STATUS OF THE NUCLOTRON

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Abstract

The Nuclotron upgrade – the Nuclotron-M project, was successfully completed in 2010. Following the project goals, Xe ions were accelerated to about 1.5 GeV/u in March 2010. In December 2010, the stable and safe operation of the power supply and energy evacuation system was achieved with a field in the lattice magnets of 2 T. In 2011 - 2012 three runs of the Nuclotron operation were carried out. The facility development is aimed to the performance increase for current physical program realization and to test equipment and operational modes of the NICA collider.

INTRODUCTION

The "Nuclotron-M" project, started in 2007 was considered as a key part of the first stage of the JINR general project NICA/MPD [1]. The extension of JINR basic facility capabilities for generation of intense heavy ion and high intensity light polarized nuclear beams, including design and construction of heavy ion collider aimed at reaching the collision energy of $\sqrt{s_{NN}}$ = 4÷11 GeV and averaged luminosity of $1\cdot10^{27}$ cm^{-2}s^{-1} is necessary for realization of the NICA/MPD.

During the Nuclotron-M project realization course almost all the Nuclotron systems were modernized and six runs at total duration of about 3200 hours were carried out. To the end of 2010 all general goals of the project were reached : the Xenon ($^{42+}Xe^{124}$) beam was accelerated up to 1.5 GeV/u and reliable work of the Nuclotron magnetic system at 2 T was provided [2].

Presently the creation of the NICA general elements is realizing in the frame of three officially approved JINR projects: "Nuclotron-NICA" (accelerator part), MPD (the project oriented to creation of one of the collider detectors) and BM@N (Baryonic Matter at Nuclotron – the new fixed target experiment with heavy ions, the detector is under construction in the existing experimental building). The Nuclotron is the key element of all three projects: as the ion source for MPD element testing and for experimental program BM@N realization, as the main synchrotron in the injection chain of the future collider and as the basic facility for testing of new equipment of the booster and collider rings.

The results of the Nuclotron upgrade and development of the accelerator complex during last two years are briefly described in this report.

RESULTS OF THE NUCLOTRON UPGRADE PROGRAM

The "Nuclotron-M" program was oriented to the development of the existing Nuclotron accelerator complex to the facility for generation of relativistic ion beams over atomic mass range from protons to gold ions at the energies corresponding to the maximum design magnetic field (2 T) in the lattice dipole magnets. Another important goal of the project was to reach new level of the beam parameters and to improve substantially reliability and efficiency of the accelerator operation, renovate or replace some part of the equipment that have been under operation since 1992-93.

As an element of the NICA collider injection chain, the Nuclotron has to accelerate single bunch of fully stripped heavy ions (as a reference Au^{79+} is considered) from 0.6 to about 4.5 GeV/u. The required bunch intensity is about $1\div1.5\cdot10^{9}$ ions. The particle losses during acceleration have to be minimized and do not exceed 10%. The magnetic field ramp rate has to be 1 T/s and more. To demonstrate the ability of the Nuclotron complex to satisfy these requirements, the general milestones of the Nuclotron-M project were specified as an acceleration of heavy ions (at atomic number larger than 100) and stable and safety operation at 2 T of the dipole magnet field.

In the frames of the "Nuclotron-M" project the following works on the LHEP accelerator complex development were performed.

1. Full scale modernization of the cryogenic system was carried out. As result the cooling power at 4,5 K was increased up to 4 kW, the reliable work at maximum magnetic field and at prolonged magnetic cycle duration was provided. The operation term was sufficiently increased; today the new equipment can be used for the NICA/MPD purposes already.

2. The vacuum system modernization permitted to decrease the residual gas pressure in the Nuclotron beam pipe by two orders of magnitude and to provide a possibility of heavy ion acceleration. The obtained result allows solving general task of the Nuclotron as a part of

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the heavy ion collider injection chain – to provide acceleration of heavy nuclei from 0,6 GeV/u (injection energy from the booster) up to 4.5 GeV/u without losses.

3. Modernization of control system, diagnostic and radio frequency accelerating systems was performed. As result new cycle control equipment, digital generator providing relation between accelerating voltage frequency and magnetic field value, new power supply system for corrector magnets, digital orbit measurement system and others were put into exploitation.

