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FIRST EXPERIMENTS WITH ACCELERATED ION BEAMS IN THE BOOSTER OF THE NICA ACCELERATOR COMPLEX

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Abstract

The NICA accelerator complex in JINR consist of two linear injector chains, a 578 MeV/u superconducting (SC) Booster synchrotron, the existing SC synchrotron Nuclotron, and a new SC collider that has two storage rings. The construction of the facility is based on the Nuclotron technology of SC magnets with an iron yoke and coil with SC hollow cable. Assembly of the Booster synchrotron was finished in autumn of 2020 and first machine run and experiments with ion beams were successfully done in December 2020. The results of this run are discussed in this paper.

INJECTION COMPLEX

The NICA accelerator complex [1, 2] is constructed and commissioned at JINR. The main elements of the NICA complex are an injection complex, a Booster [3], the SC synchrotron Nuclotron, a Collider composed of two SC rings with two beam interaction points, a Multi-Purpose Detector (MPD) and a Spin Physics Detector (SPD) and beam transport channels.

The injection complex [1] includes a set of ion sources and two linear accelerators. The LU-20 linear accelerator for protons and light ions, which has been under operation since 1974 and Heavy-Ion Linac (HILAc).

The design of a new Light Ion Linac (LILAc) was started in 2017 to replace the LU-20 by the modern accelerator.

The Heavy-Ion Linac (HILAc) constructed by the JINR-Bevatech OHG collaboration, has been operating since 2016 [4]. It is aimed to accelerate heavy ions injected from KRION-6T, a superconducting electron-string heavy ion source. At the present time KRION-6T produces $\sim 8 \cdot 10^8$ Au^{31+} and Bi^{34+} ions.

Especially for the test run of the Booster the plasma source generating a single component He^{1+} (A/z = 4) beam was created. These ions were accelerated in HILAC up to energy 3.2 MeV/u and then were transported along the beam transfer line HILAC-Booster (see Fig. 1). The achieved efficiency of the beam transmission about 90% of the beam current of 4 mA was sufficient for the first experiments. The beam profiles measured by multiwire profilometers (PM) at the meddle and exit of the beam transfer line (see Fig. 2) have a good agreement with beam sizes obtained from the optics simulations.

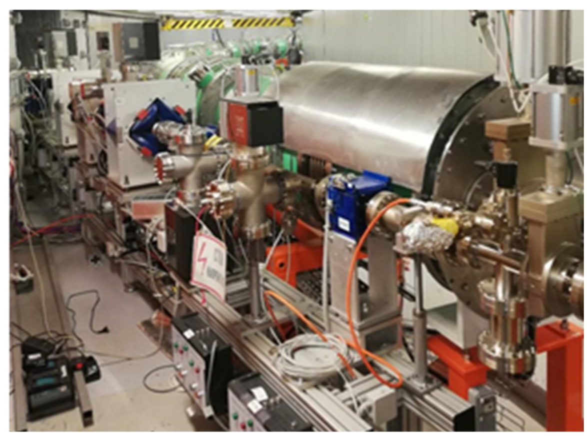

Figure 1: Transport channel HILAC-Booster.

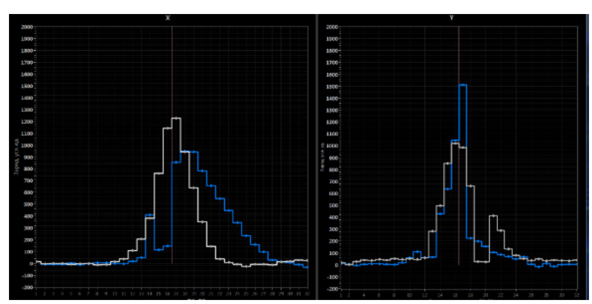

Figure 2: Beam profiles measured by PM2 and PM5.

