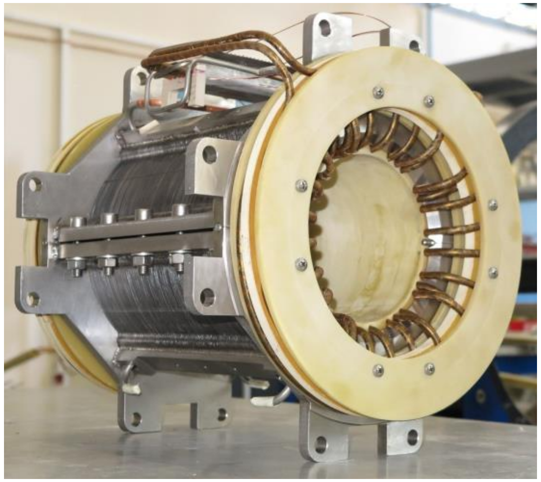
Magnets for the SIS100 Synchrotron











- A sextupole, a steerer and two quadrupole magnets were manufactured.
- Two FoS units of this magnets were assembled and prepared for cryogenic test.
- The beginning of the serial production of SC magnets for SIS100 in Dubna is scheduled for November 2017.

Facility for SC Magnets Assembling and Cryogenic Tests

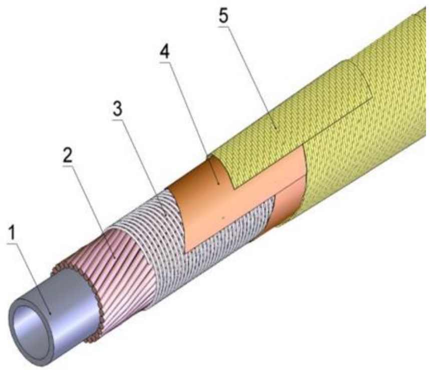
- Test facility in full configuration was commissioned in November 2016.
- 33% of the dipole magnets and 10% of the doublets for the NICA booster synchrotron have successfully passed the tests.

Facility for SC Magnets Assembling and Cryogenic Tests

The test facility includes the following sections:

- Manufacture of the SC cable
- Manufacture of the SC coils
- Assembly of coil with yoke and soldering of cooling channels
- Electrical and hydraulic measurements
- "Warm" magnetic measurements
- Vacuum testing
- Placing the magnet in a cryostat
- Cryogenic system, including three helium refrigerators, compressor and liquid *He* and N_2 supply
- 6 test benches operating in parallel
- 2 power converters and 12 HTSC current leads on 12 kA

SC Cable Production



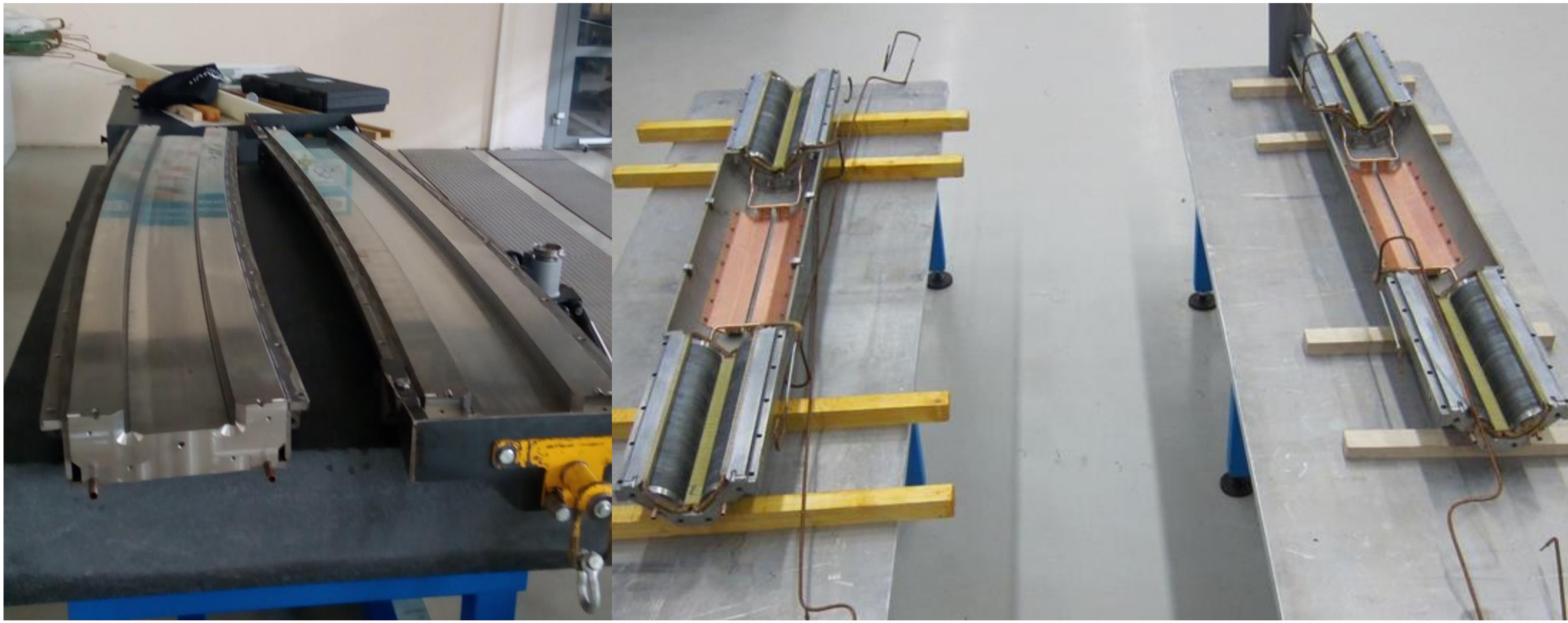
View of Nuclotron-type cable:
1 – cooling tube, 2 – SC wire, 3 – Ni-Cr wire, 4 and 5 - insulation

