SUPERCONDUCTING MAGNETS FOR THE NICA ACCELERATOR COMPLEX IN DUBNA

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Abstract

NICA is the new accelerator complex being under design and construction at JINR. The facility is aimed at providing collider experiments with heavy ions up to Uranium in a center of mass energy range from 4 to 11 GeV/u and an average luminosity up to 10^{27} cm-2s-1.The facility includes a new superconducting Booster synchrotron, the existing 6A·GeV superconducting synchrotron – Nuclotron, and the new superconducting Collider .The status of the design and construction of the full size model magnets for the Booster synchrotron as well as for the NICA Collider is presented.

INTRODUCTION

The flagship of the Joint Institute for Nuclear Research in Dubna is now the NICA/MPD project [1, 2] started in 2007. The general goal of the project is to start experimental study of hot and dense strongly interacting quantum chromodynamics matter in the coming 5-7 years. This goal is proposed to reach by: 1) upgrade of the existing superconducting synchrotron – the Nuclotron [3] as a basis for generation of intense beams over the atomic mass range from protons to uranium and light polarized ions; 2) design and construction of the facility to provide collider experiments with heavy ions like Au, Pb or U at luminosity of 10^{27} cm-2·s-1 at the kinetic energy range of 1 - 4.5 GeV/amu; 3) design and construction of the Multi Purpose Detector (MPD). The NICA facility (see Figure 1) includes two injector chains, a new 600MeV/u superconducting Booster synchrotron, the 6A·GeV superconducting synchrotron – Nuclotron, and the new superconducting Collider consisting of two rings of about 500m circumference each.

MAGNETIC SYSTEM OF THE BOOSTER SYNCHROTRON

The main goals of the Booster [4] are the following: accumulation of $4 \cdot 10^9$ Au^{32+} ions; acceleration of the heavy ions up to the energy of 600 MeV/u that is sufficient for stripping the Au ions up to the highest charge state of 79+; forming of the required beam emittance with an electron cooling system. The present layout makes it possible to place the Booster having 211 m circumference and a four fold symmetry lattice inside the yoke of the Synchrophasotron (shut down in 2002). Four large straight sections of the Booster will be used for injection from the linac, single turn extraction to transfer the beams into the Nuclotron, placing of the acceleration cavity and the electron cooler. With a maximum dipole field of 1.8 T, energy of above 600 MeV/u can be reached allowing the stripping of heavy ions up to the bare nucleus state. The magnetic system of the Booster consists of 4 quadrants and each of them has 10 dipole magnets, 6 focusing and 6 defocusing lenses. The multipole

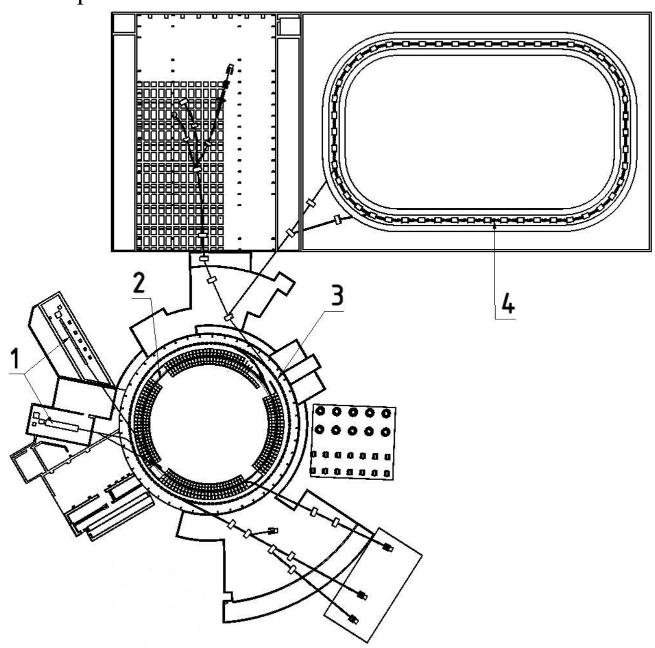

Figure 1: Schematic view of the NICA accelerator complex: 1 - injector chains; 2 - Booster synchrotron; 3 - existing superconducting accelerator Nuclotron; 4 – Collider with two superconducting rings.

correctors are also used to compensate the errors of both the main (dipole, quadrupole) and higher (sextupole, octupole) harmonics of the magnetic field. The required magnetic field in aperture is 1.8 T at the maximum rigidity. The increased aperture of both the lattice dipole and quadrupole magnets is one of the main design features.

