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PROGRESS OF THE NICA COMPLEX INJECTION FACILITY DEVELOPMENT

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Abstract

The new accelerator complex Nuclotron-based Ion Collider fAcility (NICA) is under development and construction at JINR, Dubna now. This complex is assumed to operate using two injectors: the Alvarez type linac LU-20 as injector of light ions, polarized protons and deuterons and a new linac HILAc - injector of heavy ions beams. The modernization of Alvarez-type linac began in 2016 by commissioning of new RFQ foreinjector, and in 2017 the new buncher in front of linac has been installed. The first Nuclotron run with new buncher was performed in January 2018 with beams of Xe+, Ar+ and Kr+. The beam produced by KRION-6T ion source were successfully injected and accelerated in the Nuclotron ring during the last run #55. Main results of the last Nuclotron run and plans for future development of NICA injection complex are presented in this paper.

INTRODUCTION

Nuclotron-based Ion Collider fAcility (NICA) (Fig. 1.) is new accelerator complex developing and constructing at JINR [1] for ion collision and high-density matter study.

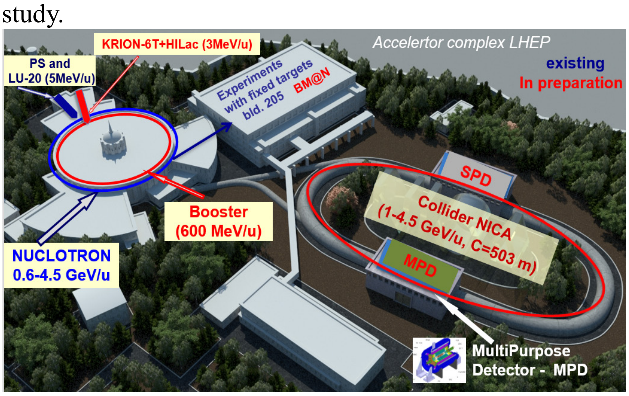

Figure 1: The NICA complex.

For the NICA collider ion beams from p to Au ions with energies from a few hundred MeV/u up to a few GeV/u will be provided by two injection LINACs and two superconducting synchrotrons: the Booster and the Nuclotron. The beams are generated by three new ion sources: SPI (Source of Polarized Ions), LIS (Laser Ion Source) and Krion (ESIS type heavy ion source). The ion sources feed two LINACs: the existing linac LU-20 with a new RFQ as pre-injector and the new heavy ion linac – HILAc. Design and development of RFQ, MEBT and two IH sections of the HILAc was performed by Bevatech GmbH (Frankfurt, Germany) [2] and described in detail in [3].

HILAC

The main parameters of the HILAc (Fig. 2) are given in the Table 1.

Table 1: HILAc Parameters

A/q	6.25
Current	< 10 emA
Pulse length	10 μs – 30 μs
Rep. rate	< 10 Hz
RFQ energy	300 keV/u
LINAC max. energy	3.2 MeV/u

The HILAc RFQ is a 4-rod structure operating at 100.625 MHz. The RFQ tank is a 3.16 m stainless steel tank of 0.35 m in diameter which is copper-plated inside. The RFQ is powered by a 140 kW solid state amplifier.

The first IH tank contains an internal quadrupole triplet lens. The IH1 and IH2 have 2.42 m and 2.15 m outer length correspondingly. For the design A/q – value of 6.5 the sum voltage gain is 20.8 MV. Both IH cavities are powered by 340 kW solid state amplifiers, one for each cavity.

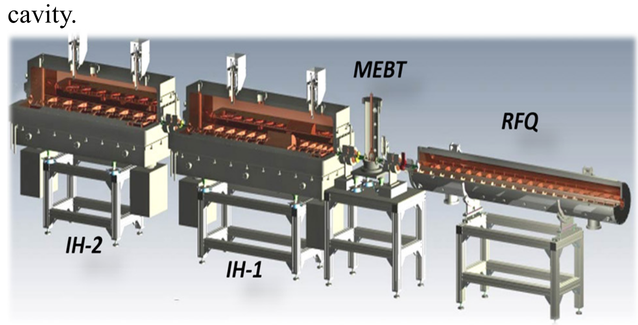

Figure 2: HILAC scheme.

