COMMISSIONING OF THE NEW HEAVY ION LINAC AT THE NICA PROJECT

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Abstract

The new accelerator complex Nuclotron-based Ion Collider fAcility (NICA) is under development and construction at JINR, Dubna. This complex assumed to operate using two linear injectors: the modernized Alvarez-type linac LU-20 as the injector of polarized and light ions and the new Heavy Ion Linear Accelerator HILAc-injector for heavy ions beams. The new heavy ion linac, which accelerates ions with q/A-values above 0.16 to 3.2 MeV/u, is under commissioning. The main components are a 4-Rod-RFQ and two IH-drift tube cavities, operated at 100.625 MHz. Most recent results of the HILac commissioning with a carbon beam from a laser ion source are presented.

INTRODUCTION

For the NICA collider ion beams from *p* to *Au* 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 ring (magnetic rigidity 25 T·m) and the Nuclotron (45 T·m) [1]. The beams 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, MBET and two IH sections of the HILAc was performed by Bevatech GmbH [2] and described in detail in [3]. HILAc commissioning was performed with the C^{3+} beam from the laser ion source (Fig. 1).

The main parameters of the new linear accelerator are given in Table 1.

Figure 1: Nd-YAG laser source at HILAc hall.

Table 1: HILAc Parameters

Target Ion	Au^{32+}
A/q	6.25
Current	< 10 emA
Pulse length	10 μs – 30 μs
Rep. rate	< 10 Hz
LEBT energy	17 keV/u
RFQ energy	300 keV/u
IH1 energy	1.87 MeV/u
IH2/LINAC max. energy	3.2 MeV/u

ION SOURCE & LEBT

The LIS is based on a commercially available Nd-YAG laser LPY 7864-2. The laser with special ion source chamber and control system was tested at its operational regimes producing carbon ions at test bench and after that installed at HILAc hall (Fig. 1).

The HILAc LEBT with a length of about 1.8 m split into two main parts. First part is an electrostatic section (three electrostatic lenses and HV tube) the second part uses two magnetic solenoids with a maximum magnetic field of 1.3 T in pulsed regime. The whole LEBT has been simulated and optimized for investigating C^{3+} beam matching into the RFQ acceptance (Fig 2).

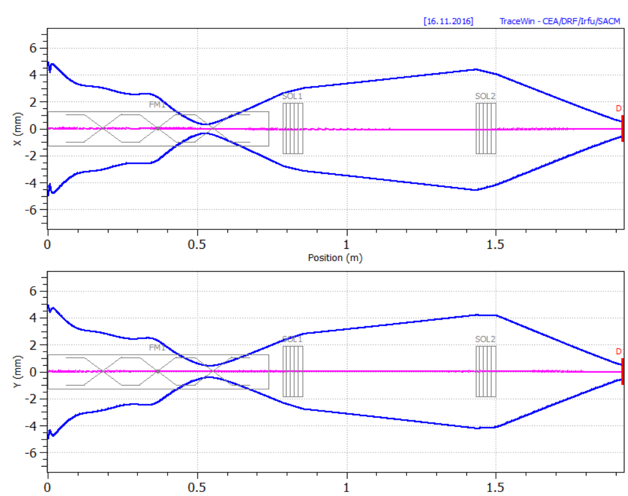

Figure 2: Matched case (rms envelope) for C^{3+} beam along the LEBT into the RFQ acceptance.

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MEBT

The MEBT is equipped with two identical pulsed quadrupole-doublets located in front and behind the rebuncher. The rebuncher built as a 4-gap quarter-wave resonator powered by a 4 kW pulsed amplifier. An impulse current transformer is located directly behind the RFQ and a phase probe is located after the second quadrupole doublet. In combination with two other phase probes, one in between the IH1-IH2 drift tube linacs and one at the exit of the linac, the probes allow TOF beam energy measurements. To overcome angular deviations from the beam axis at the MEBT entrance a magnetic-steerer has been added into the beam-line.

RFQ

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 copper-plated inside (Fig. 3). The RFQ was commissioned using high power up to 120 kW and is driven by a 140 kW solid-state amplifier produced by TOMCO company.

IH-DRIFT TUBE SECTION

Two Interdigital H-type cavities (IH) with 2.42 m and 2.15 m outer length, respectively is followed the MEBT (see Fig. 3). The first IH tank contains an internal quadrupole triplet lens. The final energies are 1.87 AMeV after IH1 and 3.2 AMeV after IH2. For the design A/q – value of 6.5 the sum voltage gain is 20.8 MV. Both IH cavities are powered by 340kW solid-state amplifiers one for each cavity (from TOMCO company).