The Nuclotron-type design [5] based on a window frame iron yoke and a saddle-shaped superconducting winding has been chosen for the Booster magnetic system. The Nuclotron magnets include a cold (4.5K) window frame iron yoke and a superconducting winding made of a hollow NbTi composite superconducting cable cooled with a two-phase helium flow.

Further development of the technology was proposed [6] to increase the efficiency of the magnetic system. A cross-section view of the Booster dipole and quadrupole magnets is shown in Figs. 2 and 3, correspondingly.

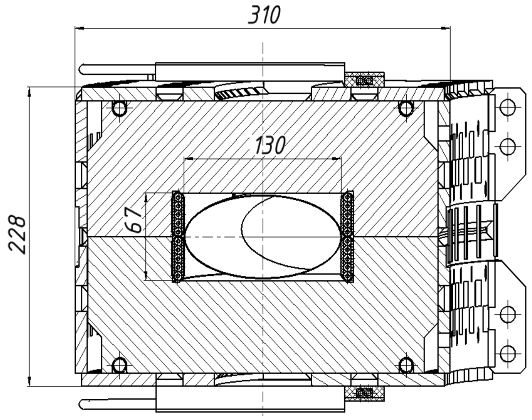

Figure 2: Cross-section view of the Booster dipole magnet.

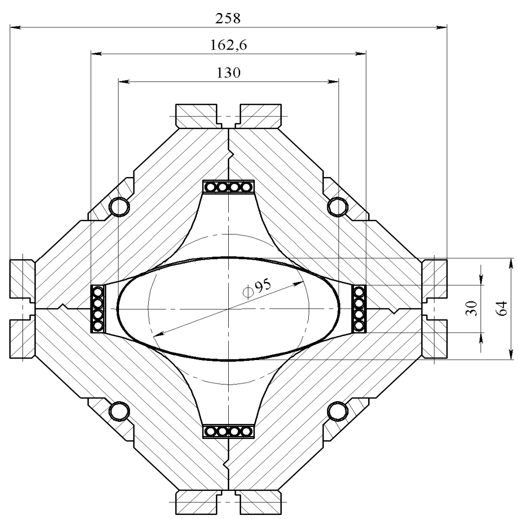

Figure 3: Cross-section view of the Booster quadrupole magnet.

In accordance with this proposal the single-layer winding bent dipole will be built to decrease the magnet cross section and AC losses in comparison with the straight double-layer winding dipole at the same aperture budget by means of the doubled structural current density in a winding. The use of curved (sector) dipoles instead of the straight ones in circular accelerators makes possible the reduction the horizontal size of the magnet useful aperture leading to less AC losses.

MAGNETIC SYSTEM OF THE NICA COLLIDER

The Nuclotron-type design based on a cold, window-frame iron yoke and a saddle-shaped winding of the hollow superconductor was chosen for the NICA Collider. The design of the Collider dipole magnet is shown in Figure 4. Two identical single-layer windings are located in the common straight iron yoke one over the other. Lorenz forces in the windings are supported by the yoke. The yoke consists of three parts made of laminated isotropic 0.65 mm thick electrical steel sheets. They are held together by longitudinal steel plates welded with laminations and frontal sheets. The distance between the beams is 320 mm. The windings are made of a hollow superconducting cable. Sixteen SC strands are spirally wound on a copper-nickel tube 4 mm in diameter. The cable is wrapped with two layers of 0.04 mm Kapton tape and two layers of 0.1 mm epoxy impregnated glass-fiber tape. The bending field in the iron-dominated magnets is limited to approximately 2 T. The field geometry is formed by the iron yoke; therefore at the maximum field of 1.8 T the relative imperfection is less than $2 \cdot 10^{-4}$. The winding current at the maximum field is designed to be 10.8 kA. The NICA Collider will be operated at constant magnetic field, but the power supply system is designed to provide a maximum field ramp of 0.5 T/s. The design of the regular collider twin bore quadrupole lens with hyperbolic poles is in progress. The production technology, assembling and cooling of the dipole and quadrupole magnets are similar.