THE BOOSTER RING

The Booster [3] is a SC synchrotron intended for accelerating heavy ions up to energy of 600 MeV/u. The magnetic system of the Booster with a 211 m-long circumference is mounted in tunnel inside the huge iron yoke of the Synchrophasotron magnet (see Fig. 3).

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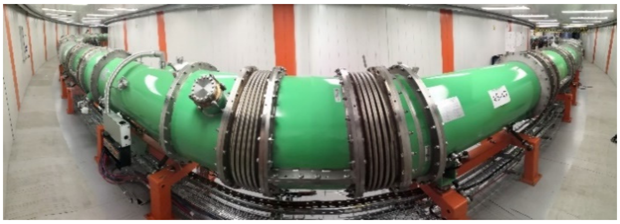

Figure 3: Booster ring in the tunnel inside the Synchrophasotron iron yoke.

The main goals of the Booster are accumulation of $2{\cdot}10^9$ Au^{31+} ions, acceleration of heavy ions up to the energy 578 MeV/u required for effective stripping, and forming of the required beam emittance with the electron cooling system. The Booster has a four-fold symmetry lattice with DFO periodic cells. Each quadrant of the Booster has ten dipole magnets, six focusing and six defocusing quadrupole lenses (six doublets), and multipole corrector magnets. All Booster dipole and quadrupole magnets were fabricated and tested at JINR. Main parameters of the ring are shown in the Table 1.

Table 1: Main Parameters of the Booster Ring

Parameter	Value
Circumference, m	210.96
Lattice type	DFO
Injection energy, MeV/u	3.2
Maximum energy, MeV/u	578
Magnetic rigidity at injection, T·m	1.6
Maximum magnetic rigidity, T·m	25.0
Ions species (project)	$^{197}Au^{31+}$

The Booster power supply system provides serial connection of dipole magnets, quadrupole focusing and defocusing lenses. The main powerful source of the power supply system forms a current of up to 10 kA with the required magnetic field ramp rate of 1.2 T/s. Two additional power supply sources are intended for flexible adjustment of the Booster working point.

The beam injection system of the Booster consists of an electrostatic septum and three electric kickers. Three methods of beam injection into the Booster are foreseen: single-turn, multi-turn and multiple injections. Beam extraction system consists of a magnetic kicker, two magnetic septa, a stripping station and, a closed orbit bump subsystem.

The Booster RF system provide 10 kV of acceleration voltage. The operating frequency range of the stations is from 587 kHz to 2.52 MHz.

The ions accelerated in the Booster are extracted and transported along a magnetic channel, and on their way, they cross a stripping target. The channel consists of five dipole magnets, eight quadrupole lenses, three correctors, separation septa, and diagnostics and vacuum equipment.

The beam extraction kicker and two septa as well as magnets and power supplies of the transfer channel (which were fabricated by BINP in spring 2021) do not used in first Booster run program.

FIRST EXPERIMENS OF IONS ACCELERATION IN THE BOOSTER

The installation of the Booster cryomagnetic equipment (see Fig. 3) was started in September 2018. The first technical Booster run was done in November-December 2020.

At the first stage the liquid helium and nitrogen pipeline, the insulating vacuum volume and beam pipe parts were assembled and tested. After this the cooling of cryomagnetic system, commissioning of thermometry, quench protection systems, tuning of main power supply and HILAC-Booster beam transfer line systems were done.

Then the beam was injected into the Booster on the plateau of the magnetic field corresponding to the injection energy. The beam circulation was achieved without activation of the closed orbit correction system.

Turn-by-turn measurements were used for the injection optimization. The signals from two nearest BPMs and virtual model of the injection section permitted to calculate linear optics and closed orbit position at the injection striate section depending on the quadrupole settings (see Fig. 4).

