STATUS OF THE NUCLOTRON

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Abstract

The 6 GeV/u superconducting synchrotron was put into commissioning in March 1993 at the Laboratory of High Energies of the Joint Institute for Nuclear Research in Dubna[1]. Four runs of a total duration of about 1100 hours have been provided since that time. A maximum deuteron momentum of 3.5 GeV/c per nucleon at a beam intensity of 2×10^9 particles per pulse has been reached in accordance with a magnetic field cycle amplitude of B=1 T. Physics experiments on a beam of deuterons were started by three teams of experimentalists using an internal beam-target system. A beam of krypton ions (Z=29) was accelerated in the linac and injected into the Nuclotron beam pipe for the first time. The next Nuclotron run with heavy ions is being prepared to be performed in July.

1 INTRODUCTION

The Nuclotron is intended to accelerate nuclei and multicharged ions including the heaviest ones (uranium) up to an energy of 6 GeV/u for the charge to mass ratio Z/A=1/2. The basic program of fundamental physics research on the Nuclotron beams was motivated by ideas of relativistic nuclear physics[2]. Since 1957 the major accelerating facility of the Laboratory has been the 10 GeV Synchrophasotron which provides beams of protons, light ions (including sulphur), polarized and aligned deuterons as well as secondary beams (neutrons, pions, ^{3}H). A general view of the LHE accelerator centre is shown in Fig.1. About 500 physicists from 120 institutions are involved in the research program. The investigations of relativistic nuclear collisions have begun at the Synchrophasotron since 1970. The first experiment was carried out with 4.3 GeV/u deuterons[3].

The first conceptual design proposal of specialized relativistic nuclear beam facility at the LHE – Nuclotron was published in 1973[4]. The "Nuclotron" was considered as a three-stage accelerating complex:

- 10 MeV/u linac;
- 750 MeV/u booster ring (both conventional and superconducting ones were proposed);
- 20-25 GeV/u main ring – superconducting strong focusing synchrotron.

Pulsed superconducting dipoles with a peak magnetic field of 6 T were suggested to be used for the Nuclotron main ring. However this proposal was not supported by funding, and a decision should be found to make the construction of a new machine more feasible and substantially cheaper.

The final version of the Nuclotron concept was developed early in the 80th[5], and the project of "Reconstruction of the Synchrophasotron magnetic system to the superconducting one – Nuclotron" was approved in December 1986. The upgrading of the existing linac LU-20 and the construction of a booster and a new building for the accelerator ring were not included in the project due to very limited funding.

2 GENERAL DESCRIPTION

2.1 *The Ring Lattice*

The Nuclotron lattice is typical of a strong-focusing separated function synchrotron. It contains 8 superperiods. Each superperiod consists of three regular FODO cells, the fourth one without a dipole magnet. The regular cell includes F- and D-quadrupole magnets, four dipole magnets, and two small drift spaces for the installation of correcting magnets, beam monitors, etc.

There are 96 dipole, 64 quadrupole, 32 correcting multipole SC-magnets in the Nuclotron magnetic ring with circumference of 251.5 m (limited by the sizes of the existing tunnel). The frequency of betatron oscillations $Q_x \simeq Q_z \simeq 6.75$.

2.2 *SC-magnets*

Special type of superconducting magnets was proposed and investigated for the Nuclotron. These are fast cycling iron-shaped magnetic field magnets with a winding of hollow composite superconductor and a circulatory refrigeration system[6]. In this case the maximum value of magnetic field is about 2 T. The SC cable represents a 5 mm OD copper-nickel tube wrapped by thirty one 0.5 mm diameter wires. Each wire contains 1045 NbTi filaments ∅ 10 μm in a copper matrix. The tube allows a high helium pressure after quenching or vacuum breaking. A high electric strength, a low inductance of the windings, and good conditions of their cooling make it possible to provide a high (up to 1 Hz) frequency of accelerating cycles.

