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ACCELERATION OF He^+ BEAMS FOR INJECTION INTO NICA BOOSTER DURING ITS FIRST RUN

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Abstract

Heavy Ion Linear Accelerator (HILAC) is designed to accelerate the heavy ions with ratio $A/Z \leq 6.25$ produced by ESIS ion source up to the 3.2 MeV for the injection into superconducting synchrotron (SC) Booster. HILAC was commissioned in 2018 using the carbon beams from Laser Ion Source (LIS). The project output energy was verified. Transmission could be estimated only for DTL structure because of the presence at the RFQ input the mixture of ions with different charge states extracted from laser plasma. To estimate transmission through the whole linac the ion source producing the only species He^+ was designed. The beams of He^+ ions were used for the first run of SC Booster. Design of the helium ion source and results of the He^+ beam acceleration and injection are described.

HEAVY ION LINEAR INJECTOR

Heavy ion linear accelerator (HILAC) is proposed to be injectors for SC Booster synchrotron of the NICA facility. The main features of it are presented in the Table 1.

Table 1: Main Features of HILAC

	HILAC
Species of ions	Au^{31+}
Z/A	≥ 0.16
Input energy	17 keV/u
Output energy	3.2 MeV/u
Beam current, mA	10
Operating frequency, MHz	100.625
Beam transmission rate, %	98

The accelerator is based on 4-rod RFQ [1] and IH DTL cavities with the KONUS accelerating structure inside [2]. The Heavy Ion Linear accelerator (HILAC) is to inject the gold ions into the superconducting synchrotron Booster and designed to accelerate particles with a ratio $A/Z \leq 0.16$ up to energy 3.2 MeV/u. In 2015-2018, HILAC commissioning had been done [3, 4]. The carbon beams C^{2+}, C^{3+}, C^{4+}, C^{5+} и C^{6+} were accelerated and measured energy of accelerated carbon ions was in good agreement with the design value of 3.2 MeV/u. Beams transmission through DTL structure was estimated ~65% [3, 4]. To estimate transmission through the whole linac the only species of ions should be injected in RFQ. On that reason the ion source producing the only He^+ ions was developed and assembled.

HELIUM ION SOURCE

For designing helium ion source the proton ion sources described in [5, 6] were taken as a prototype. Ion source with cold magnetron cathode and magnetic plasma compression consists of the two basic parts: plasma generator and system of ions extraction and beam formation. There are three basic space emay be attributed to plasma generator: space of auxiliary discharge between magnetron cathode and magnetron anode, space of the basic discharge between magnetron cathode and anode, and area of plasma expansion.

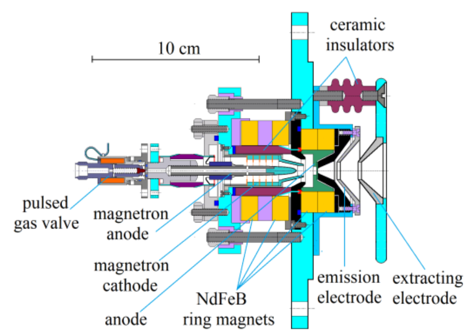

Fig. 1 Helium ion source design.

Gas system provides pulsed gas injection into space of magnetron discharge. Pulsed voltage up to 1 kV in the gaps between magnetron anode and magnetron cathode, and between magnetron cathode and anode was provided with the generator of HV pulses (see Fig. 1). Extraction voltage was supplied with the pulsed transformer and applied to the terminal whereas extraction electrode had a ground potential. Test bench for the TOF studies had three Faraday cups, beam modulation electrode and drift space ~1.8 m (see Figs. 2 and 3). The total ion current was estimated with the signal from FC1and the value observed was up to 50 mA. There was the aperture 8 mm diameter in the bottom of the FC1.for the beam passing. About 25 cm behind the extracting electrode Faraday cup 2 and beam modulation electrode mounted together in one assembly could be placed manually on the beam way. The signals registered by Faraday cup 1 and Faraday cup 2 (Fig. 2) were used for the source tuning.

