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LIQUID HELIUM PLANT IN DUBNA

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INTRODUCTION

The LHE has old traditions and long-term experience in cryophysics and cryotechnique. A special division was formed in the early 50th for the construction of large (1 m and 2 m) liquid hydrogen bubble chambers and liquid hydrogen targets aimed to investigate elementary particle interactions at the Synchrophasotron in Dubna and at the 70 GeV proton synchrotron at Protvino. A lot of different cryogenic equipment and superconducting devices have been developed and constructed for experiments in the field of particle and relativistic nuclear physics by the specialists of the LHE.

A new step in the development of research in cryogenics was initiated by the construction of the specialized superconducting relativistic heavy ion accelerator Nuclotron and the program for relativistic nuclear physics [1]. R&D works on the superconductor magnets were completed in 1980 by testing a novel type SC-magnet: fast cycling (up to 1 Hz), force cooling by two-phase helium, window-frame type dipoles with an iron-shaped magnetic field up to 2.2 T [2]. The construction and test of the model SC synchrotron (SPIN) for a 1.5 GeV proton energy have also been performed before the production of the Nuclotron systems. The Nuclotron project was approved in December 1986. In 1987-92 the systems were fabricated, assembled and tested and the first beam was announced around the March of 1993 [3]. The ring with a length of 250 m comprises 96 dipole magnets of 1.5 m each, 64 quadrupole lenses of 0.4 m, 28 multipole correctors of 0.31 m with different types of coils in each, twelve 6 kA helium-cooled main current leads, 234 leads of a 100 A current for correcting coils and special-purpose magnets, 32 special units of equipment for beam injection, acceleration, extraction, diagnostics and also about 600 sensors of cryogenic temperatures. In more detail the Nuclotron was described in papers [4]. The total "cold" mass of the Nuclotron is about 80 tons.

CENTRAL LIQUEFIER STATION

A general view of the LHE accelerators and the main cryogenic equipment is shown in Fig. 1. There are three KGU-1600 refrigerator-liquefiers, a compressor station, receivers for gaseous helium storage, gas bags and a liquid helium storage tank. According to the project, the Nuclotron cryogenic supply system must provide:

– cooling of the magnets down to 4.5 K over 100–120 hours after starting,

– a refrigeration power of 1.75 kW to compensate the static heat flow and up to 2.9 kW for dynamic heat losses in the magnets under a current cycle,

– production of about 100 l/h of liquid helium simultaneously with refrigeration for the cooling current leads.

As shown in Fig. 2, two of the three KGU setups are connected to their half-ring and can operate independently. The third one is aimed at increasing the total capacity in case of the hardest mode of Nuclotron operation (peak repetition rate at a maximum design energy) or in case of failure of any other refrigerator. The third setup can be also used for liquid helium production in the process of Nuclotron operation.

The KGU setup includes three gas turboexpanders T1, T2, T3, a liquid nitrogen bath, double- and triple flow heat exchangers, wet turboexpander T4 and a liquid helium receiver of 1000 l. After oil and water purification, the compressed helium is divided into main and turbine streams at the entrance of each refrigerator. The turbine stream is expanded step-by-step in the three turbines from 2.5 MPa to 0.13 MPa. The optimum temperatures of helium at the input of the turboexpanders are 150 K, 50 K and 19 K. After cooling in the heat exchanger to a temperature of 5.5 K – 7.5 K, the main stream is expanded in the wet turbine from 2.5 MPa to 0.17. After that one part of the main stream is removed to the liquid helium receiver, and in case of Nuclotron operation the other is directed to the half-ring via a liquid/vapour separator. Main design parameters of the helium compressors are presented in Table 1.

The basis of the compressor system is a screw compressor CASCADE-80/25. The piston compressors are useful for step variation of the compressed helium flow and its redundancy. The screw compressors are supplied with oil and water purifiers. The final purification of oil vapour is performed by two charcoal adsorbers with a duty cycle of 2500 hours each. Water purification is provided with two ceolite adsorbers.

Gaseous helium is stored in 10 vessels of a 20 m^3 capacity each at a maximum pressure of 3 MPa and in 3 gas bags of a 20 m^3 capacity each.

Table 1.