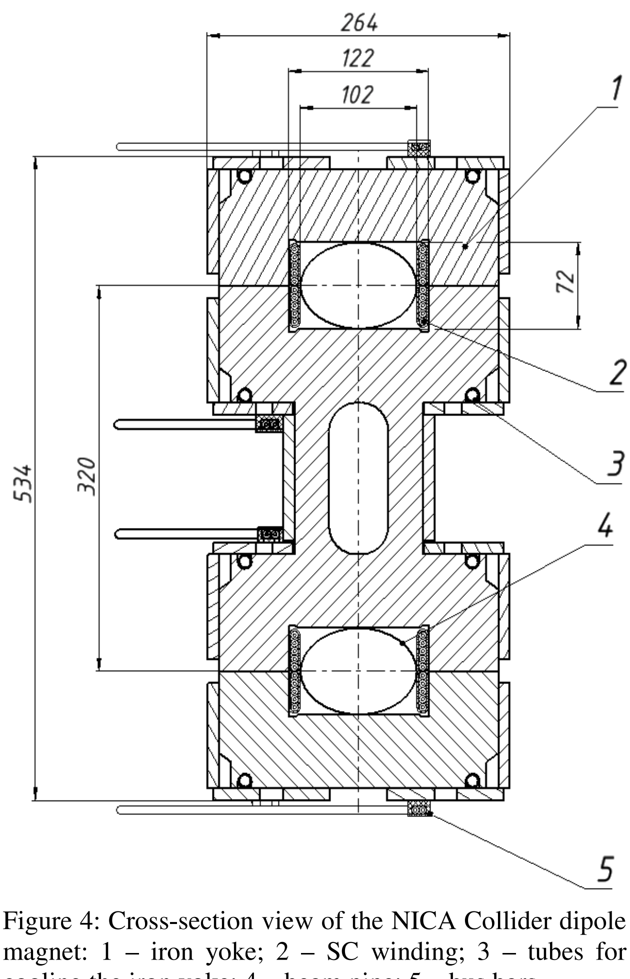

Figure 4: Cross-section view of the NICA Collider dipole magnet: 1 – iron yoke; 2 – SC winding; 3 – tubes for cooling the iron yoke; 4 – beam pipe; 5 – bus bars.

The dipole and quadrupole magnets are cooled with a two-phase helium flow [7] 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. The cooling of the magnets with a two-phase helium flow is justified because it was checked and confirmed by the long-term Nuclotron operation. The mass vapor content of helium at the inlet is kept approximately equal to zero. Hydraulic resistance of the cooling channels of magnets are adjusted so that the mass vapor content of helium at the outlet of the dipole and two type quadrupoles should be identical and equal to 90%. The estimated value of the total heat input to liquid helium in the Collider is 1100 W. The consumption of liquid helium for cooling the current leads is approximately 1.2 g/s.

STATUS OF THE PRODUCTION PROTOTYPE MAGNET

Making a full-scale prototype dipole magnet for the Booster synchrotron is about to be completed. All the components of the magnet yoke (lamination sheets, brackets, and end plates) were manufactured in the industry. Approximately 7000 sheets of isotropic electrical steel 0.65 mm thick were manufactured with high precision using a laser cutting machine.

The yoke assembly and its final machining have been carried out at the LHEP, JINR, in July - August 2010 (see Figure 6). The superconducting wire was made at the Bochvar Research Institute in July 2010. Now the device for winding a curved coil is being manufactured at JINR.

The production of SC cable and winding of the coil at LHEP JINR is planned for September and October 2010.

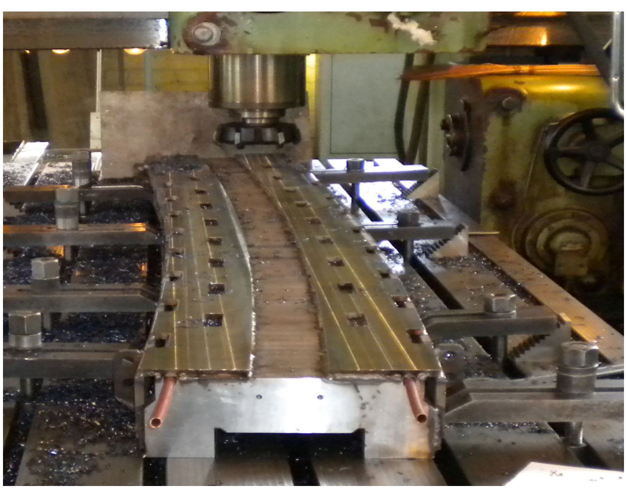

Figure 6: View of the Booster magnet yoke during processing on the milling machine.

The design of the twin bore straight dipole magnet prototype for the Collider was completed and the manufacturing process was started in August of this year. Completion of the full-size Collider magnet production is planned by the end of 2010. Cryogenic tests of both the prototype dipoles and production of the quadrupole magnet prototype for the Booster and the Collider are planned for 2011.

CONCLUSION

In accordance with our R&D program the design and manufacturing of the first NICA Booster and Collider full-size dipole prototype magnets are close to completion which is planned for October and December 2010, respectively. Cryogenic tests of both the dipole prototypes and production of the quadrupole magnet prototype for the Booster and the Collider are planned in 2011.

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