4. New power supply and quench protection system based on consequent connection of the Nuclotron structural magnets, all supply units and energy evacuation switches was created. Practical realization of this scheme required modernization of existing supply units, development and construction of two new units for current variation in focusing and defocusing lenses, disassembly of old cable lines and assembly of a few kilometers of new ones. The new system was put into operation during the last run performed in the frame of the Nuclotron-M project when the stable and reliable operation of the magnetic system at 2 T of dipole field is demonstrated (Fig. 1).

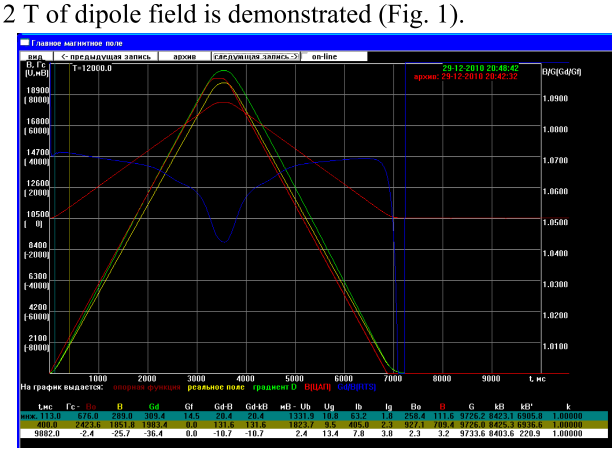

Figure 1: Cycle diagram at dipole magnetic field of 2 T. Red curve – basic function, yellow and green – field of the magnets and gradient of the lenses correspondingly. December 2010.

After completion of the Nuclotron upgrade tree runs (#43 - #45) at total duration of about 2900 hours were performed. About 1400 hours were spent for physical experiments including the shifts dedicated to machine development.

MACHINE DEVELOPMENT

The machine development aimed to increase the Nuclotron ability for the current physical program realization is provided in the following main directions:

- Step by step increase of the beam energy up to maximum design value (6 GeV/u for deuterons);
- Optimization of the beam dynamics in order to minimize the particle losses during acceleration;
- Further development of power supply system in order to provide required quality of slow extraction;
- Development of the diagnostics;
- Development of ion sources and fore-injector modernization.

Before the modernization the Nuclotron provided the beam energy up to 3 GeV/u maximum (for the ions with A/Z = 2). During the run #44 (December 2012) carbon beam was accelerated up to about 3.5 GeV/u and after slow extraction transported along the transport line to the point of the future location of the BM@N detector. During the same run the slow extraction of deuteron beam was realized at 4 GeV/u. In the run #45 (March 2012) the slow extracted 4 GeV/u deuteron beam was routinely used for physical experiments. At the end of the run #45 the possibility of the slow extraction was demonstrated at the deuteron beam energy of 4.5 GeV/u. Further increase of the extracted beam energy is related to development of the slow extraction system (increase of the electrostatic septum Voltage and current of the slow extraction quadrupoles) and optimization of operational conditions of the power supply system.

Decrease of the ion losses during acceleration is related with further development of the accelerating RF system, optimization of the closed orbit (including the orbit bump in the slow extraction region), development of the beam diagnostics. Sufficient part of these works was performed during runs #43 – #45.

Fast current transformer (FCT) installed at the Nuclotron before the run #44 was optimized for work in required dynamic range. Now the analogous device is installed in the beam injection line. In future one plans to use such FCTs at the Booster and collider.

New ionization beam profile monitor based on MCP was installed in the warm section of the Nuclotron. During run#45 it was optimized for work with heavy ion beams at relatively low intensity.

During the runs #44 and #45 experimental fragment (two octants of the ring) of new system of superconducting element thermometry were tested. Full scale implementation of the new system is scheduled to the end of this year.

In the frame of the Nuclotron upgrade program a new quench detection system was designed. Prototypes of the quench detector were consequently tested and serial production of the detectors was started in 2010. During the runs #44 and #45 the fragment of the new quench detection system including 20 quench detectors was operated during more than 1500 hours. Stable and reliable work of all elements was demonstrated [3].

The works oriented to creation of new sources of high intensive heavy ions and light polarized nuclei are in the final stage. In 2011 the 6 T solenoid for the heavy ion source (of electron string type – ESIS) was constructed, assembly of the source was completed this year. Experimental investigations of the source parameters have been started. The atomic beam source for the source of polarized particles was assembled and tested at INR (Troitsk), the plasma ionizer and test bench for the final assembly and test of the source is under construction at JINR. Completion of these works is scheduled for 2012. Reconstruction of LU-20 fore-injector, required for effective operation of the new sources, is in progress.

