SUPERCONDUCTING MAGNETS FOR THE NICA FACILITY AT JINR: STATUS OF THE DESIGN AND CONSTRUCTION PLANS

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Abstract

NICA (**N**uclotron-based **I**on **C**ollider f**A**cility) is the new accelerator complex being under design and construction at JINR since 2007. The facility is aimed to provide collider experiments with heavy ions up to uranium (gold at the beginning stage) with a centre of mass energy up to 11 GeV/u and an average luminosity up to 10^{27} cm^{-2} s^{-1}. The collisions of polarized deuterons and protons are foreseen also. The accelerator complex includes two injector linacs, a superconducting booster synchrotron, the modernized Nuclotron - 6 GeV/u superconducting synchrotron and a collider consisting of two storage rings. Different modifications of magnets based on a hollow composite NbTi cable at 4.5 K are considered for the NICA booster and collider rings. The twin-aperture collider structural dipole and quadrupole magnet units consist of two vertically assembled cold masses placed inside a common cryostat are fixed as basis for the collider lattice structure. Both 2 T window-frame and 4 T Cosine(θ) dipoles options were considered. The 2 T curved dipole option was recommended for the collider ring circumference longer then 200 m (external option). Design and manufacturing of the first model magnets is in progress. Substantial efforts were devoted rearrangement of the facility for assembling and full-scale tests of different superconducting magnets at the Laboratory. Reaching of the planned production capacity of 2 – 2.5 magnet units per week will make it possible to complete the NICA magnets manufacturing and tests within three years.

INTRODUCTION

The new project, NICA/MPD, was proposed at the Joint Institute for Nuclear Research in 2006 [1]. The main goal of the project is to study experimentally hot and dense strongly interacting QCD matter at the new JINR facility in the upcoming years. This goal is proposed to be reached by: 1) upgrade of the existing accelerator facility Nuclotron; 2) design and construction of a heavy ion collider with a maximum collision energy of $\sqrt{s}$ = 7 GeV/u and an average luminosity of 10^{27} $cm^{-2}\cdot s^{-1}$ [2]. The further discussion of the desired parameters was resulted in the following: 1) maximum c.m. energy of heavy ion collisions was increased up to $\sqrt{s}$ = 11 GeV/u (for gold ions); 2) the study of polarized proton and deuteron collisions at energies up to 27 GeV/u and of 12.7 GeV/u respectively at average luminosity of 10^{30} - 10^{31} $cm^{-2}s^{-1}$ were included in the NICA research program [3]. In addition, realization of asymmetric collisions i.e. p - or d - ion (head-on and merge collisions as well) was requested by the users group [4]. The project presumes also continues operation of the Nuclotron-M for the fixed target experiments. In accordance with the NICA start version, it was planned to install all the components of the new facility within the existing buildings of the Nuclotron accelerator complex, nevertheless the latest extension of the users capabilities of the NICA and the recommendations made by the Machine Advisory Committee in January 2010 lead to consideration and analysis of the other places for installation of the collider ring, in particular, around the existing experimental hall 205 shown in Fig. 1. The chosen place for the booster installation, namely: inside the JINR Synchrophasotron magnet aperture did not changed.

NICA MAGNETS DESIGN APPROACH

Basically, the NICA magnets design is similar to that was proposed and used for the Nuclotron magnets and the improvements have been done later on. These are cold iron magnets with the coils made of hollow NbTi composite cable cooled with forced two-phase helium flow at 4.5 K. The use of hollow cable makes it possible, in particular: 1) to restrict the volume of coolant (for example, liquid He in the case); 2) to realize very predictable and efficient cooling of a superconductor wires; 3) to provide stable operation of the magnet even in the case of a wide dynamic range of the heat releases in the magnet. Long-term experience of operation such magnets at the JINR Laboratory of High Energies confirm the above mentioned. The new hollow Nuclotron-type SC-cable R&D performed at the Laboratory during the past several years [5] have completed by improvement of the cable parameters, in particular the peak current was increased up to 12 kA (instead of ~ 8 kA for the original Nuclotron) at practically the same outer cable diameter. This fact gave real basis for construction of a single layer 1.5 T dipole and very low turn number coil (2 turns per pole) quadrupole of the NICA booster magnets. This result is extremely important for the SIS100 dipoles of the new international facility FAIR in Darmstadt (Germany)[6].

Figure 1: View of the JINR LHEP Accelerator facility site.

General specification of the NICA booster and collider magnets is presented in Table 1.

Table 1: Basic Parameters of Structural Magnets

Parameter	Booster	Collider [7]	Collider [8]
Circumference, m	211	201	About 400
Magnetic rigidity, T·m	25	45	45
Dipole field/length, m	~1.8/2.2	~3.9/1.8	~2.0/2.2
Number of dipoles	40	40	64
Quads gradient/length	~19/0.4	34/0.4	30/0.4
Number of quads	48	40	32
Cold mass weight, kg	~ 850	~ 2700	~ 1200
Curvature radius, m	14.09	11.25	22.5
Useful aperture, mm	128x64	D60	D70
Axis separation, mm	-	320	320

The dipoles of 4 T are considered as the research goal for future upgrade of the collider.

The collider dipoles and quadrupole units in the both internal and external versions consist of two vertically assembled cold masses placed inside a common thermal shield and common vacuum jacket. The dipole good field area ($\Delta B/B \sim \pm 1\cdot 10^{-4}$) is set to a circle of 60 and 70 mm diameter for the mentioned versions respectively. The use of curved dipole magnets is supposed in all the considered cases. As it followed from Table 1, the total number of structural dipole and quadrupole magnets needed for the booster and collider rings (external option) is reached to about 300. Moreover, the number of different corrector magnets will reach to about 150 units. The set of final focus magnets represents special case also. Although final design of beam intersection areas is not completed, it is clear that a large double aperture high gradient (~ 100 T/m) quadrupoles should be designed for that purpose. Special design of the dipoles served for vertical deflection of the beams circulating in the storage rings near intersection points is also necessary. Preliminary parameters of these magnets are listed in Table 2.