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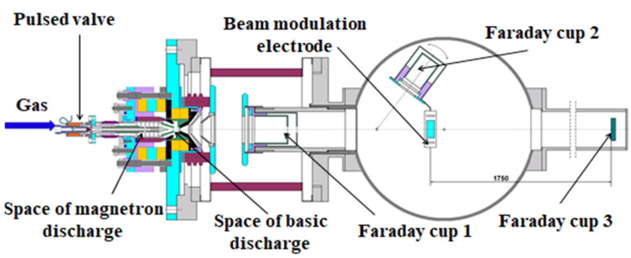

Figure 2: Test bench layout for the TOF measurements.

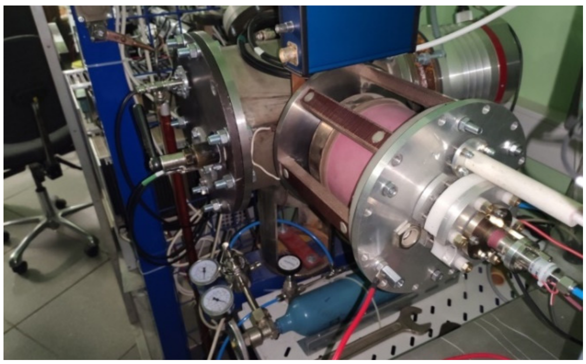
Figure 3: Helium ion source at the test bench.

For the beam modulation the 1 kV pulses 50 ns duration were applied to the electrode. Faraday cup-3 signals were registered to obtain TOF spectrum. He^+ ions were the main species in the beam produced. Traces of impurities of carbon, oxygen and nitrogen were observed also (see Fig. 4).

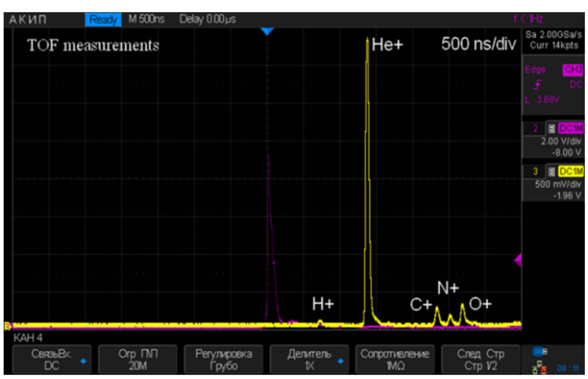

Fig. 4: TOF spectrum obtained at the test bench for the helium ion source.

FORMATION THE BEAMS FROM HELIUM ION SOURCE WITH THE LEBT

To provide with the He^+ beams the first run of the SC Booster helium ion source was placed on the HV terminal and fixed to the LEBT (see Fig. 5). Beam was formed by two focusing electrode and accelerated in electrostatic tube up to RFQ input energy 17 keV/u. Two solenoids were used for beam focusing at the RFQ input. Steerers bend the beam in vertical and horizontal planes if needed (see Fig. 6).

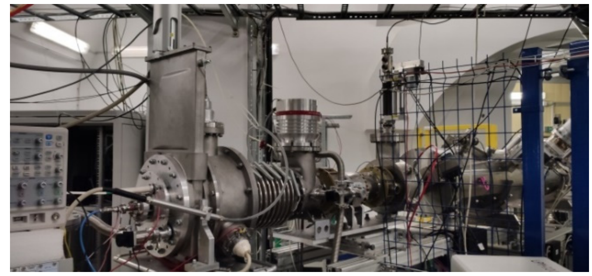
Figure 5: Helium ion source on the HV terminal fixed to the LEBT

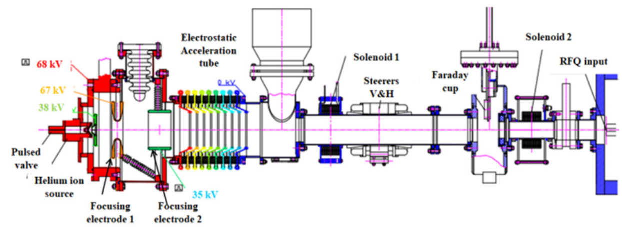

Fig. 6: LEBT layout.