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NUCLOTRON AS A TEST FACILITY FOR NICA

The Nuclotron having the same magnetic rigidity as the future NICA collider and based on the same type of the magnetic system is the best facility for testing of the collider equipment and operational regimes. Simulation of the collider magnetic system operational conditions was performed at the Nuclotron during runs #44 and #45. This presumed test of the Nuclotron magnetic system, power supply and quench protection systems, cycle control and diagnostic equipment in the operational mode with long plateau of the magnetic field. In the run #44 the magnetic field cycle duration was prolonged up to 500 s without beam acceleration, in the run #45 the circulation of accelerated deuteron beam during 1000 s was demonstrated (Fig. 2).

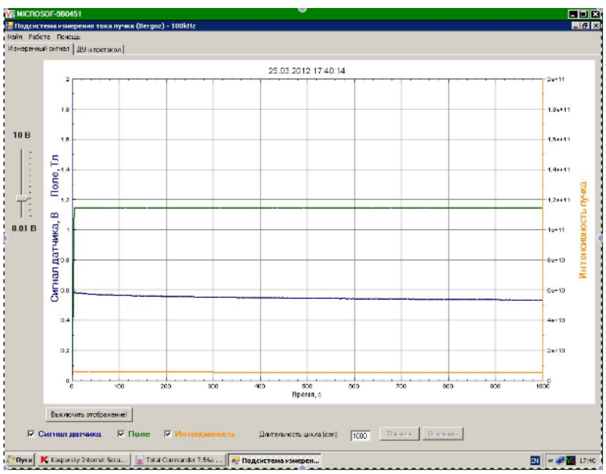

Figure 2: Circulation of the deuteron beam at the field plateau during 1000 s. Dipole field is 1.2 T (upper curve), the beam intensity is $5{\cdot}10^9$ particles (lower curve). Blue curve – BCT signal in Volts. March 2012.

Application of beam cooling methods (electron and stochastic) in the collider ring has the purposes of beam accumulation using cooling-stacking procedure and luminosity preservation during experiments. Experimental test of the stochastic cooling at the Nuclotron is considered as important phase of the collider cooling system design. During 2010-2011 the elements of the stochastic cooling chain for test at the Nuclotron were designed, constructed and after vacuum and cryogenic tests installed at the ring (Fig. 3). Experiments started in December 2011 were prolonged in 2012. We plan step by step investigate longitudinal and transverse cooling of coasting and bunched beams [4].

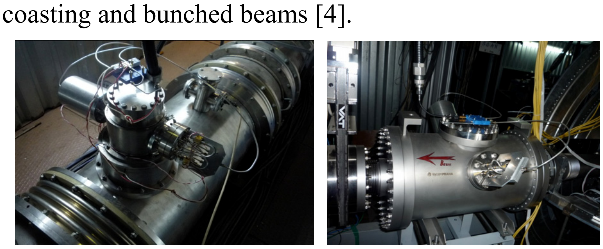

Figure 3: Pick-up (left) and kicker (right) of the Nuclotron stochastic cooling chain.

CONCLUSIONS AND OUTLOOK

In 2010 the Nuclotron-M project was successfully completed. The last three Nuclotron runs (#43 - #45) were performed in the frame of new JINR project, so called “Nuclotron-NICA”, dedicated to construction of the NICA facility main elements. During this project the Nuclotron will be used for prolongation and development of its current experimental program, test of the MPD elements, test of new equipment of the booster and collider rings.

In parallel with the existing accelerator complex development the technical design of the NICA collider injection chain elements (new heavy ion linear accelerator, small booster synchrotron) was prepared. Technical design of the collider is at the final stage.

The full-scale Nuclotron–type superconducting model dipole and quadrupole magnets for the NICA booster and collider were manufactured during 2010 - 2012. First dipole and quadrupole magnets for the NICA booster have successfully passed the cryogenic test on the bench. To construct the Booster and collider rings, it is necessary to fabricate more than two and half hundreds of the dipole magnets and lenses during a short period of time. Special area for the magnet assembly and full-scaled tests required for the magnet commissioning are currently being prepared [5].

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