Cryogenic Technologies of the NICA Accelerator Complex

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Abstract

Since 1992, the largest Russian cryogenic helium complex of the superconducting accelerator **Nuclotron** with the refrigerating capacity of 4000 W at 4.5 K has been operating at JINR in Dubna, Russia. The construction of this high efficient cryogenic system included a large number of technical ideas never used before in the world practice: **the fast cycling superconducting magnets, cooling by the two-phase helium flow, parallel connection of cooling channels of the magnets, «wet» turbo expanders, screw compressors with the outlet pressure of more than 2.5 MPa and jet pumps for liquid helium.**

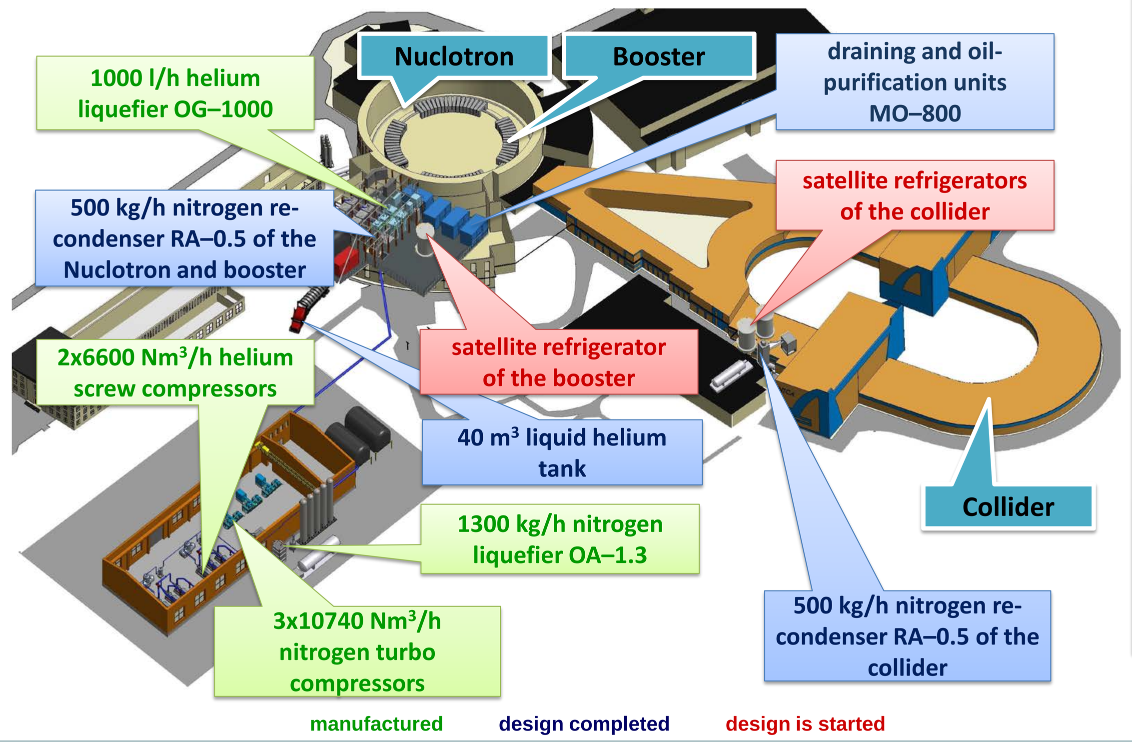
NICA (Nuclotron-based Ion Collider fAcility), presently under construction at JINR, is a new accelerator complex designed to study properties of **the dense baryonic matter.** Accelerator complex will consist of three superconducting rings: the Nuclotron, the booster and the collider. After putting of the NICA collider into operation the scientists will be able to create a special state of matter in which our Universe stayed shortly after the Big Bang – **the Quark-Gluon Plasma (QGP).**

The helium cryogenics of the **NICA** complex will be based on **the modernized liquid helium plant for the Nuclotron.** The **main goals of the modernization** are: to increase the total refrigerating capacity from 4000 W to 8000 W at 4.5 K; to create a new system of liquid helium distribution; to ensure the shortest time of cooling down three accelerators rings with the total length of about 1 km and the "cold" mass of 290 tons. These goals will be achieved by means of commissioning of a new **1000 l/hour helium liquefier, "satellite" refrigerators** of the booster and the collider, **6600 Nm³/h helium screw compressor aggregates**.