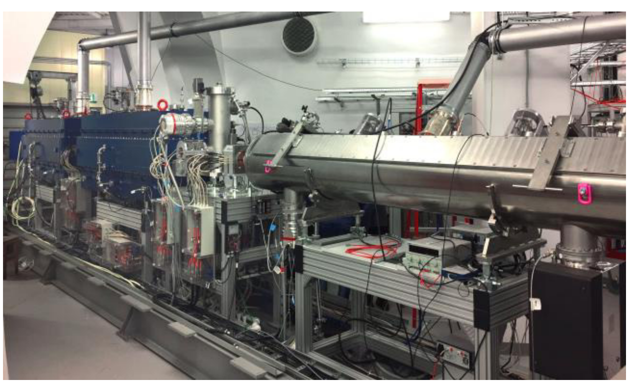

Figure 3: RFQ, MEBT and two interdigital H-type cavities IH1 and IH2 at JINR.

COMMISSIONING

RF Commissioning

All solid-state power amplifiers have been pre-tested with full power on a water load and a calibrated bi-directional coupler. Additionally a cavity with a Q factor of around 7000 has been used to test sensitivity and behavior in the matched and unmatched cases. In a stress test the 140 kW RFQ amplifier and the two 340 kW IH DTL amplifiers were driven with 5 – 10 % excess power. Long term stability tests at 90 % full power have been performed over 2 days. A digital Low Level RF system developed by ITEP [4] Similar system also in use at LU20 of the JINR facility is providing amplitude and phase adjustments all cavities.
After installation of all amplifiers, connectivity to LLRF system, rigid lines and HILAc cavities at JINR, the pre-conditioned cavities were tested successfully up to full power.

RFQ Commissioning

Before installing the IH cavities the RFQ has been commissioned with carbon beam. The beam energy was measured with a magnet spectrometer 300 keV/u ± 3% . The beam injected into the RFQ contained a mixture of carbon ion species C^{3+} and C^{2+} from LIS (Fig. 4). The total RFQ beam transmission was about 90%. During daily runs in August and September, the RFQ demonstrated a very stable operation with good reserve of RF power when extrapolated to the A/Q design value of 6.25.

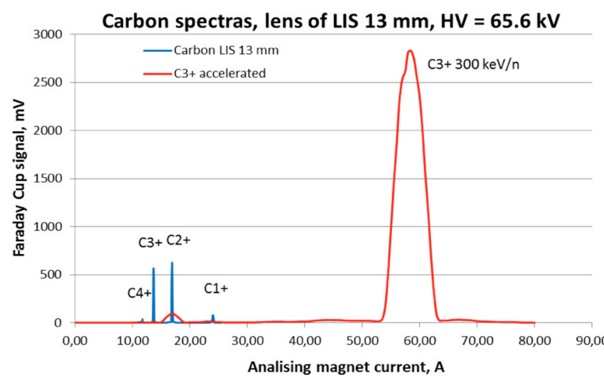

Figure 4: Spectrum of the carbon beam: blue curve – beam drifted through the RFQ without RF (17 keV/u); red curve – beam accelerated in RFQ (300 keV/u).

MEBT Commissioning

MEBT commissioning followed beginning of October 2016. All quadrupole magnets had been tested in the factory for alignment precision of the magnetic axis of 100 µm and a maximum tilt of 1 mrad. The alignment precision of the magnets in the beam line against the axis was provided using a laser tracker with an accuracy of 50 µm having precision markers on all beam line elements. The coaxial rebuncher showed a transient oscillation behavior with less than 5 % reflected power.

IH DTL Commissioning

Phase probe signals behind the RFQ, IH1 and IH2 allowed to detect the macropulse shape as a signal envelope as well as the microbunch signal (see Fig 5). Beam pulse lengths of 10 µs – 30 µs according the design specifications were measured with the phase probes. In one of the next steps, these probes will also be used for TOF beam energy diagnosis during operation, once the probes and their cable lengths are calibrated and checked against the energy measurements by the magnetic spectrometer at the end of IH2. Two identical pulsed

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current transformers (ICT made by BERGOZ), one in the MEBT and one after IH2, allow to measure Linac beam transmission.

