STATUS OF THE NUCLOTRON. “NUCLOTRON-M” PROJECT

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Abstract

The “Nuclotron-M” project started in 2007 is considered as the key point of the first stage of the NICA/MPD project. General goal of the “Nuclotron-M” project is to prepare all the systems of the Nuclotron for its long and reliable operation as a part of the NICA collider injection chain. Additionally the project realization will increase the Nuclotron ability for realization of its current experimental program. Results of the last runs of the Nuclotron operation are presented.

INTRODUCTION

The project “Nuclotron-M” is considered as a key part of the first stage of the JINR general project NICA/MPD (**N**uclotron-based **I**on **C**ollider f**A**cility and **M**ulty **P**urpose **D**etector). The NICA/MPD project is aimed at investigation of the mixed phase formation in strongly interacting nuclear matter at extremely high baryon densities and polarization phenomena in few-body nucleon systems. 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÷9 GeV and averaged luminosity of $1\cdot10^{27}$ $cm^{-2}s^{-1}$ is necessary for realization of the NICA/MPD. The NICA specified parameters (average luminosity, c.m. collision energy, atomic mass range) can be practically reached after: 1) development, modernization and improvement of the Nuclotron systems, 2) design and construction of heavy ion injector, 3) design and construction of heavy ion booster synchrotron and 4) design and construction of the collider rings.

The first stage of the NICA/MPD realization includes the following tasks:

- upgrade the Nuclotron facility (the “Nuclotron-M” project);
- elaboration of the NICA technical design report;
- development of the laboratory infrastructure aimed for long term stable operation of the accelerator complex and preparation for construction of the NICA elements;
- R&D works for MPD elements.

The “Nuclotron-M” work program includes all necessary works on 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 and uranium ions at the energies corresponding to the maximum design magnetic field (2 T) in the lattice dipole magnets. Realization of the project will make it possible 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 well.

The project has been started in 2007 and its completion is scheduled for the fall of 2009.

STATUS AND MAIN PARAMETERS OF THE NUCLOTRON

The first run at the Nuclotron was performed in March 1993. Since that time 38 runs of the accelerator operation were carried out. There were no any problems in operation of its cryomagnetic system.

Main elements and systems of the Nuclotron facility (Fig. 1) are the following:

1. superconductive synchrotron Nuclotron, which magnetic-cryostat system of the circumference of 251,5 m is located in the tunnel surrounding the Synchrophasotron basement;
2. cryogenic supply system consisting of two helium refrigerators KGU-1600/4.5 with required infrastructure for storage and circulation of the gaseous helium, tanks for the liquid nitrogen storage and nitrogen transport lines for thermal screens of the Nuclotron lattice magnets;
3. the injection complex consisting of HV fore-injector and Alvarez-type linac LU-20. The fore-injector voltage up to 700 kV is produced by pulsed transformer. The LU-20 accelerates the protons up to the energy of 20 MeV and ions at Z/A ≥ 0.33 up to the energy of 5 MeV/u. The wide range of the ion species is provided by the heavy ion source “KRION-2”, duoplasmatron ion source, polarized deuteron source POLARIS and laser ion source.
4. transport line from LU-20 to the Nuclotron ring including equipment for the beam injection onto the orbit;
5. system of the resonant slow extraction of the accelerated beam in the direction to main experimental hall (bld. 205) to the so called «focus F3» point;
6. transport lines for the extracted beam from the F3 point to the experimental facilities in the building 205;
7. power supply units for the Nuclotron lattice magnets and the transport lines located in the separated building 1A (it does not shown in the Fig. 1);
8. control system, diagnostics of the beam and the accelerator complex parameters;

9. RF system for the beam acceleration in the Nuclotron;
10. radiation shielding and automatic system for the radiation measurements.

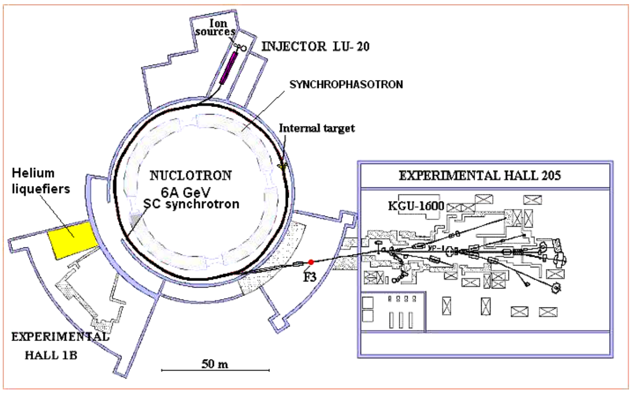

Figure 1. Schematics of the Nuclotron facility.