Machine for production Nuclotron-type superconducting cable

Production of SC Coil

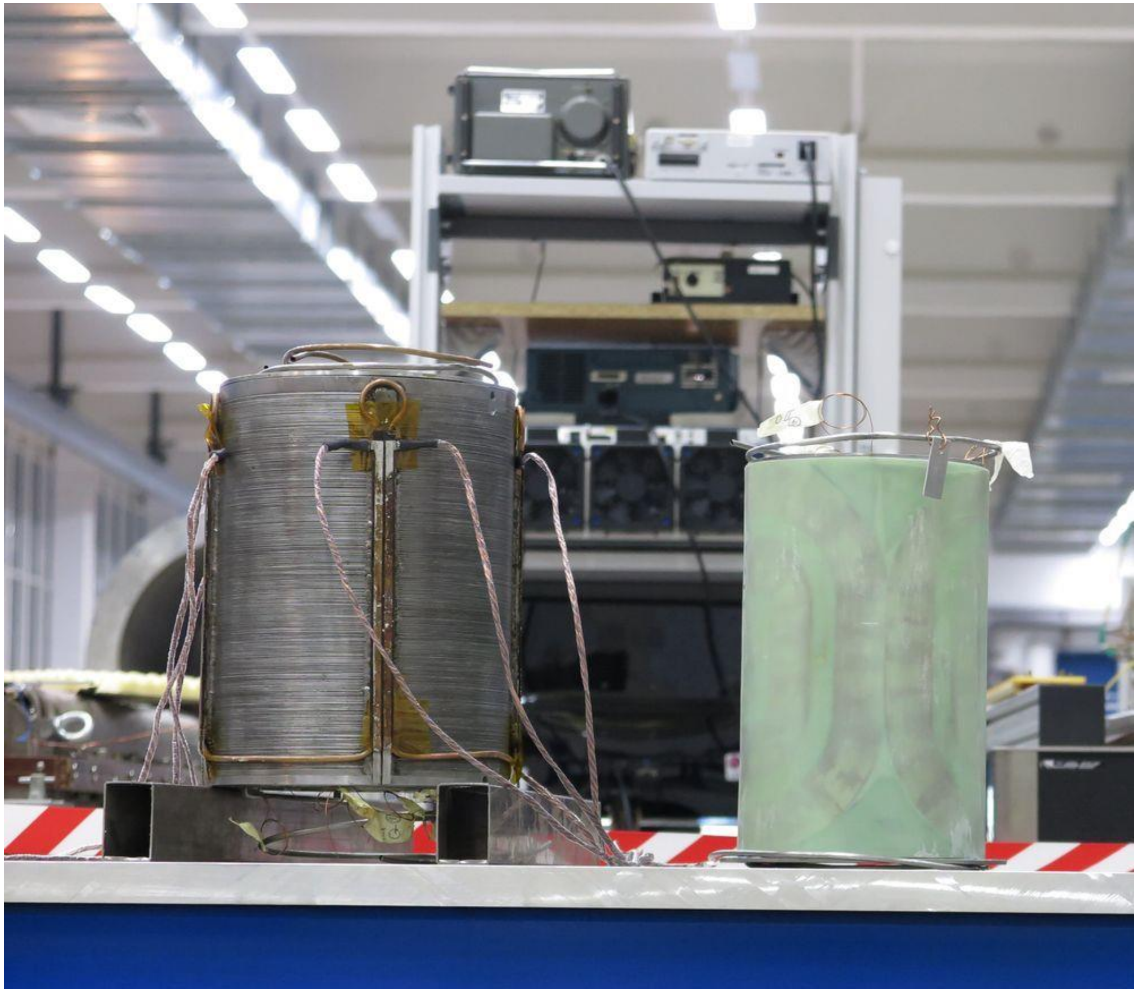
SC Coil manufacturing

Coil with Yoke Assembling

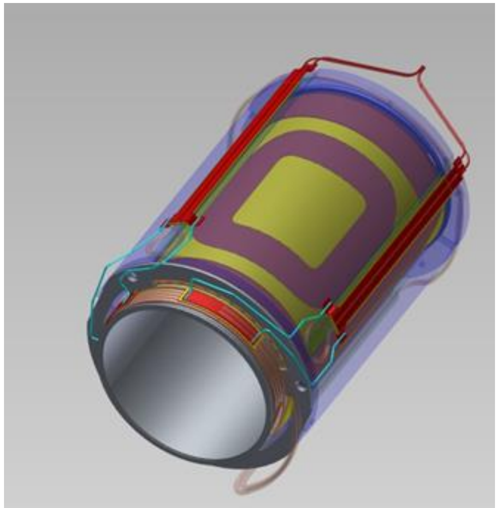


Half-coils assembling with half-yokes for the booster dipole magnet (left) and doublet of the lenses (right)