Component	CASCADE-80	305NP-20	2GM4-12	1VUV-45
Number	2	3	4	4
Type	screw	piston	piston	piston
Capacity, m^3/h	5040	1200	900	45
Discharge pressure, MPa	2.5	3.0	3.1	15.0
Number of stages	2	3	3	3
Power of drive, kW	2×630	200	160	22
Voltage of drive, V	6000	380	380	380

Since 1993 a big 8 thousand gallon tank has been used for liquid helium storage.

OPERATION MODES AND EFFICIENCY

Specific properties of operating the cryoplant in case of Nuclotron runs are the mixed refrigerator-liquefier mode and variation of heat loads over a wide range. The capability of the KGU setup for mixed mode operation was investigated under different conditions. The dependences of refrigeration power versus the amount of liquid are presented in Fig. 3. Curve 1 shows the case of JT-valve expansion at the final stage of a cooling cycle. Using the wet turboexpander instead of the JT-valve led to a substantial increase of refrigeration power (curve 2). A 1.5-fold increase was observed (from 1.1 to 1.7 kW) in case of the pure refrigeration mode. Increasing a compressor gas flow from 3600 to 4800 m^3/h in case of using the JT-valve provides additional 0.4 kW of refrigeration power. A maximum cooling power and efficiency are realized if the wet piston expander machine is used instead of the JT-valve (curve 4), but turbine-type machines are mostly used due to higher reliability of the last ones.

So, to make the cryogenic cooling efficiency of the systems higher, one needs to use an expander instead of a JT-valve. That was proposed and realized for a hydrogen liquefier [5] at our Laboratory in 1965. For a helium liquefier it was made by S.Collins in 1970 [6]. Piston type expander machines were used in both cases.

The first successful attempt to replace a piston type wet expander of the KGU setup by a wet turboexpander was made by our specialists in

1985. It was extremely important that a high efficiency of setup operation was guaranteed over a full dynamic range under a constant gas flow provided with the compressors despite the absence of jet cross-section adjustment in the nozzle apparatus. Such a phenomenon of "self-adjustment" of the gas flow distribution under transition from the refrigerator to the liquefier mode is explained by a difference of optimum temperatures which are needed in both cases. The optimum temperature at the input of the turbine is 5.2 K in the refrigerator mode when a maximum gas flow through the turbine must be provided and 8.5 K in the liquefier mode. It is clear that the temperature growth leads to decreasing the total helium flow and that is enough for an effective redistribution of gas flows.

As was mentioned above, the main compressor at our cryoplant is a screw oil-filled two-stage compressor CASCADE-80/25. It was specially designed and constructed by the enterprise "KAZANCOMPRESSORMASH" for a cryogenic supply system of large-scale superconducting equipment in nuclear physics research. The pilot sample of the CASCADE-80/25 was tested at LHE. The first stage of this machine consists of two compressors connected in parallel and driven by an electric motor of a 0.63 MW power and a 6 kV voltage. The second stage is based on a screw compressor with a vertical oil separator and an electric motor of the same parameters as for the first stage. Main operational characteristics of the CASCADE-80/25 are the following:

Capacity, m^3/h	6000-6400
Input pressure, MPa	0.071-0.086
Output pressure, MPa	2.32-2.54
Electric power, kW	
I - stage	563-640
II - stage	339-393
Isothermic efficiency	0.52-0.55

The results of the stand test have shown a high reliability and a good efficiency of the machine over the values of gas pressure from 0.02 to 0.085 MPa at the input under a constant pressure at the output. This makes it possible to use such equipment in powerful cryogenic systems aimed at cooling down to 3 K and below.

The efficiency and reliability of the industrial refrigerator KGU and the Nuclotron cryogenic supply system respectively was substantially improved after the described above new equipment was put into operation. There were six runs at the Nuclotron during the last one and half years. The total running time was about 2000 h. It took 92-110 hours to provide temperature of 4.5 K for all 200 elements of the accelerator ring connected in parallel to helium headers. The time dependent temperature distribution at different points of the Nuclotron ring is shown in Fig. 4.

The LHE cryogenic facilities are intensively used to provide different users with liquid helium both at JINR and outside. About 60000 litres were produced for 500-litre Dewar vessels for JINR's needs in 1994. The main users are experimental physics equipment at different laboratories of the Institute. The Orenburg helium plant is one of the nine basic producers of helium in the world. Till 1992 it had no output to world market for lack of helium liquefiers. The use of the cryogenic plant in Dubna allowed for the first time to produce liquid helium for large scale Russian export [7].