Pulse transformer provided HV terminal with electrical pulsed potential up to 100 kV of amplitude at the 200 µs of the total pulse duration. To match the He^+ beam energy to RFQ input energy the value 68 kV of electrical potential was provided at the terminal during accelerating run. Beam intensity in range 0.5-4 mA at the injection point into Booster was varied by solenoids.

ACCELERATION WITH HILAC

The beam diagnostic system included 3 phase probes (PP), 4 current transformers (CT), 4 Faraday cups (FC), 6 beam profile monitors (BPM), 5 shoebox pickups and 4 button pickups arranged along beam pipe (see Figs. 7 and 8). The longitudinal bunch shape is determined with capacitive phase probes (pick-up-plates). It is also possible to estimate the beam energy by using two phase probes with a time of flight measurement. To monitor beam current for the HILAC commissioning and daily operation beam current transformers were placed in four points (see Figs. 7 and 8). CT1 and CT2 are ACCT transformers and have range from 10 µA up to 10 mA with a rise time of up to 1.2 µs. CT3 and CT4 are FCT transformers used in tandem with wideband voltage amplifier having the range (10-60) dB.

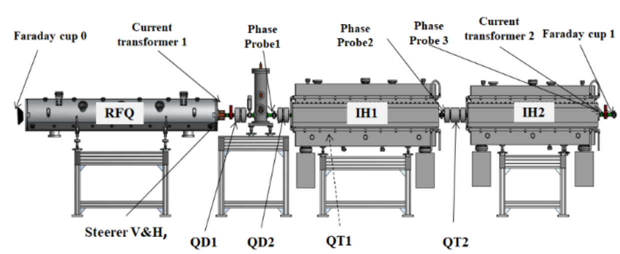

Fig. 7: Beam diagnostic units arranged along HILAC.

Beam transmission through DTL structure was estimated by comparing the signals of CT1 and CT2 (see Fig. 7), transmission through channel HEBT – CT2 and CT4 (see Fig. 8).

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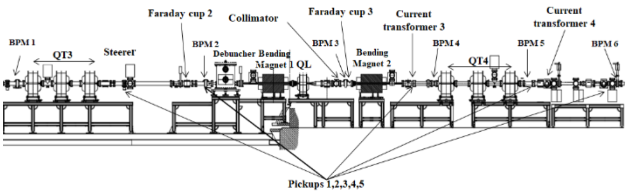

Fig. 8: Beam diagnostic units arranged along HEBT.

For the beam current ~7 mA at the RFQ output, transmission through DTL structure was estimated ~ 80%. The beam losses at the point of CT4 were ~ 50% (see Fig. 9). The maximum current 12-14 mA of He^+ was achieved at the RFQ output, herewith current 18-22 mA was detected by Faraday cup "0", placed at the RFQ input. There were no attempts of accurate transmission tuning the beams of such currents during accelerating run.

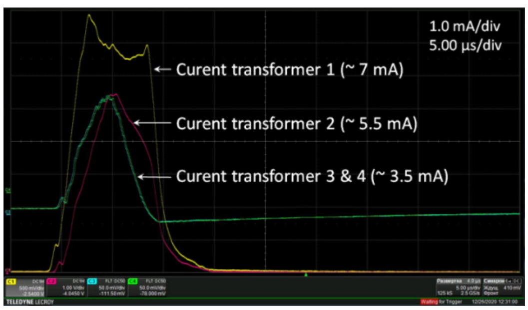

Fig. 9: Current transformer signals, 7 mA-RFQ output, 5.5 mA-IH2 output, 3.5 mA –behind QT4 triplet.

During the 2016-2018 commissioning and accelerating run in Dec. 2020 RF system of HILAC was managed by LLRF system designed and commissioned in collaboration with ITEP [7]. Five output sin RF signals up to 1V amplitude were the input signals for RF amplifiers of RFQ, IH1, IH2, buncher and debuncher, having fixed gain. So output RF power of the amplifier is tuned by the amplitude of the LLRF output signal. Phase shifting between LLRF signals is tuned with accuracy 0.1˚.