Corrector Magnet



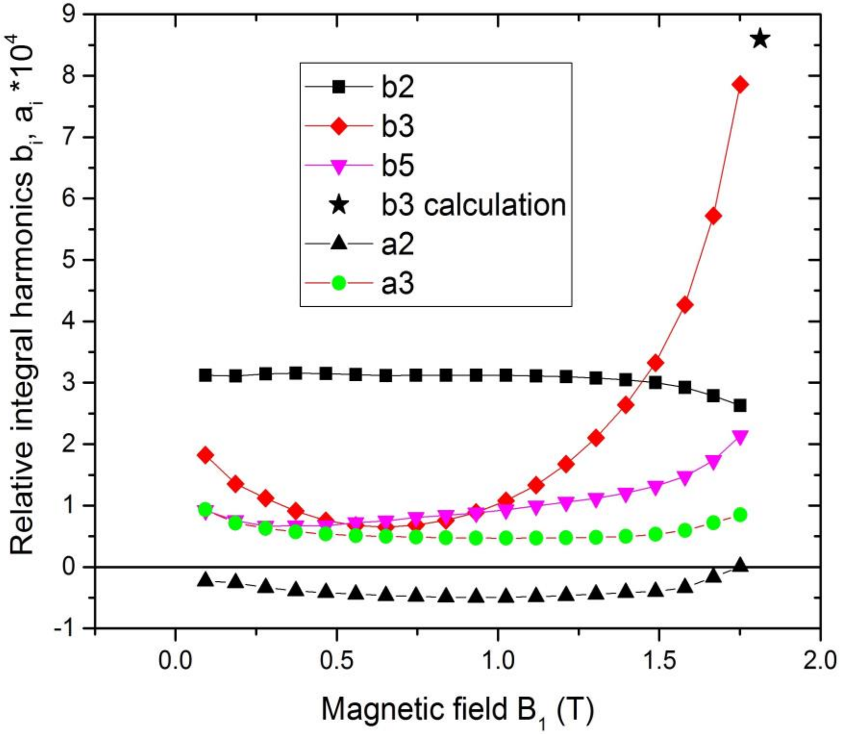
24 steering magnets will have two coils each (horizontal and vertical dipole coils) and 8 corrector magnets will contain four coils each (normal and skew quadrupole and sextupole coils).