The dipole magnet has a window-frame type iron yoke 1.4 m long. The sizes of the window are 110×55 mm^2, the mass of a dipole 500 kg, the number of turns in the winding 2×8, and the inductance 1.1 mH. The quadrupole magnet yoke 0.45 m long has hyperbolic shaped poles. The

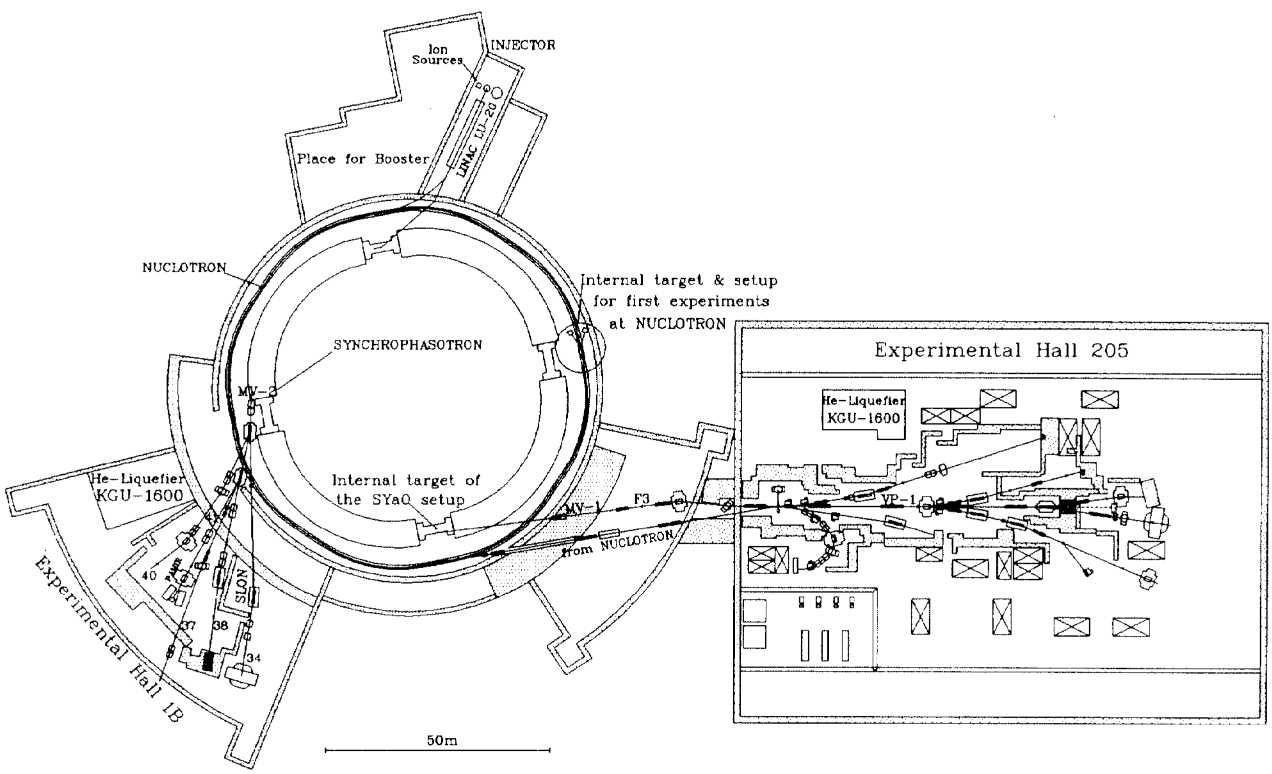

Figure 1: Accelerating centre of the Laboratory of High Energies

mass of the quadrupole is about 200 kg, the number of turns in the winding 4×5, and the inductance 0.44 mH. The magnet is fastened to a vacuum shell of the cryostat ∅ 540 mm by 8 suspension parts of stainless steel. A nitrogen shield ∅ 490 mm covered with 20 layers of superinsulation is placed in the vacuum space between the magnet and the vacuum shell. The cooling of the magnets is performed by a two-phase helium flow. The mass vapour content of helium varies from k=0 at the inlet of the magnet to k=0.9 at its outlet. The temperature sensors are placed at the helium inlet and at the outlet of the winding and also at the helium outlet of the iron yoke of each magnet.

The dynamic heat releases at $\dot{B}$=2 T/s, B_{max}=2 T, and a pulse repetition rate of f=0.5 Hz are 21 and 12 W for the dipole and quadrupole magnets, respectively. The static heat releases are 6.6 W and 5.8 W. The magnetic field gradient in quadrupole at a nominal current of 5.6 kA is 33.4 T/m.