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Before installing the IH cavities the RFQ has been tested with beam. The beam energy was measured with a magnet spectrometer to be 300 keV/u ± 3%. The beam injected into the RFQ contained a carbon ion species C^{3+} from LIS. The total RFQ beam transmission was up to 90%. Thun the energy measurements was provided by the magnetic spectrometer at the exit of IH2. Spectrums of different beam energies (after RFQ, without acceleration in IH; after IH1 when the IH2 is switched off; and after IH2 with full energy beam 3.2 AMeV) is shown on the Fig. 3. The transmission factor for C^{3+} is about 65% from RFQ exit to IH2 exit at the last stage of running in August 2018.

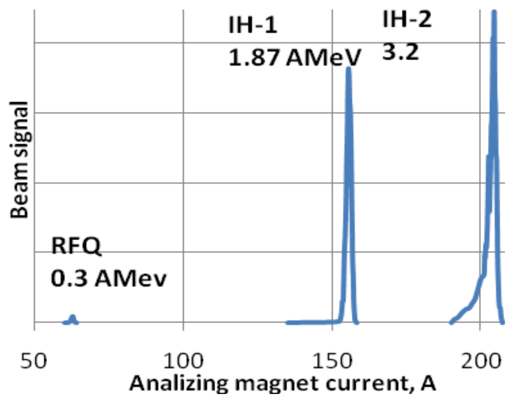

Figure 3: Measurements of the beam energy at the exit of HILAc in three steps of acceleration combined in one picture: only RFQ acceleration, RFQ+IH1, and full linac energy.

All accelerating structures, the solid state RF power amplifiers and the digital LLRF system run stable. As one of the next steps the ESIS source will be added providing beam with A/Q = 6.25 using target ions of Au^{31+} for which HILac was designed.

THE BOOSTER & NUCLOTRON

The Nuclotron was built during 1987-92. This accelerator based on the unique technology of superconducting magnetic system [4]. All design, tests and assembling works were carried out at the JINR. 55 runs of the Nuclotron operation were performed since March 1993. During last 7 years all the systems of the ring was completely modernized and prepared for long and stable operation in the NICA complex.

The Booster superconducting ring is under assembling presently. The ring commissioning is planned at the first part of the 2019 year. The main goals of the Booster ring are the following:

-accumulation of $2{\cdot}10^9$ Au^{31+} ions;

-forming of the required beam emittances with electron cooling system;

-acceleration of the heavy ions up to energy required for effective stripping and transferring to the Nuclotron ring.

The main parameters of both rings are given in Table 2.

Table 2: Booster and Nuclotron Parameters

	Booster	Nuclotron
Magnetic rigidity, T/m	25	45
Circumference, m	211	251
Beam intensity, particles per pulse	2 x 10^9	1.1 x 10^9
Max. energy	600 MeV/u	4.5 GeV/u

LINEAR INJECTOR OF LIGHT IONS

Injector of light ions, polarized protons, deuterons and ion ($A/q \leq 3$) beams is based on existing conventional Alvarez-type DTL at the frequency of 145.2 MHz.

The upgrade of this injector includes replacement of the 700-kV DC acceleration tube for the drift-tube linac with an RFQ (Fig. 4). The RFQ designed by ITEP provides 156 keV/u ion beams for following acceleration by the DTL at 2βλ-mode to the energy of 5 MeV/u and was successfully commissioned in 2016 [5].

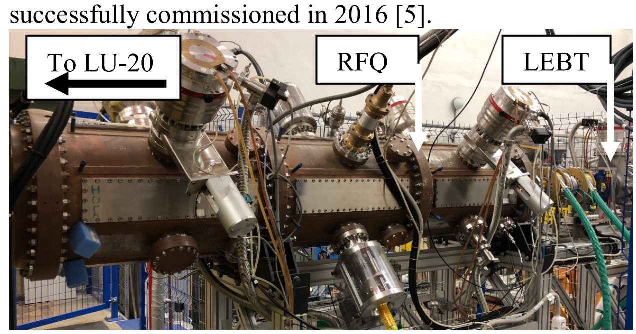

Figure 4: The new RFQ fore-injector.