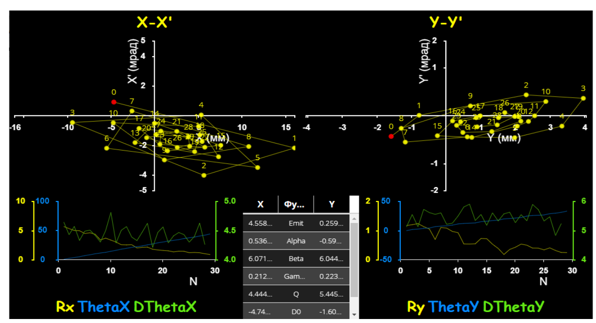

Figure 4: Turn-by-turn measurements of the linear optics and closed orbit position in the injection striate section.

The intensity of the circulating beam was increased up to $7{\times}10^{10}$ ions per cycle (see Fig. 5) that corresponding to design charge of $2{\times}10^9$ Au^{31+} ions. Measured the He^{+1} ion life time was 1.32 s that corresponds to the average pressure in the beam pipe of about $3{\times}10^{-10}$ Torr, and it is in a good agreement with gauge measurement data.

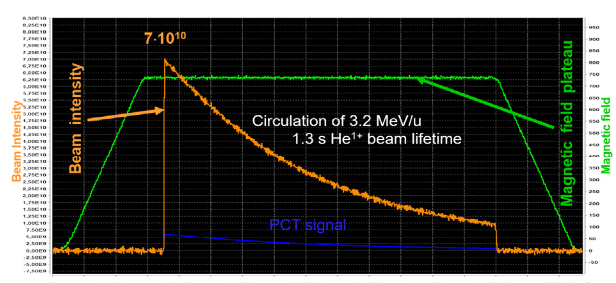

Figure 5: PCT signal, beam intensity and magnetic field time dependencies during the cycle.

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Similar measurement has been performed with electron cooler turned on. At variation of the electron energy when it is approaching optimum value (equality of electron and ion velocities) the ion beam lifetime decreased that demonstrated real influence of the cooling effect. Worth noting such effect was observed at very first electron cooling experiments at Budker INP in 1974.

The beam position (Fig. 6) was measured by 24 BPMs with 24 amplifiers and 8 Libera Hadron processor blocks.

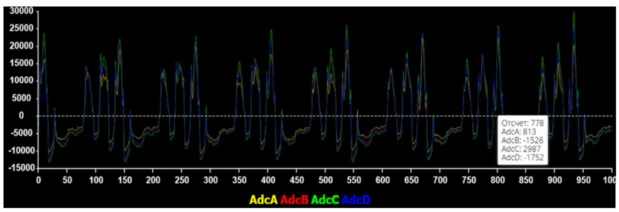

Figure 6: BPM measurements (example).

The beam current at ion acceleration up to energy of 100 MeV/u was measured with Parametric Current Transformer (PCT) (see Fig. 7). The choice of maximal ion energy was defined by the radiation safety conditions at Booster operation without beam extraction system. At the present time the Booster extraction system is under commissioning. The next Booster run with beam extraction and using the Booster-Nuclotron transfer line is scheduled on June-July 2021.

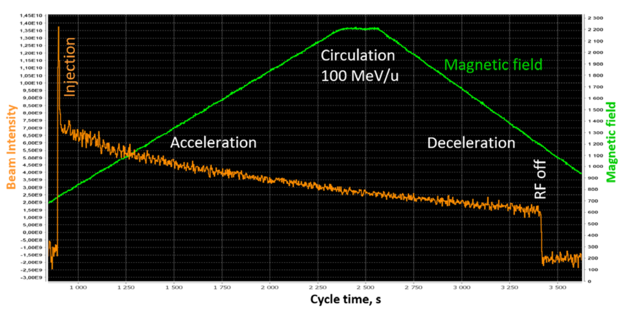

Figure 7: Beam current transformer signal at ion acceleration.

To reach the project value of the magnetic field and ramping rate the training procedure of the magnetic elements accompanied by quenches was done at the final stage of this run. During 11 hours 28 times the quench protection system evacuate energy from magnets. 17 quenches of SC magnetic optics elements and 11 ones of interconnections were detected (see Fig. 8).