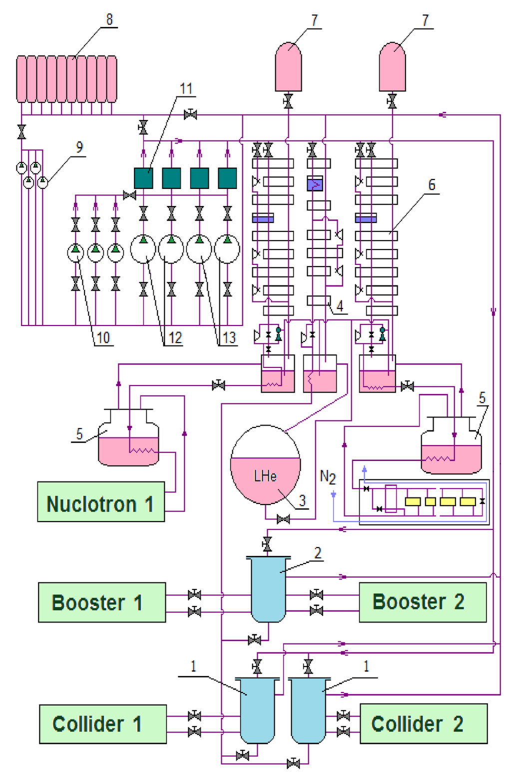
NICA Cryogenics

General View

The helium cryogenic system of the NICA complex will be constructed as **a result of the modernization of the existing equipment for cryogenic supply of the Nuclotron.**



Flow Diagram of the Helium Cryogenic System

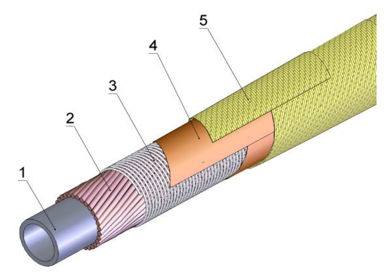


Operating temperature, *[K]*	4.5
Refrigerating capacity at 4.5 K, *[W]*	8000
Total capacity of the compressors, *[Nm³/h]*	30420
Total power of electric motors, *[kW]*	7600
Flow rate of cooling water, *[m³/h]*	400
Total «cold» mass, *[t]*	290

1. "Satellite" refrigerators of the collider; 2. "satellite" refrigerator of the booster; 3. 40 m³ liquid helium tank; 4. 1000 l/h helium liquefier OG–1000; 5. liquid helium separators; 6. KGU–1600/4.5 helium refrigerators; 7. 100 m³ gas-holders; 8. compressed-helium reservoirs; 9. 45 Nm³/h piston compressors 1VUV–45/150; 10. 1200 Nm³/h piston compressors 305NP–20/30; 11. draining and oil-purification units MO-800; 12. 6600 Nm³/h screw compressor "Kaskad–110/30"; 3. 5040 Nm³/h screw compressors "Kaskad–80/25".

Technical Ideas and Solutions

Fast Cycling Magnets and Refrigeration by two-phase Helium Flow



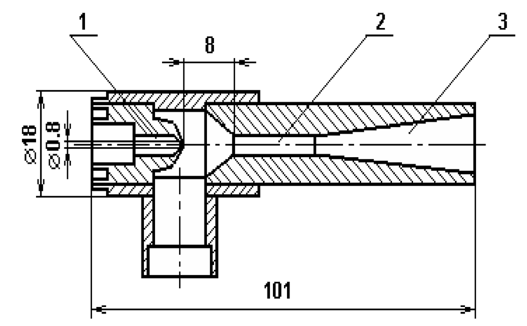
Superconducting cable of the NICA accelerators:

1. CuNi tube;
2. SC wire;
3. NiCr wire;
4. Capton tape;
5. Glass tape

Parameters	Nuclotron	Booster	Collider
Diameter of channel, *[mm]*	5	3	3
Quantity of wires	31	18	16
Diameter of SC 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

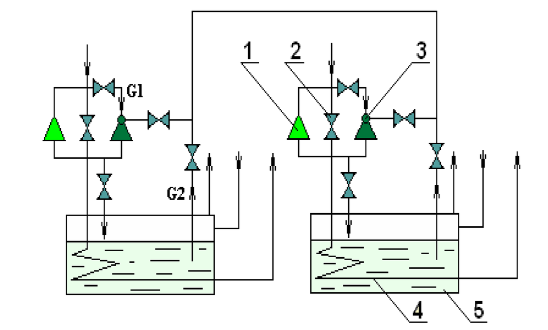
The reliable conditions of cooling of the Nuclotron **fast cycling magnets** (with the pulse repetition rate up to 1 Hz) are possible due to using **a two-phase liquid-vapor helium flow** and **a hollow superconductor.**

Liquid Helium Jet Pump



Liquid helium jet pump:

1. nozzle;
2. cylindrical mixing tube;
3. inlet diffuser



Final cooling stages of the helium refrigerators KGU–1600/4.5:

1. "wet" turbo expander; 2. throttle valve; 3. liquid helium jet pump; 4. sub-cooler; 5. liquid helium vessel

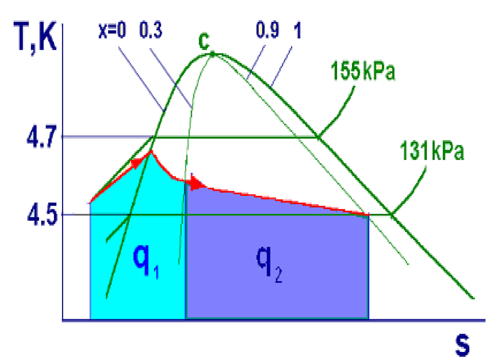
Usage of liquid helium jet pumps allowed one to increase greatly **the flow rate of helium (by about 50%)** circulated through the magnets, as well to decrease greatly **the energy consumption (about 600 kW)** because of not operating of additional compressors.

Influence on the Development of Helium Industry

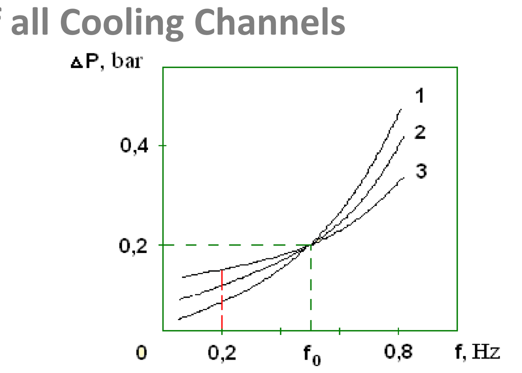
The helium complex of the Nuclotron was the most modern and the largest in Russia plant of liquid helium production.
By means of its usage **in 1992 – 93 for the first time in Russia the liquefaction of helium in industrial scale was mastered – up to 1 mln. l/year of liquid helium.**

The cryogenic complex of the NICA 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 Nm³/h.**
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.