Level of RF power inside each cavity was controlled by the pickups signals monitoring. The detected signals of RFQ, IH1 and IH2 pickups (Fig. 10) were observed synchronously to the beam currents presented on Fig. 9. One can see how the part of stored field energy was eaten by the beam passing through. One can also see the reaction of the amplifier – pushing back the cavity to equilibrium level after the extra requirement of beam acceleration has gone.

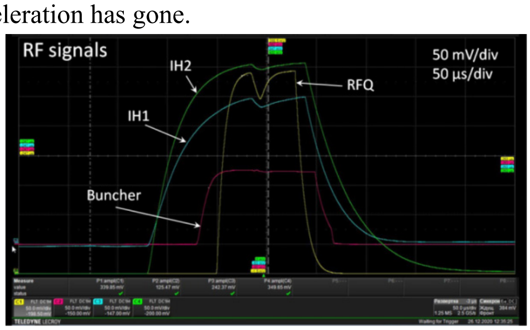

Fig. 10: RF dropdowns in the HILAC cavities.

If the RF power and phase shifts are tuned properly the beam energy at the HILAC output is 3.2 MeV/u and transmission is satisfactory. The energy of the beam was controlled by the signal of FC3 arranged behind bending magnet 1 (see Fig. 8). For the He^+ ions beam energy 3.2 MeV/u maximum signal of FC3 was observed if value of bending magnetic field was ~0.5 T. There was found such tuning of IH2 phase shifting as maximum signal of FC3 was observed at ~0.38 T (see Fig. 11). This value of magnetic field corresponds to 1.84 MeV/u, that is the energy at the output of IH1. Thus one may say that depending on RF phase tuning of IH2 the beams of 3.2 MeV/u or 1.84 MeV/u may be obtained at the HILAC output at the almost same transmission. It was looked interesting that phase shift needed to "change" HILAC output energy was ~180˚.

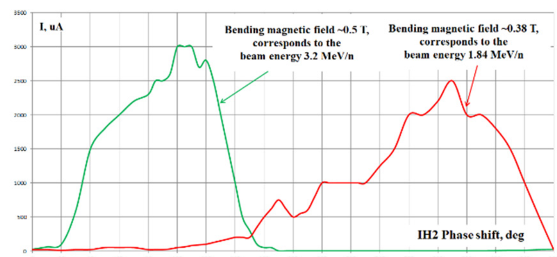

Figure 11: Faraday cup 3 signal vs RF phase shift of IH2.

The beam at the very output of HILAC was monitored with the phase probe 3 and current transformer 2 (see Fig. 7). The longitudinal bunch shapes obtained by the phase probes are presented on Fig. 12.

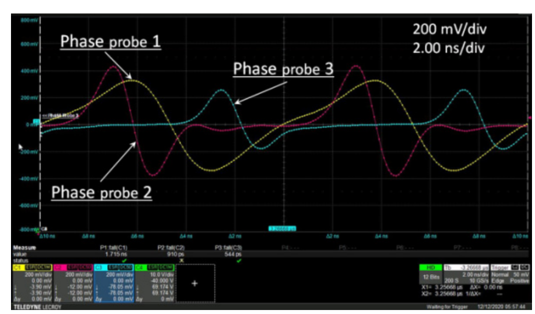

Figure 12: Phase probe signals produced helium beam, 1-behind RFQ, 2-behind IH1, 3-behind IH3.

CONCLUSION

Heavy ion linear injector based on HILAC for the first time injected the He^+ ions beams into SC synchrotron Booster during its first run. The beams were produced by the new designed helium ion source that proved its reliability. For the first time the beams of relatively high currents were accelerated by HILAC and search for tuning for the best transmission is needed. Dropdowns RF in accelerating cavities were observed and should be compensated. Found effect of appearance at the HILAC output beams of different energies should be explained.

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