2.3 Cryogenic Supply System

The cryogenic supply system[7] is based on three refrigerators/liquefiers of a nominal capacity of 1600 W at 4.5 K. The first and the second refrigerators are connected to the half-rings, respectively. The third one is aimed to run in the liquefaction mode with liquid helium fed to any refrigerator in the case of its failure or the Nuclotron operation at a maximum frequency of accelerating cycles. The nominal pressure of compressed helium at the entrance of the refrigerator is 2.5 MPa. The pressure in the liquid helium receiver is about 0.13 MPa. The basis of the compressor system is a screw compressor of a 5040 m^3/h capacity. Seven piston compressors with a capacity of 1200 m^3/h and 900 m^3/h are used for step-by-step variation of the compressed helium flow and its redundancy.

3 COMMISSIONING OF THE NUCLOTRON RING

The stand tests of a string of 12 dipole magnets and 4 quadrupole lenses were performed in the February of 1990. The time spent on cooldown of the string of magnets with a total cold mass of 7 tons from room to LHe temperature was about 46 hours. The time difference between cooling down the first and the last magnets to LHe temperature was 17 hours.

The cooling was performed by a KGU-1600 refrigerator at a mean helium flow rate of 0.45 g/s through each magnet. The first spontaneous quench current was 5.9 kA, the second one 6.4 kA (an operating current is 6 kA). Several tens of quenches were initiated during the run. No breakdowns were observed in the energy evacuation system. Recovery from a quench takes less than 5 minutes. When the windings were excited by current pulses of triangular shape with an amplitude of 6 kA, a pulse duration of 2×1.55 s, and a pulse repetition period of 3.55 s, the measured energy losses in the magnets were 140 W. The

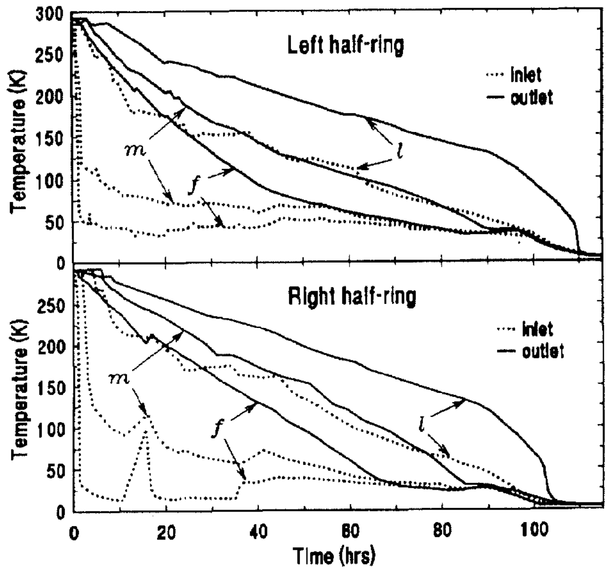

Figure 2: Cooldown history of the Nuclotron half-rings during the pilot run. *f*, *m*, *l* - the first, fortieth, and eightieth magnet on the way of helium, respectively.

heat leak from the surroundings to the magnet string and two current leads cryostats was 100 W. The helium flow rate per one current lead was 0.37 g/s at a constant current of 6 kA. The mass vapour content of helium in the supply header, reliably measured by means of a void fraction sensor, was controlled close to zero with the aid of a subcooler. The pressure difference between the supply and return headers was kept equal to 9 kPa. In this case the mass vapour content of helium in the return header was about 1 and the helium temperature approximately 4.5 K. The cooling and operation of the magnets were stable. No flow rate oscillations were observed in the parallel cooling channels. In the indicated operating mode the magnets ramped 192 hours (2×10^5 excitation cycles). The operation of the magnets was also stable at significant deviations of cooling parameters from nominal ones. The pressure difference between the supply and return headers was decreased to 6 kPa. In this case the superheated vapour, having a temperature from 5.1 K for the magnet with the lowest hydraulic resistance to 7.8 K for the magnet with the highest hydraulic resistance of the cooling channels, went out of the channels for cooling yoke.