The Nuclotron is intended to accelerate nuclei and multi charged heavy ions. Presently the Nuclotron delivers ion beams for experiments on internal targets and for fixed target experiments using slow extraction system. Achieved energy of protons and nucleons (up to A = 56) is 5.7 GeV and 2.2 GeV/u correspondingly. The annual running time of 2000 hours was provided during the last years.

The maximum achieved energy is limited by the system of the energy evacuation of the Nuclotron SC magnets and power supply of the lattice magnets. Main limitation of the heavy ion beam intensity was related to vacuum conditions that lead to large ions loss at the initial stage of the acceleration.

During last three years sufficient attention was devoted to the development of the facility infrastructure, which status does not permit presently to provide required increase of the Nuclotron running time. Last runs demonstrated that the reliability of a few systems has to be sufficiently improved for successive realization of the current Nuclotron physical program. Another problem, which has to be solved, is low efficiency of the beam acceleration. At the moment the accelerated beam intensity does not exceed 20 – 30% from intensity of the injected beam.

NUCLOTRON-M PROJECT

As an element of the NICA collider injection chain the Nuclotron has to accelerate single bunch of fully stripped heavy ions (U^{92+}, Pb^{82+} or Au^{79+}) from 0.44 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 has to be ≥ 1 T/s. Before injection into the collider ring the Nuclotron RF system has to provide compression of the accelerated bunch.

To satisfy these requirements the Nuclotron ring has to be equipped with new injection kicker, fast (single turn) extraction system of the accelerated beam, new RF station providing the bunch compression after its acceleration. Design of these new devices is providing in the frame of the NICA technical design report preparation. Their construction and installation at the Nuclotron ring will be performed after completion of the "Nuclotron-M" project.

General goal of the "Nuclotron-M" project is to prepare all the existing systems of the Nuclotron for its long and reliable operation as a part of the NICA collider injection chain. Additionally the project realization will increase the Nuclotron ability for realization of its current experimental program. The project working program includes the next main tasks:

1. Development of the heavy ion source ESIS by increase of the magnetic field value and the electron energy.
2. Development of the polarized deuteron source.
3. Sufficient improvement of the vacuum conditions in the Nuclotron ring and linear accelerator-injector.
4. Development of the power supply system in order to reach magnetic field in dipole magnets of 1.8 - 2 T.
5. Upgrade of the Nuclotron RF system, realization of the adiabatic trapping into acceleration.
6. Development of the slow extraction system.
7. Development of the beam transfer lines and radiation shielding.
8. Beam dynamics investigations, minimizations of the particle loss at all stages of the acceleration.
9. Preparation of the KRION-2 ion source for generation of the ion beam at A > 100 and q/A > 0.33.
10. Design of new linear injector.

FIRST RESULTS

From the beginning of the "Nuclotron-M" project good progress was achieved in design of new elements of the NICA complex. Sufficient part of the two last Nuclotron runs - #37 (November of 2007) and #38 (June of 2008) - was devoted to the test of new equipment and machine development experiments.

Development of the ion sources

The Electron String Ion Source (ESIS) developed in JINR was chosen as the base for the heavy ion injector for the NICA facility. Technical design of the new electron-string highly-charged state heavy ion source KRION-6T has been completed this year. The source is aimed at generation of intensive heavy ion beams like Au^{32+} or U^{32+}. As a reserve option the source can be used for generation of the ions at q/A up to 0.33 (for example $Au^{65+} \div Au^{69+}$). The source construction has been started. The first experiments are scheduled for the next year and they includes:

- Study of the electron string phenomenon at different conditions in the source working volume (magnetic field range up to 6 T, energy of electron beam up to 25 keV).
- Development and optimization of heavy atoms injection into the string and ion-ion cooling process.