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References

[1] Baldin, A.M. et al., IEEE Trans. on Nucl. Sci., NS-30, 4, 3247 (1983)

[2] Agapov, N.N. et al., Cryogenics, 20, 345 (1980).

[3] Baldin, A.M. and A.D. Kovalenko, "The status of the Dubna relativistic heavy ion accelerator facility", CERN bulletin, 14, 4, Geneva (1993).

[4] Baldin, A.M. et al., Advances in Cryogenic Engineering, 39, 501 (1994).

[5] Balandikov, N.I. et al., Cryogenics, 6, 158 (1966).

[6] Johnson, R.W., Collins, S.C., Smith, I.L., Advances in Cryogenics Engineering, 16, 171 (1971).

[7] "Russian helium supply agreement", Cryogenics, 34, 171 (1994).

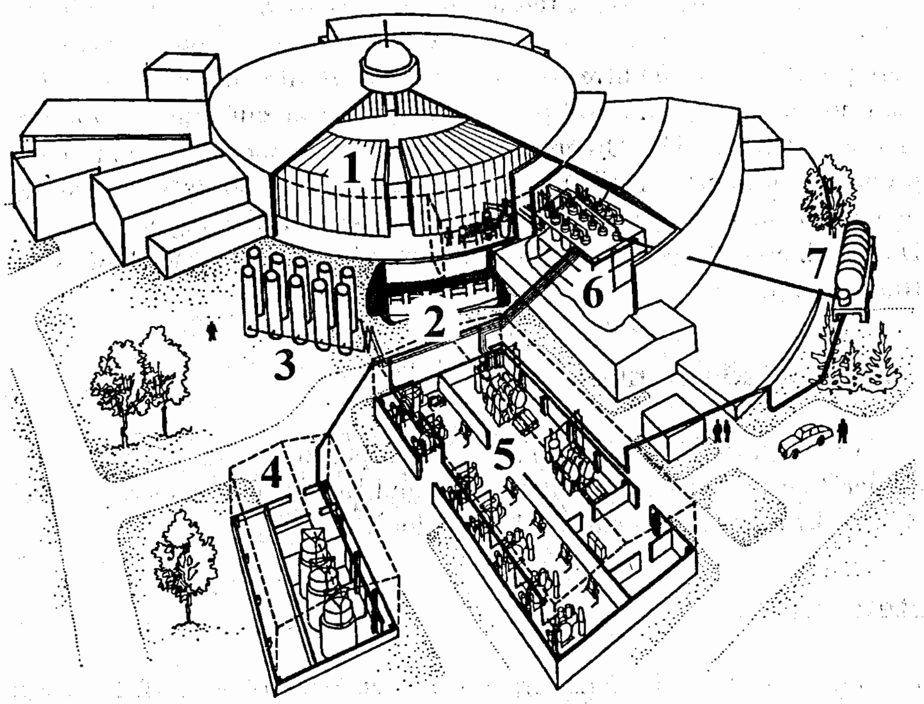

Figure 1. General view of the LHE accelerators and central liquefier station. 1 – 10 GeV Synchrophasotron, 2 – Nuclotron, 3 – vessels for gaseous helium storage, 4 – gas bags, 5 – compressors, 6 – refrigerators/liquefiers, 7 – liquid helium tank.