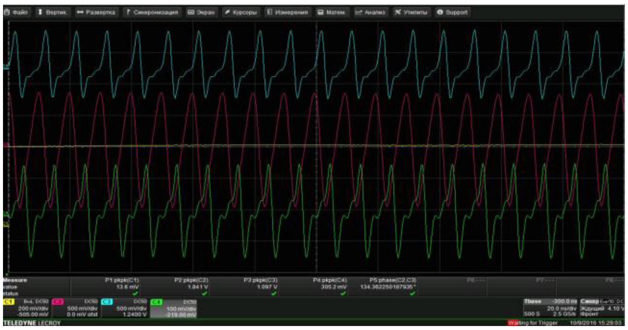

Figure 5: Phaseprobe signals: red – behind RFQ, green – behind IH1, blue – behind IH2.

Figure 6 shows the signals from current transformers in MEBT and after IH2, blue line – signal from Faraday cup in the spectrometer (more than 90% of the beam in the spectra after the magnet is accelerated beam, see Fig. 7). The transmission factor for C^{3+} is about 60% from RFQ exit to IH2 exit at this stage of running in.

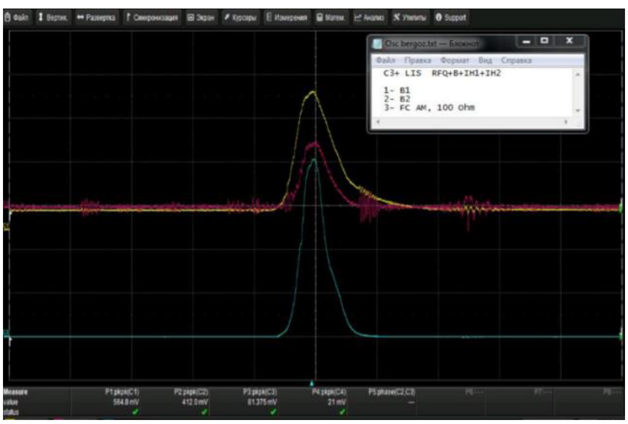

Figure 6: MEBT and IH1 ICT in yellow/red and Faraday cup at the spectrometer in blue.

Further optimization of quadrupole settings and steerer behind the RFQ allow improvements. In a third series of measurements the beam energy at the exit of the two IH cavities was validated with the magnetic spectrometer. Due to timing constraints it was not possible to optimize the spectrometer setup at its position behind IH2. The energies behind IH1 and IH2 could be verified with the spectrometer well to be at 1.87 AMeV 3.2 AMeV (Fig. 7).

SUMMARY

After 4.5 years of design and development work the Heavy Ion Linac - HILAc at NICA new injector complex has been successfully commissioned. Ion source, LEBT, RFQ, MEBT and IH DTLs are in good agreement between simulations and measurements. The installation of the vacuum-, electrical-systems and alignment have been performed in best practice by the JINR team. Vacuum conditions were at the 10^{-8} mbar level after three days of continuous pumping. The RFQ was operated absolutely stable with a transmission factor up to 90% for all carbon species from the LIS mixed beam. The injector commissioning lasted 3 weeks. During this time a total transmission of accelerated beam after LEBT of more than 50% for C^{3+} was measured in first tests. The energy behind the RFQ and for each IH cavity was validated to be in well agreement with the design values. All accelerating structures, the solid state RF power amplifiers and the digital LLRF system run stable. The optimization process for HILAc will start in summer 2017. As one of the next steps the ESIS source will be added providing beam with $A/Q = 6.25$ using target ions of Au^{32+} for which HILAc was designed. Goal of the next steps is to optimize all settings for maximum beam transmission.

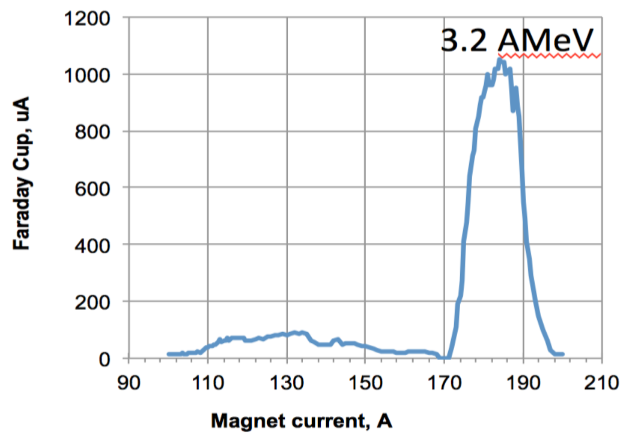

Figure 7: HILac at nominal energy.

ACKNOWLEDGMENTS

Figure 8: HILac team for commissioning.

The work on HILAc has been performed in a mixed team consisting of Russian and German scientists (Fig. 8). We would like to express our best thanks for all the good work, the fruitful discussions and exchanged ideas with all team members. Our good cooperation was the basis for this successful project.

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