Parallel Connections of all Cooling Channels



q_1 – discharge from SC windings;
q_2 – discharge from iron yoke

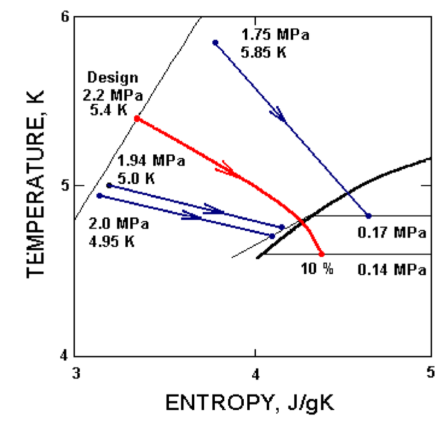


1, 2, 3 – type of magnet

Pressure drop ΔP in the cooling channels versus the pulse repetition rate f at a outlet mass vapor content of helium x=0.9

1. Hydraulic resistance of cooling channels is performed so that **the mass vapor content of helium at the outlet of magnets was identical and equal to 90% at the design operating mode with pulse repetition rate f_0=0.5 Hz.**
2. Phase separator, main and 62 additional subcoolers are constructed in each half-ring of the Nuclotron to keep the helium in a liquid state inside the supply collector.

"Wet" Turbo Expander



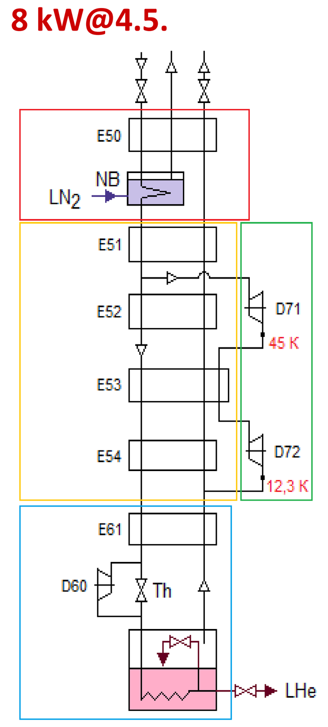
The test results of "wet" turbo expander for the Nuclotron helium refrigerators KGU–1600/4.5

Photo of the second generation "wet" turbo expander of the Nuclotron refrigerators KGU–1600/4.5

The application of this expansion machine in the final cooling stage increases **the efficiency** of the Nuclotron helium refrigerators **by 25 % (from 1.6 to 2 kW@4.5 K)** and decreases **the compression work per unit of refrigeration capacity (figure of merit) to about 290 W/W.**

Helium Liquefier OG-1000

Commissioning of the new **1000 l/h liquefier OG–1000** will allow one to increase the refrigerator capacity of the helium cryogenic system of the NICA complex **from 4 up to 8 kW@4.5.**



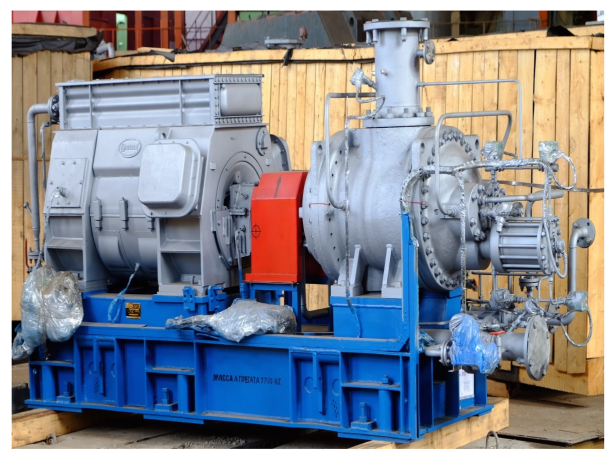
Operating gas	helium
Capacity, *[l/h]*	1100±100
Liquid nitrogen consumption, *[kg/h]*	≤560
Energy consumption, *[kW]*	1760
Compressed helium pressure, *[MPa]*	2.5
Compressed helium flow rate, *[Nm³/h]*	6600
Total mass, *[kg]*	14000
External dimensions, *[m×m×m]*	5×5×10

The principal scheme of the liquefier OG–1000: E – heat exchangers; D – turbo expanders; Th – throttle; NB – bath of liquid nitrogen.

Helium Compressor "Kaskad-110/30"

The cryogenic system of the NICA complex will use compressors of various types and modifications.
The smaller capacity piston machines will be used for stage-by-stage regulation of flow rate of the compressed helium. But as the main ones four oil-lubricated screw compressor aggregates **5040 nm³ "Kaskad–80/25"** and **6600 nm³ "Kaskad–110/30"** will be used.

