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LIQUID HELIUM TECHNOLOGIES AT CRYOGENIC COMPLEX OF THE HEAVY ION COLLIDER NICA

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Abstract

NICA (Nuclotron-based Ion Collider fAcility), presently under construction at the Joint Institute for Nuclear Research (JINR), will be, upon its completion, among the most advanced research instruments of the physics community. The facility is aimed at providing 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} $cm^{-2} \cdot s^{-1}$. The NICA cryogenics includes a large number of technical ideas and solutions never used before. The most significant of these solutions are the fast cycling superconducting magnets, cooling by the two-phase helium flow, an unusually short period of time for cool down till the operating temperature, parallel connection of cooling channels of the magnets, «wet» turbo expanders, screw compressors with the outlet pressure of more than 25 bars and jet pumps for liquid helium. These technical solutions allow one to construct an efficient and reliable cryogenic system of the NICA complex.

INTRODUCTION

Since 1992, the largest Russian liquid helium plant for the superconducting Nuclotron accelerator has been operating at JINR in Dubna near Moscow. Plans for further development of the basic facilities at the JINR Laboratory of High Energy Physics (LHEP) include building new accelerators: booster and collider, both using magnets with superconducting windings cooled to liquid helium temperature. These two accelerators together with the existing Nuclotron will be united into the NICA complex [1].

The NICA cryogenics will be constructed as a result of modernization of the existing equipment for cryogenic supply of the Nuclotron. The main goals of the modernization are: increasing the total refrigerator capacity from 4000 W to 8000 W at 4.5 K, development a new distribution system of liquid helium and ensuring the shortest possible cool down time. These goals will be achieved by means of an additional 1000 l/hour helium liquefier and "satellite" refrigerators located near the accelerator rings.

CRYOGENICS OF THE NICA ACCELERATOR COMPLEX

New installations, which will appear while updating and building of the NICA complex, and their technical characteristics are presented in [2]. The general view of the NICA cryogenics is shown in Figure 1. The technical solutions which allowed one to have the most modern and the largest in Russia cryogenic system of the Nuclotron and will allow one to construct an efficient and reliable cryogenic system of the NICA complex are listed below.

Fast Cycling Magnets and Refrigeration by Two-phase Helium Flow

The most interesting feature of the Nuclotron-type magnets is their capability for very fast cycling (with the pulse repetition rate up to 1 Hz). The magnets therefore had to have very reliable conditions of their cooling. These conditions are possible due to using a two-phase helium flow and a hollow superconductor [3, 4]. The superconducting cable represents a copper-nickel tube, inside which a two-phase helium flow passes through. This tube is coated with epoxy compound and wrapped with superconducting wires. Each wire contains NbTi filaments in a copper matrix. This design provides a good thermal contact of the superconducting wires with the cooling helium flow. The main technical characteristics of superconducting cables of the Nuclotron, booster and collider are listed in Table.1.

Table 1: The Main Technical Characteristics of Superconducting Cables of the Nuclotron, Booster and Collider

Parameters	Nuclotron	Booster	Collider
Diameter of channel, mm	5	3	3
Quantity of wires	31	18	16
Diameter of superconducting wire, mm	0.5	0.78	0.9
Superconductor	50% Nb – 50% Ti		
Diameter of filaments, μm	10	7	8
Outer diameter of cable, mm	6.5	6.6	7.0
Nominal current, kA	6	9.68	10.4
Critical current, kA	7.38	14.2	16.8

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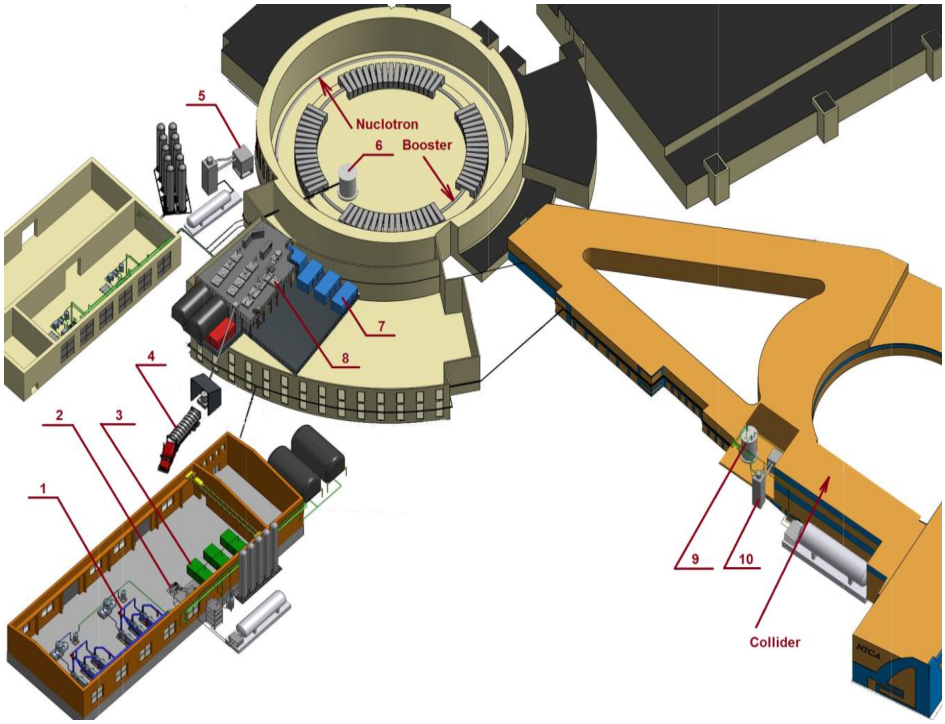