The SC magnetic and power supply systems were tested at the design magnetic field cycle (see Fig. 9). The magnetic cycle has three plateaus: at injection, electron cooling and beam extraction. The achieved ramping rate 1.2 T/s of the magnetic field and its maximum value 1.8 T correspond to the project value. Power supply system provides relative current stability at plateau of 4×10^{-6}. At magnetic field ramping the relative current stability is equal to 4×10^{-4}. Further improvement of the Booster main power supply is planned to reduce relative current instability in ramping regime to the level of 10^{-4}.

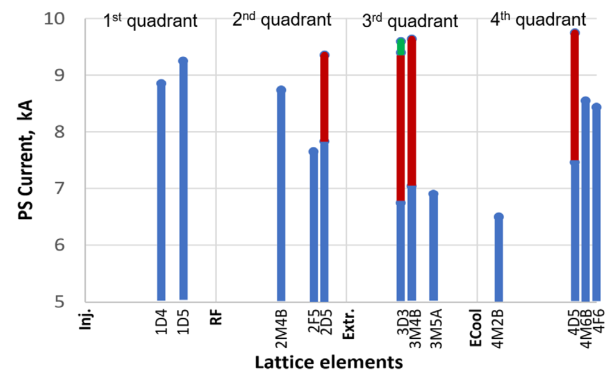

Figure 8: Current amplitude in SC magnetic elements and numbers of detected quenches (blue – first, red – second, green – third one).

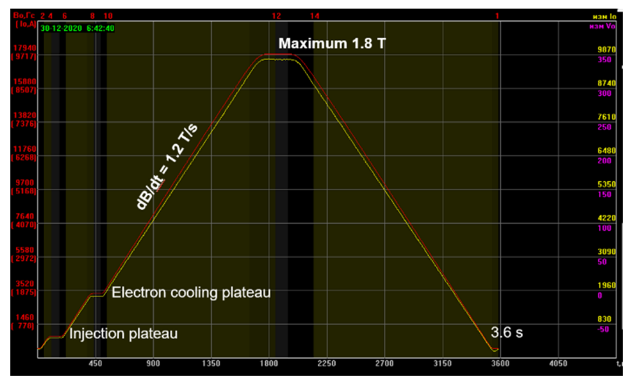

Figure 9: Screenshot from the Booster magnetic field cycle control system at design parameters.

CONCLUSION

The first run of the Booster allows to test and commission the main systems of the superconducting synchrotron. All the tasks planned during the tests of the new accelerator were successfully solved: the systems of injection, diagnostics, power supply, protection, electron cooling were tested, an acceleration regime with minimal losses of ions was obtained, and the design cycle of the magnetic system was obtained.

REFERENCES

[1] I. N. Meshkov and G. V. Trubnikov, "Technical Project of NICA Acceleration Complex", JINR, Dubna, Russia, 2015.

[2] V. D. Kekelidze *et al.*, "Three stages of the NICA accelerator complex", *Eur. Phys.* J. A, vol. 52, no. 211, p. 390, 2016. doi:10.1088/1742-6596/668/1/012023

[3] A. Tuzikov *et al.*, "Booster Synchrotron at NICA Accelerator Complex", in *Proc. 25th Russian Particle Accelerator Conf. (RuPAC'16)*, Saint Petersburg, Russia, Nov. 2016, pp. 160-162. doi:10.18429/JACoW-RuPAC2016-FRCAMH05

[4] A. V. Butenko *et al.*, "Commissioning of the New Heavy Ion Linac at the NICA Project", in *Proc. 25th Russian Particle Accelerator Conf. (RuPAC'16)*, Saint Petersburg, Russia, Nov. 2016, pp. 156-159. doi:10.18429/JACoW-RuPAC2016-FRCAMH03