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SPECIAL PROPERTIES OF THE REFRIGERATION OF THE ACCELERATOR NUCLOTRON

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The Nuclotron is the first superconducting synchrotron intended for the acceleration of nuclei and heavy ions up to uranium. The accelerator is designed to provide beams of relativistic particles with energies up to 6 GeV per nucleon. Its cryogenic system includes three helium refrigerators. Each refrigerator has a nominal capacity of 1600 W at 4.5 K. These refrigerators cool the accelerator ring, which has a perimeter of 251 m and a «cold» mass of about 80 tons. The experience of using some new technical solutions in the design of the Nuclotron cryogenic system is discussed.

The investigation has been performed at the Laboratory of High Energies, JINR.

Особенности криостатирования магнитной системы нуклотрона

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Нуклотрон — первый сверхпроводящий синхротрон, предназначенный для ускорения ядер и тяжелых ионов вплоть до урана. Ускоритель служит для получения пучков релятивистских частиц с энергией до 6 ГэВ на нуклон. Криогенная система включает в себя три гелиевых рефрижератора с номинальной холодопроизводительностью 1600 Вт на уровне 4,5 К каждая. Рефрижераторы охлаждают кольцо ускорителя, которое имеет периметр 251 м и «холодную» массу около 80 тонн. Обсуждается опыт использования некоторых новых технических решений, заложенных в проекте криогенной системы нуклотрона.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Introduction

The superconducting synchrotron Nuclotron [1,2] has been used to conduct eleven physics experiments since 1993. The design of its cryogenic system includes a large number of novel technical solutions. This system is described in such general terms as «fast cycling superconducting magnets», «refrigeration by two-phase helium flow», «unusually short cooldown time», «parallel connection of all cooling channels», «wet turboexpanders», «two-stage screw compressor with an outlet pressure of 2.5 MPa». Now it becomes evident that all of these rather bold solutions have been very important. The Nuclotron cryogenic system has a high reliability and a good efficiency. During all runs of the Nuclotron there have been no losses of the running time due to the cryogenic system failures. This paper summarises basic properties of the refrigeration of the Nuclotron.

Fast Cycling Magnets and Refrigeration by Two-Phase Helium Flow

The main parameters of the accelerator are given in the Table. The most interesting feature of the magnets is their capability for fast cycling. It is really unusual for superconducting accelerator magnets to operate up to 1 Hz. That is why in our case dynamic heat releases are larger than the value of static heat leaks. The Nuclotron 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.

The superconducting cable [3] represents a 5 mm diameter copper-nickel tube, inside which a two-phase helium flow proceeds. This tube is coated with epoxy compound and wrapped with 31 wires 0.5 mm in diameter. Each wire contains 1045 NbTi filaments of 10 microns in a copper matrix. Such a design provides a good thermal contact of super-

Table. Main parameters of the Nuclotron

1.	Maximum design energy of particles	6 GeV/n
2.	Perimeter	251.5 m
3.	Maximum magnetic field	2.0 T
4.	Stored energy	2.35 MJ
5.	Temperature	4.5 K
6.	Total static heat leak	1.75 kW
7.	Maximum dynamic heat releases at 0.5 Hz	2.9 kW
8.	Repetition rate	up to 1 Hz
9.	Total «cold» mass	80 tons
10.	Cooldown time	80 h

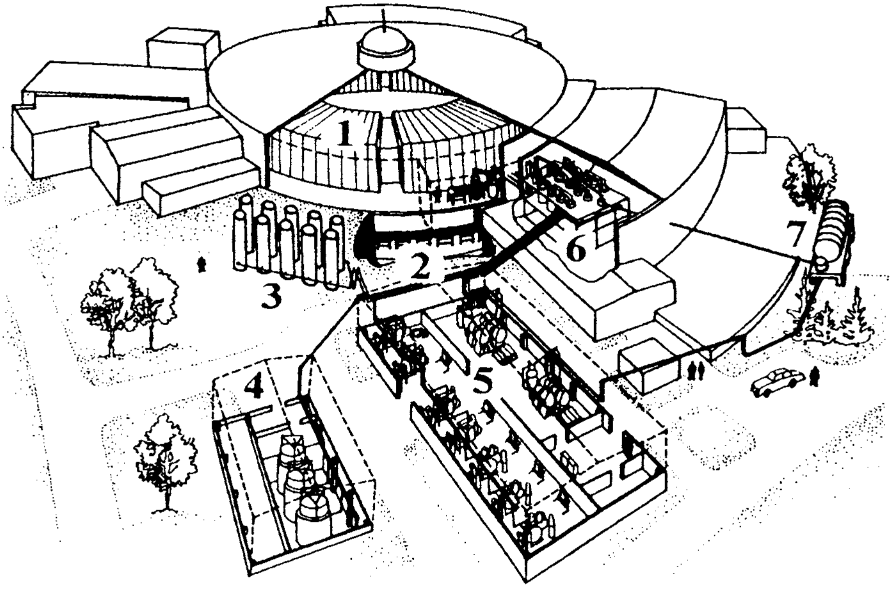

Fig.1. General view of the Nuclotron cryogenic system. 1 — «warm» accelerator Synchrophasotron, 2 — superconducting ring of the Nuclotron, 3 — gaseous helium storage, 4 — gas bags, 5 — compressors, 6 — refrigerators, 7 — liquid helium tank