Figure 1: General view of the cryogenics for the NICA complex: 1. 6600 nm^3/h screw compressors “Kaskad–110/30”, 2. 1300 kg/h nitrogen liquefier OA–1.3, 3. Nitrogen turbo compressor Samsung Techwin SM–5000, 4. 40 m^3 auto transport container for liquid helium, 5. Nitrogen re-condenser RA–0.5 of the booster, 6. Satellite refrigerator of the booster, 7. Draining and oil-purification units MO–800, 8. 1000 l/h helium liquefier OG–1000, 9. Satellite refrigerator of the collider, 10. Nitrogen re-condenser RA–0.5 of the collider.

Parallel Connections of All Cooling Channels and Liquid Helium Jet Pump

Each of the Nuclotron magnets connected in parallel to the collectors of supply and return flows is fed with liquid helium from the collector of supply flow extending along the entire length of the accelerator [3, 4]. In order to provide the required distribution of cooling helium flows in about 100 channels in each half-ring of the Nuclotron and to exclude the probability of fluctuations of bubbling helium flows, the following methods were applied: the hydraulic resistance of the cooling channels of magnets is performed so that the mass vapor content of helium at the outlet of the magnets is identical and equal to 90%; to be quite sure that there is only liquid at the inlet of each of the magnets, 62 subcoolers are constructed in each half-ring of the Nuclotron for keeping helium in a liquid state inside the supply collector.

But these actions were not always sufficient. At the difference in pressure between the supply and return helium collectors less than 0.02 MPa the refrigeration of the magnets was not stable. We observed transitions of superconducting windings in a resistive condition in multitude. To increase the pressure drop higher than 0.02 MPa, it was necessary to raise greatly a helium flow at the input of refrigerator. It resulted in the large extra energy consumption because operating of additional compressors. Additionally, the refrigerator capacity reduced due to deviation from the optimum mode.

In order to increase liquid helium flow directed to superconducting magnets, jet pumps were used (Fig. 2). Such an apparatus is extremely simple. It costs nothing and its operational reliability is very high. Usage of a jet pump leads to the small decrease of the refrigerator capacity due to 10% bypass of the “wet” turbo expander at the final cooling stage of the helium refrigerator KGU–1600/4.5 (Fig. 1). But it allows one to have the pressure drop between the supply and return helium collectors of the Nuclotron more than 0.025 MPa. In this case the superconducting magnets operate very stably. The energy consumption is greatly lowered (about 600 kW) as well because of not operating of additional compressors [4].

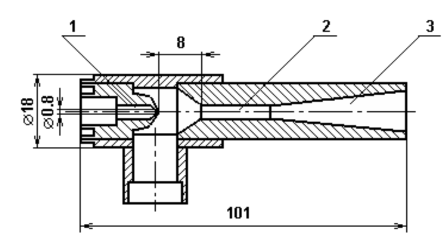

Figure 2: Liquid helium jet pump: 1. Nozzle, 2. Cylindrical mixing tube, 3. Inlet diffuser.

“Wet” Turbo Expander

In order to raise the efficiency of cryogenic refrigerators and liquefiers, it is very important to replace

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the Joule – Thompson process by the improved process of adiabatic expansion in the expander. The first successful experiment on the usage of an expander of the turbine type was realized in 1985 at LHEP. The test results of the "wet" turbo expander for the Nuclotron helium refrigerators KGU–1600/4.5 are given in Fig. 3. As a result of using this "wet" turbo expander in the final cooling stage, the capacity of the refrigerator increased from 1600 to 2000 W, and the compression work per unit of refrigeration capacity (figure of merit) lowered to about 290 W/W [3, 4].