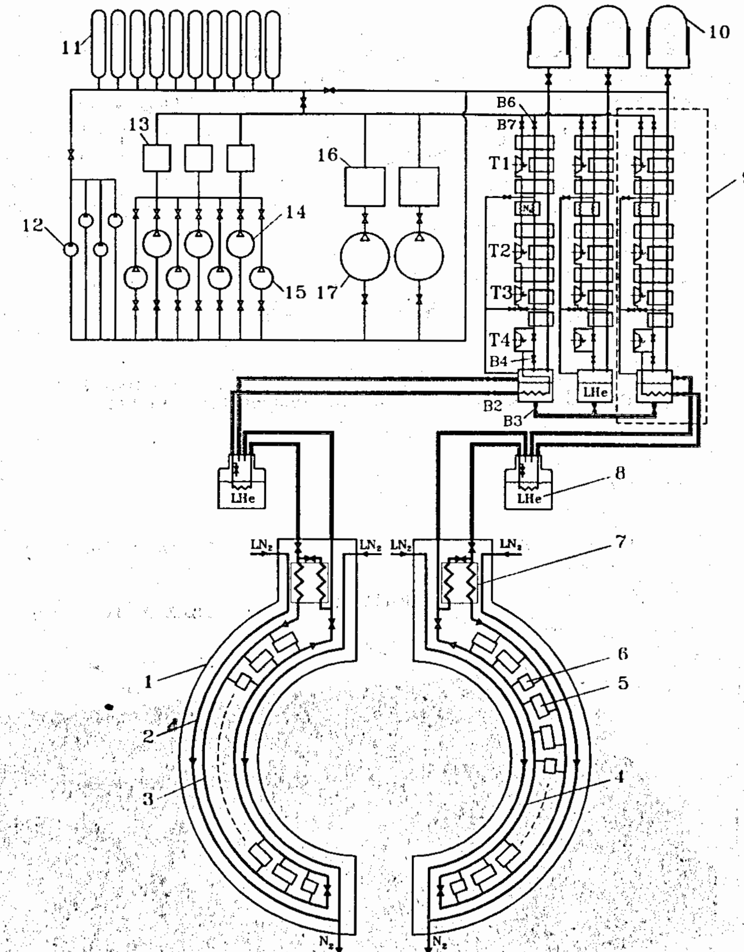

Figure 2. Flow diagram of the Nuclotron cryogenics. 1 – vacuum shell; 2 – heat shield; 3 – supply header; 4 – return header; 5 – dipole magnet; 6 – quadrupole magnet; 7 subcooler; 8 – separator; 9 – refrigerator; 10 – gas bag; 11 – storage vessel; 12, 14, 15, 17 – compressors; 13, 16 – purifiers.

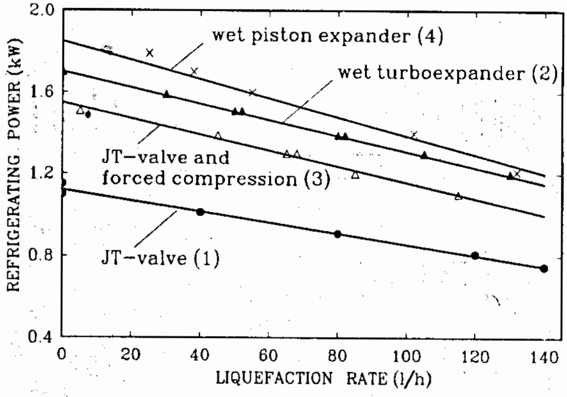

Figure 3. Characteristics of the refrigerator/liquefier

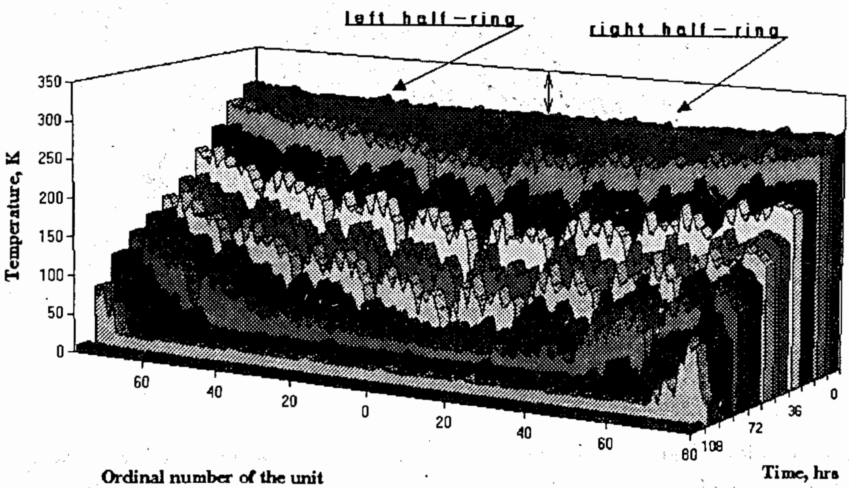

Figure 4. Typical process of the NUCLOTRONs cool down.

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