Table 2: Magnets of the Intersection Points (IP).

Parameter	Value
Quads gradient/length, T/m;m	~60 / 0.4
Number of quads	6
Aperture, mm	100
Dipole field/length, T;m	3.0 / 1.0
Number of dipoles	3
Aperture, mm	70, …. , 100

The design concept of this set of the collider lattice elements was discussed, nevertheless no final technical solution have not been proposed.

REALIZATION STATUS AND PLANS

Full-scale work program including design, manufacturing, assembling and tests of all the magnets for the Nuclotron (96 dipole, 64 quadrupole and 32 multipole corrector magnet units plus some extra magnets for the measuring purposes) was performed completely at the Laboratory facilities. Ten different technological test benches were formed to fulfill that work. Serial production of the Nuclotron magnet-cryostat units was taken of about three years. The preparatory phase including construction and tests of full size dipole and quadrupole models, pre-series prototypes manufacturing and string tests was continued of about three years. The total number of different magnets for the NICA elements is about 350. It could be prepared within three and half year in the case of the manufacturing and tests facility production capacity not less than two magnets per week. To realize the goal we started formation of the new facility for assembling and tests of superconducting magnets at the Laboratory based on a separate industrial building (Fig. 2).

Figure 2: General view of the Laboratory site: 9, 10, 11, 12, 13 – main buildings of the accelerator complex; 7 – the existing SC-magnet test facility; 17 – workshops; 22 – the new facility for SC magnets assembling and tests facility.

General technological scheme of the magnet-cryostat unit preparation is shown in Fig. 3.

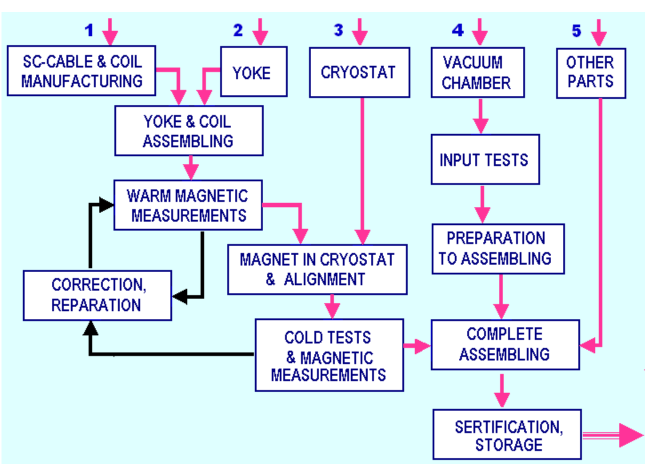

Figure 3: General technological scheme of the new facility for assembling and full-scale tests of SC – magnets at the JINR Laboratory of High Energy Physics.

In accordance with the proposed scheme, fabrication of the yokes, cryostat vessels, beam pipe units and all other mechanical parts is provided by the collaborative partners or by industrial companies. The cable and coils are manufactured at the Laboratory equipment. There are two cabling machines, several different tools for coil winding manufacturing and two ovens for the coils heat treatment are supposed to be put into operation in the coming 1.5 years. The other necessary sub-facilities will be also completely equipped by that time. It is suppose, two cryogenic test bench equipped with power supplies, magnetic and cryogenic measurement systems will be put into operation and a non-stop process of the magnets production can be organized, if necessary.

SUMMARY & OUTLOOK

Realization of the NICA facility at JINR is continuing. The new results were obtained at the modernized Nuclotron, namely: acceleration of xenon ions. More detailed report on the status of the Nuclotron-M project is presented at this Conference [9]. Manufacturing of the first model magnets for the booster is in progress. The status of NICA booster design is presented in separate paper [10]. The design of the collider model magnets is continuing. Substantial efforts were devoted to organization and realization of the new facility for preparation of different superconducting magnets at the Laboratory. Production capacity of the new facility should be sufficient to satisfy the both as NICA and FAIR magnets manufacturing and tests in accordance with the approved plans.

REFERENCES

[1] A.N. Sissakian et al. XXIII Int. Symposium. on Lepton and Photon Interactions at High Energy, LP07, Daegu, Korea. (2007).
[2] Search for the Mixed Phase of Strongly Interacting Nuclear Matter. Dubna Round Table –1. http://theor.jinr.ru/meetings/2006/roundtable/
[3] NICA Conceptual Design Report, Dubna 2008.
[4] NICA White Pages book. http://theor.jinr.ru/twiki-gi/view/NICA/WebHome
[5] H. Khodzhibagiyan et al, IEEE Trans. Appl. Supercond., vol.15, N2, 2005, pp. 1529-1532.
[6] E. Fischer et al., ASC´08, also IEEE Trans. on Appl. Superconductivity. vol 19, pp. 1087 -1091.
[7] A.D. Kovalenko et al. "Design of a Twin Aperture 4 T Curved Dipole Based on a High Current Hollow Superconducting Cable for the NICA Facility at JINR, EUCAS'2009, Dresden, September 2009.
[8] O. Sidorin et al. "Lattice of the NICA Collider Rings", IPAC2010, paper MOPD010.
[9] N. Agapov et al. "Status of the Nuclotron", IPAC2010, paper MOPD008.
[10] N. Agapov et al. "Design of the Nuclotron Booster in the NICA project, ibid., paper MOPD007.