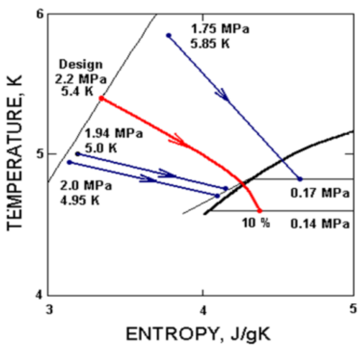

Figure 3: The test results of "wet" turbo expander for the Nuclotron helium refrigerators.

INFLUENCE OF THE DEVELOPMENT OF HELIUN INDUSTRY

The helium complex of the Nuclotron was the most modern and the largest in Russia plant of liquid helium production – two KGU–1600/4.5 refrigerators capable to operate for a common collector of delivery of liquid helium to the consumer, provided the total capacity of 1000 l/hour.

Its usage in 1992 allowed one to begin for the first time in Russia the large-scale export of liquid helium by 40 m^3 auto transport containers. In 1992 – 93 the liquefaction of helium in industrial scale was mastered – up to 1 mln. l/year of liquid helium.

To meet the needs of the NICA project the refrigerator capacity of the cryogenic complex at LHEP will be doubled in the near future (up to 8000 W at 4.5 K). This complex will include the latest Russian developments: helium liquefiers with the capacity of 1100 l/h and screw helium compressor aggregates with the outlet pressure of 3 MPa and capacity of 6600 Nm^3/h (Fig. 1). This equipment being commissioned to mass production may lay the foundation for the technology of industrial liquefaction of helium for the development of new deposits in Eastern Siberia.

FACILITY FOR THE ASSEMBLING AND TESTING OF SUPERCONDUCTING MAGNETS

At the present time, the new facility is constructed by JINR (Dubna) – GSI/FAIR (Darmstadt) collaboration at LHEP for round the clock assembling and cryogenic testing of Nuclotron-type superconducting magnets of the booster, collider and synchrotron SIS100 [5]. Area for installation of necessary equipment is equal to more than 2600 m^2.

The place for cryogenic tests of the magnets will be equipped with 3 helium satellite refrigerators SRU, 6 feed boxes with 12 HTS current leads on 18 kA pulse operation, a system for cold magnetic measurements, vacuum and control systems. It is intended to carry out the cold tests of up to 17 superconducting magnets per month, when operating in parallel on 6 benches.

Each test bench is provided with the equipment necessary to carry out the training of superconducting magnets and cold magnetic measurements, and also to measure the energy losses and pressure drop in the magnet when operating in pulsed mode.

Each of 3 satellite refrigerators SRU provides 2 benches with liquid helium alternately (Fig. 4). The cool-down process of superconducting magnet is divided into two stages. At the first stage the cooling of the magnet is carried out by compressed helium (up to 25 bars) cooled in liquid nitrogen bath of SRU by means of evaporation of cryoagent. Liquid helium from the 1000 l Dewar vessel is used at the second stage of cool-down. The nominal capacity of the refrigerator is 100 W at 4.5 K.

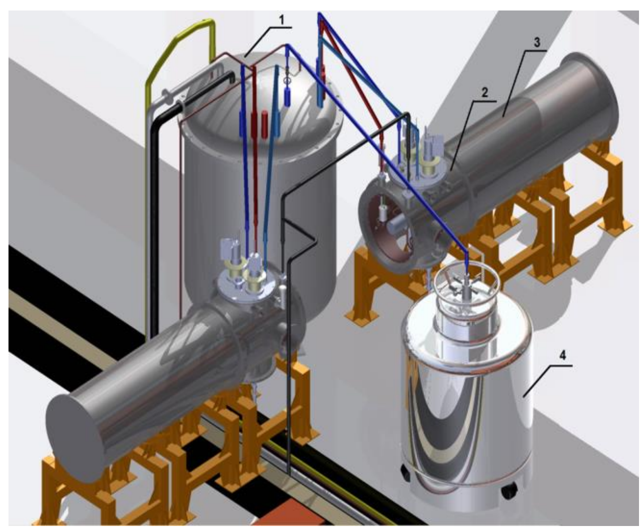

Figure 4: The equipment of one of three lines for cryogenic tests of superconducting magnets: 1. Satellite refrigerator SRU 100W@4.5K, 2. Vacuum cryostat of the current leads, 3. Vacuum cryostat of the superconducting magnet, 4. Dewar vessel of liquid helium.

Commissioning of the facility for superconducting magnets assembling and serial testing is scheduled for the end of 2014 in full configuration. More than 430 magnets will be tested on 6 benches of the facility in the next 4 years.

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