conducting wires with a cooling helium flow. The Nuclotron ring comprises 96 dipole magnets with a superconducting cable 62 m long in each magnet. The mass of the dipole magnet is 500 kg, the static heat releases are 6.6 W. Dynamic heat releases depend on the repetition frequency of accelerating cycles. In case of 0.5 Hz, they are 21 W. Other main elements of the ring are 64 quadrupole magnets. This type of magnets has a superconducting cable 24 m long. The mass of the quadrupole magnet is 200 kg, the static and dynamic heat releases ($f = 0.5$ Hz) are 5.2 W and 12 W, respectively. The figure shows a general view of the Nuclotron cryogenic system.

Parallel Connection of All Cooling Channels

The magnets are assembled in the ring cryostat equipped with a copper shield cooled with liquid nitrogen. Supply and return helium headers are placed inside the cryostat, too. Two of the three refrigerators are connected to the half-rings that can operate independently. The third one is intended for increasing the total capacity in case of peak repetition rates and maximum energies of the accelerator.

At the first stage of designing, we were thinking rather carefully of the system, in which the magnets are piped in parallel resulting in about 100 channels in each half-ring returning two-phase helium flow. There were at least two reasons for that. First, it was not obvious whether it was possible to satisfy the required distributions of cooling helium flows in such a large number of different channels. Second, the probability of fluctuations of helium streams was not excluded. The following ways were accepted to avoid such bad consequences:

The hydraulic resistance of the cooling channels of the dipole and quadrupole magnets is performed so that the mass vapour content of helium at the outlet of the magnets is equal to 90%.

To be quite sure that there is only the liquid at the inlet of each of the magnets, 62 subcoolers are constructed in each half-ring for keeping helium in a liquid state inside the supply header.

The subcoolers operate as heaters when the system is being cooled down. Identical rates of temperature reduction for different magnets are practically achieved in this way [4].

Very Short Cooldown Time

There was no question on the limits of temperature gradients and stresses in the magnets in our case. Testing all of our superconducting magnets was accomplished with a cooldown time of about 10 hours. Therefore, it was necessary to cool down the whole magnet system for some adequate time, generally considered to be about 80 hours. The chosen solution uses a forced-flow of gaseous helium refrigerated by vaporising 80 cubic meters of liquid nitrogen. The process of cooldown is realised without any extra facilities. The main refrigerator system is only used. The supply and return streams are the same as in the case of ordinary refrigeration at 4.5 K. But in order to decrease the cooldown time, each of the refrigerators is equipped with bypass lines.

Wet Turboexpanders

To make an efficiency of cryogenic systems higher, one needs to use expanders instead of JT-valves. This useful idea was accomplished for a hydrogen liquefier at our cryogenic division in 1965 .The output of the hydrogen liquefier was 50-60 per cent higher with an expander than with a JT-valve [5]. For a helium liquefier, it was made by S.Collins [6]. Machines with a piston were used in both the cases. The first successful experience to use wet turbines [7] was gained by our specialists in 1985.These machines are high-speed and small size turbine expanders. A rotor is fixed vertically by a combination of gas and hydrostatic oil bearings. The turbines are capable to work at a speed of 300000 revolutions per minute. The operation speed of rotation is much lower, therefore the expanders have a high reliability and a smooth run. The penetration of oil into the cool areas is prevented by feeding of compressed helium into the labyrinth packing. The oil bearings are used as a loader.

Two-Stage Screw Compressor with an Outlet Pressure of 2.5 MPa

The main compressor at our liquid helium plant is a two-stage screw machine CASCADE-80/25 with an inlet absolute pressure of about 0.1 MPa, an outlet pressure of 2.5 MPa and a capacity of 5000 Nm^3/h. This oil-lubricated compressor was specially designed and constructed by the Russian enterprise «Kazancompressormash» for a cryogenic supply of large-scale superconducting accelerators. Its pilot unit was tested [8] in our cryogenic division before the first run of the Nuclotron. The results of the test and a total running time of about 5000 hours without any defects and without any serious service have shown its very high reliability. The isothermal efficiency of the machine is more than 50 per cent.

Conclusion

The new technical ideas used at the Nuclotron have provided a low cost of its refrigeration, a good thermodynamic efficiency and a high reliability during a long-term operation. We believe that these ideas can be successfully applied in the frames of the low-cost approach to very large scale cryomagnetic systems, for example, future superconducting hadron colliders. The concept of the Nuclotron-type cryomagnetic system for a 100 TeV Synchrotron/Collider is considered [9].

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