The iron yoke (left) and the coil (right) for corrector magnet

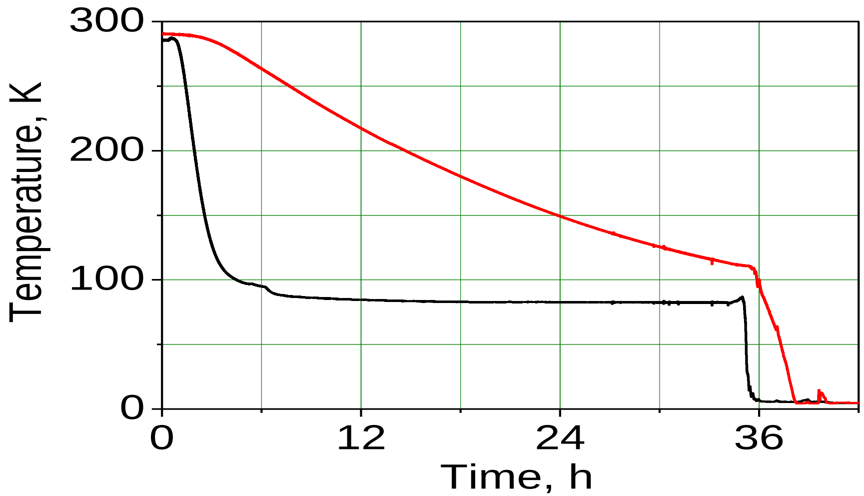
Series Test of the magnets

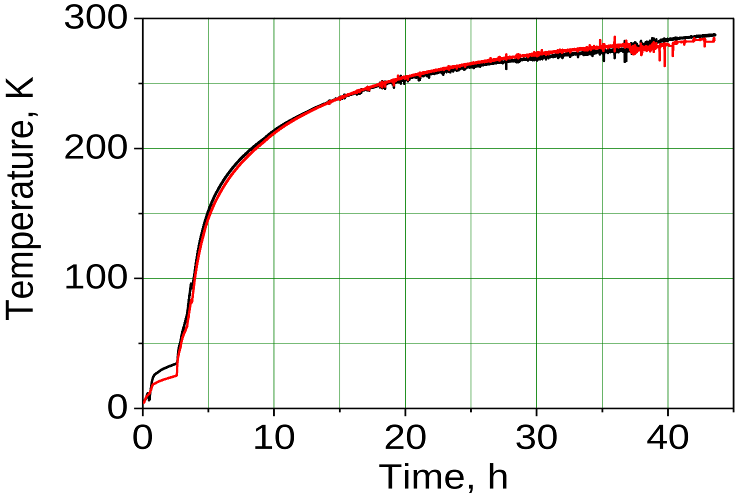
One third of the dipole magnets for the NICA booster synchrotron was successfully passed cryogenic test and can be installed in the tunnel of the accelerator. Magnetic measurements have good repeatability and their magnitude is within the permissible values.



Relative integral harmonics of the magnetic field in the aperture of the NICA booster magnet at the radius of 30 mm as a function of the magnetic field in the magnet center.

Series Test of the magnets





Cooling-down (left) and warm-up (right) of the dipole magnet for the NICA booster. Black line is inlet and red line – outlet of the magnet.

Series Test of the magnets

Series dipole magnet (left) and doublet (center) for NICA booster, and pre series dipole magnet for NICA collider (right).

Conclusion

- Serial production of the magnets for the NICA booster is in the stage of completion.
- Facility for assembling and cryogenic tests of the SC magnets for the NICA and FAIR projects was put into operation in full configuration in November 2016.
- One third of the dipole magnets for the NICA booster was successfully passed cryogenic test and can be installed in the tunnel of the accelerator.
- Completing the cold tests and start installation in the tunnel of the magnets for the booster is scheduled for mid-2018.
- The pre-series dipole magnet for the NICA collider is prepared for cryogenic tests in June 2017.
- The beginning of the serial production of the collider magnets is scheduled for the second half of 2017.
- Two SIS100 FoS units are assembled and prepared for cryogenic test.
- The beginning of the serial production of SC magnets for SIS100 in Dubna is scheduled for November 2017.

Risks and reasons for possible delay in the implementation of the plans

- Too long time is being spent for preparation of contract with suppliers.
- Delays in payment of products under invoices and contracts.
- Deficit of staff of necessary qualifications.
- Delay in delivery of products by suppliers.
- Delay in the delivery of the beam pipes, the beam position monitors and the coils of corrector magnets for the booster synchrotron is alarming.

Thank you for your attention