The 2.2 m of the length the 145.2-MHz RFQ is based on a 4-vane resonator with magnetic coupling windows. The structure provides both reliable dipole-free range and compactness compared to a conventional 4-vane. Higher RF power losses of the structure is not an issue for the RFQ injector since it operates in a pulsed mode at RF pulse width less than 150 μs and repetition rate not higher than 1 Hz. The RFQ parameters are presented at Table 3.

Table 3: RFQ Parameters

A/q	1.0	0.5	≥0.3
Current, mA	10	20	10
Injection energy, keV	31	62	103
Output energy, keV/u		156	
Norm. emittance		≤0.5 π cm mrad	
Transmission, %	85	89	93

NUCLOTRON LAST RUNS WITH RFQ

During two last years the new fore-injector of the Lu-20 was operated during three beam runs of the Nuclotron with total duration almost 4000 hours.

Two runs dedicated to experimental investigations in spin physics (with polarized deuterons and protons) was provided in autumn of 2016 and spring 2017. The run dedicated to experimental investigations in spin physics (with polarized deuterons) was started 26 of October 2016 and its total duration was more than 1500 hours. Average intensity of the polarized deuteron beam was about 5-

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7·10^8 particles per cycle and during the run performed in February-March 2017 it was increased up to 2·10^9 ppc. In this run the acceleration of polarized proton beam from SPI as well as the lithium and carbon beams from the laser source was provided.

During preparation to Run #55 the Krion-6T ion source replaced the SPI at the RFQ injection line. The Run was performed with acceleration of Xe^{41+}, Kr^{26+} and Ar^{16+} ion beams. Ion source and linac demonstrated stable operation and acceleration with intensity in Nuclotron up to 2·10^5 Kr ions per cycle. Very good quality of the low intensity extracted beam spill was achieved (Fig 5.).

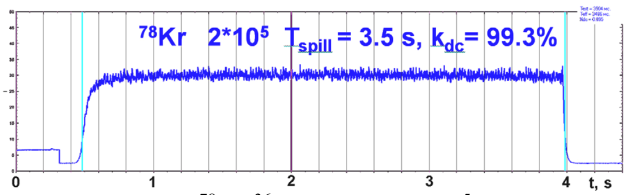

Figure 5: $^{78}Kr^{+36}$ beam spill 2 x 10^5 ppp.

FUTURE DEVELOPMENT

Future development and modernization of NICA injection complex presupposes replacement of the old LU-20 linac (in operation since 1974) with new Light Ion Linear accelerator (LILAc, Fig. 6). The first part of new linac for acceleration up to energy of 7 MeV/u, is under design and will be constructed by Bevatech GmbH (Frankfurt, Germany) [6].

Figure 6: LILAc project view.

Next step of the LILAc project – design of a middle energy section from 7 up to 13 MeV/u. And the third part – additional superconducting RF cavities, which will provide a total energy of the beam up to 50 MeV/u. Increased beam energy of LILAc is required for future research with polarized proton beams. SC linac will consist of a number of independently phased cavities and focusing solenoids.

The operating frequency of the linac was chosen equal to 162 MHz for QWRs with further increase to 324 MHz for HWR cavities. Detailed QWR and HWR designs are presented in [7].

The development of the SRF technologies is the key task of new Russian - Belarusian collaboration started on March 2015. Now the JINR, NRNU MEPhI, ITEP of NRC "Kurchatov Institute", INP BSU, PTI NASB, BSUIR and SPMRC NASB are participating in the collaboration.

CONCLUSION

The injection complex of the Nuclotron and NICA project demonstrates good progress. The HILAc is ready to provide the first booster run with heavy ion beam. The new RFQ pre-injector was put into operation and well worked during few last runs of the Nuclotron with polarized light ions and heavy ions. Current results of new light ion linac development for the NICA complex showed a good progress.

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