Screw compressor "KASKAD-80/25" (currently in operation)



Screw compressor "KASKAD-110/30" (ready for assembling)

	Nuclotron	NICA complex
Total capacity of the helium compressors, *[Nm³/h]*	17220	30420
Installed power of electrical motors, *[MW]*	4.2	7.4
Flow rate of cooling water, *[m³/h]*	200	400

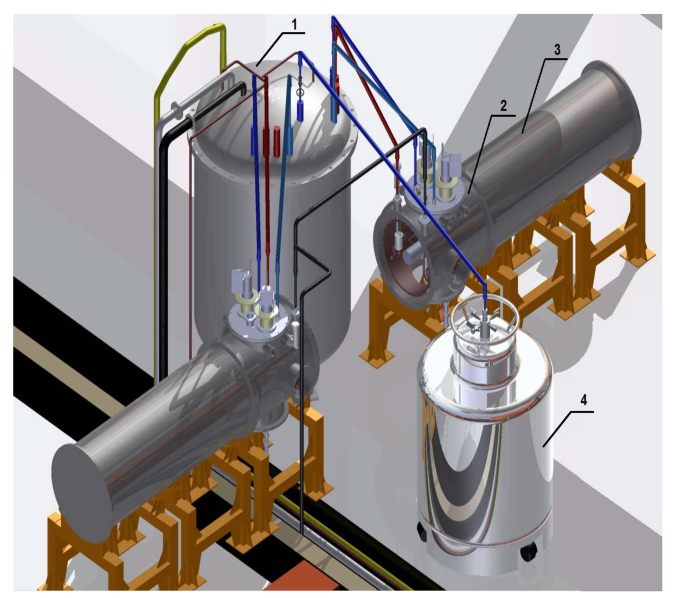
Facility for the Assembling and Testing of Superconducting Magnets

The SC magnets factory was put into operation in full configuration at November 2016. More than **430 magnets** will be tested on **6 benches** of this facility in the nearest years:

- **40** dipole magnets for the NICA booster;
- **48** quadrupole magnets with multipole correctors for the NICA booster;
- **80** dipole magnets for the NICA collider;
- **86** quadrupole magnets with multipole correctors for the NICA collider;
- **175** quadrupole magnets with correction magnets or sextupole, steerer and multipole corrector for the SIS-100 synchrotron (FAIR project)

1. place for SC cable manufacturing; 2. place for SC windings production; 3. place for assembling the yoke with the winding; 4. place for "warm" magnetic measurements; 5. place for check of vacuum tightness; 6. place for assembling magnets in cryostats; ***7. place for cryogenic tests of 6 magnets in parallel****; 8. place for two power converters.*

The place for cryogenic tests of the SC magnets will be equipped with 3 **helium satellite refrigerators SRU 100W@4.5K**, 6 feed boxes with 12 **HTSC current leads on 18 kA pulse operation**, a system for cold magnetic measurements, vacuum and control systems.



Each of 3 satellite refrigerators SRU provides 2 benches with liquid helium alternately. The cool-down process of SC magnet are divided into two stages:

1. by compressed helium (up to 25 bars) cooled in LN2 bath of the SRU by means of evaporation of liquid nitrogen;
2. by helium cooled in LHe vessel of the SRU by means of evaporation of liquid helium from the 1000 l Dewar vessel.

The equipment of one of three lines for cryogenic tests of SC magnets:

1. satellite refrigerator SRU 100W@4.5K; 2. vacuum cryostat of the current leads; 3. vacuum cryostat of the SC magnet; 4. Dewar vessel of liquid helium

Presented at the 25th International Conference on Magnet Technology, August 27 – September 1, 2017, Amsterdam, the Netherlands; Session: H1 - Cryostats and Cryogenics; **Program ID number: Mon-Af-Po1.11-05**