The first quadrant of the Nuclotron was installed in the accelerator tunnel in February 1992, and its test commissioning was performed. It took about 84 hours to cool down 28 dipoles and 11 quadrupoles to LHe temperatures. The cooldown was performed at a mean helium flow rate of 0.34 g/s through each magnet. Cooling of the magnets was stable. The pressure in the vacuum chamber of the accelerator was less than 1×10^{-7} Pa. The injection of a beam of polarized deuterons with an energy of 5 MeV/u was performed at an intensity of 2×10^9 p.p.p., and the beam was transported through 1/4 of the ring.

The Nuclotron ring assembling in the tunnel was finished on January 13, 1993, and the first run of cooling and operation with a beam was carried out on March 17-26. Both half-rings of the Nuclotron with a total cold mass of 80 tons were cooled down simultaneously. The cooling down was performed at a mean helium flow rate of 0.16 g/s through each magnet. The cooldown time of the left and right half-rings was 110 and 103 hours, respectively (see Fig.2). All systems of the accelerator were tested, and the first turns of the deuteron beam in the ring were obtained for an injection energy of 5 MeV/u. The pressure in the beam pipe was less than 2×10^{-7} Pa. The system of 26 old diffusion vacuum pumps, having a capacity of 0.5 m^3/s each and aimed to control helium, nitrogen, and air leakages, was unnecessary and switched off. The vacuum in the insulation volume was kept no worse than 2×10^{-3} Pa by two 2.5 m^3/s booster pumps only. The flow rate of liquid nitrogen for cooling the shields after cooling down was equal to 0.186 kg/s. The cooldown times were 64 and 61 hours for the nitrogen shields of the left and right half-rings, respectively.

Deuteron beam acceleration up to an energy of 0.2 GeV/u and internal target irradiation were performed for the first time in the second Nuclotron run during June 26 – July 6. The intensity of an accelerated beam was about 3×10^9 p.p.p. The parameters of a magnetic cycle were: B_{max}=2 kG, $\dot{B}$=2 kG/s. Beam dynamics was stable enough, and a maximum beam energy was limited by the magnetic field amplitude.

New results on the acceleration of heavier ions were obtained at Nuclotron in December run. The cryogenic electron beam ionizer "CRION-S" [8] was installed at the linac. This modification of a Donetz type ion source is considered as the main operational device for the first stage of the Nuclotron heavy ion program. Beams of Ar^{16+} and Kr^{29+} were obtained and accelerated to an energy of 5 MeV/u at the linac. A beam of krypton was injected into the Nuclotron vacuum chamber.

The operation of laser ion source at the Nuclotron was also tested in this run. An accelerated beam of carbon ions with an intensity of 10^9 p.p.p. was obtained. The magnetic field cycle parameters were B_{max}=2 kG, $\dot{B}$=2 kG/s.

The fourth Nuclotron run was carried out on March 17-29, 1994. It was scheduled just after the completing the Synchrophasotron run with polarized deuterons. In accordance with the run program, polarized deuteron beam injection and limited acceleration (up to 100 MeV/u) were provided.

Then the polarized deuteron source was replaced by a duoplasmatron, and the Nuclotron operation was continued with non polarized particles. The parameters of a magnetic field cycle in this run were B_{max}=6; 8.5; 10 kG and $\dot{B}$=6 kG/s. The maximum deuteron momentum of 3.5 GeV/c per nucleon was reached at a beam intensity of 2×10^9 particle per pulse.

The next Nuclotron run is scheduled in the first part of July. The ion source "CRION-S" is prepared and tested with the linac. An additional monitor of low intensity beams is installed at the end of the beam transportation line. The acceleration of krypton ions will be tested for the first time. After that, the "CRION-S" will be replaced by the duoplasmatron, and accelerated deuterons will be used for physics experiments (mainly) and for beam dynamics investigations.

Main points which will be of first priority in the near future are the following:

- the Nuclotron operation with an internal beam for physics experiments;
- completion of the beam slow extraction system;
- development of an injector, ion sources, and other systems, in particular a system of liquid nitrogen cooling;
- design and construction of a booster ring.

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