The main direction of work aimed at increase of polarized beam intensity at the Nuclotron is connected with the design and construction of the new high current polarized ion source (IPSN) based on the equipment of CIPIOS polarized proton and deuteron ion source from

Bloomington (Indiana University, Bloomington, USA). The work is carried out in collaboration with INR (Troitsk). The ion source equipment (not completed) was transported to Dubna from IUCF (Indiana University Cyclotron Facility, Bloomington). Some parts of suitable equipment for the new source were presented by DAPHNIA (Saclay).

Progress in modernization of the magnet power supply

Presently the maximum achievable ion energy at the Nuclotron is limited by the reliability of the quench detection and energy evacuation system and parameters of the power supply of the lattice magnets. To provide long and safe operation of the accelerator magnetic system at maximum design level of the magnetic field (2 T) the following modifications of the power supply system are necessary:

- manufacturing, assembling and put into operation seven units of the new switches for energy damp from the magnets in a case of quench for both the dipoles and the quadrupoles power supply circuits;
- upgrade of the quench detection system;
- development of scheme of the Nuclotron magnet power supply.

The new scheme of the Nuclotron magnet power supply was designed. The scheme is based on consequent connection of dipole and quadrupole magnets. Two additional power supply units will be used for control of the ring working point in the tune diagram. Preliminary test of the consequent magnet connection was performed during the run #37. It was demonstrated that the large inductivity sufficiently suppresses the magnetic field ripple. It leads to stable acceleration process and improve the quality of slow extracted beam.

The new improved unit for the energy damp switch (so-called "thyristor key") was designed, constructed and tested.

Upgrade of the Nuclotron ring vacuum system

The Nuclotron vacuum system consists of two sub-systems: insulator vacuum system of the cryostat and high vacuum system for the beam pipe. Insulator vacuum system satisfied to all the requirements of the accelerator operation and its upgrade is not necessary. The Nuclotron beam pipe has no effective pumping of gaseous hydrogen and helium, while gaseous helium can to penetrate into the pipe due to diffusion from insulation vacuum volume of the cryostat through non welded connection between beam extraction channel and circulating beam chamber.

During the run #37 the experimental estimate of average vacuum in the Nuclotron was made based on the studies of $^2H^+$ and deuteron beam circulation at the injection energy (5 MeV/u). It was shown, the beam pipe pressure scaled to equivalent concentration of N_2 molecules at T = 300 K is measured to about $p \approx 2{\cdot}10^{-8}$ Torr. Between the runs #37 and #38 the vacuum system was sufficiently upgraded. A few sections of the ring were reconstructed; new turbo molecular pumps and diagnostic equipment were installed. All the equipment was tested and put into operation during the run #38 and its application was resulted in improvement of the vacuum conditions by about one order of magnitude.

Development of the RF system

Presently the beam injection is provided into the linearly razing magnetic field at constant RF voltage amplitude. Such a scheme is acceptable for the NICA operation, when a short bunch is injected from the Booster. But it limits seriously the Nuclotron performance for realization of the current scientific program. At this injection scheme about 50% of the ions injected from LU-20 occur outside the Nuclotron longitudinal acceptance.

Realization of flexible (adiabatic) scheme of the particle capture and adequate increase of the particle capture efficiency is one of the goal of the "Nuclotron-M" project. It presumes sufficient improvement of the electronics related with the automatic frequency control system, control of the RF voltage from the central control room. The realization of the adiabatic trapping in the Nuclotron is considered also as the R&D stage of the Booster RF system design that has to provide the heavy ion trapping with the efficiency closed to 100 % at minimum dilution of the longitudinal beam emittance. The required new equipment is installing and testing step by step. During last runs it was experimentally shown that full-scale realization of the adiabatic trapping will lead to increase of the accelerated beam intensity as minimum by a factor of two.

Beam diagnostics

To minimize the particle loss at all stages of acceleration the following works were performed:

- accuracy of the beam intensity measurements was sufficiently improved by installation of new DC current transformer;
- modernization of the system for orbit position measurements has been started, the existing PU stations and correctors were tested and calibrated during the run #37;
- methodic for the closed orbit correction is under development, required additional PU stations were designed and are under construction now.

CONCLUSION

The project realization will result in:

- acceleration of the heavy ion beam at A > 100 up to the energy of about 3.5 GeV/u at intensity > 10^7 ions per cycle;
- achievement (at test bench) from new ESIS-type ion source the beam of Au^{32+} at intensity ~ 10^9 ions per pulse at the pulse duration < 10 μs.

We plan the completion of the project by fall of 2009.

REFERENCES

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