THE HEAVY ION LINAC AT THE NICA PROJECT

A.V.Butenko, V.S.Aleksandrov, E.E.Donets, E.D.Donets, D.E.Donets, A.I.Govorov, V.V.Kobets, A.D.Kovalenko, K.A.Levterov, V.A.Monchinsky, I.N.Meshkov, V.A.Mikhailov, A.O.Sidorin, G.V.Trubnikov, Dubna, Russia, T.V.Kulevoy, D. Liakin ITEP, Moscow, Russia, H.Hoeltermann, U.Ratzinger, A.Schempp, H.Podlech BEVATECH OHG, Frankfurt, Germany.

Abstract

The **N**uclotron-based **I**on **C**ollider f**A**cility (NICA) project at JINR (Dubna) has a goal to set up experimental studies of both hot and dense strongly interacting baryonic matter and spin physics. The experiments will be performed in collider mode and at fixed target [1]. The first part of the project program requires heavy ion collisions generation of $^{197}Au^{79+}$ nuclei. The new linear accelerator for the heavy ions – HILAc (Heavy Ion Linear Accelerator) as the injector for the Nuclotron Booster ring is under construction presently. The progress and the main characteristics of the 3.2 MeV/u linear accelerator HILAc are presented.

INTRODUCTION

NICA facility is aimed to perform at JINR wide program of fundamental and applied researches with the ion beams from p to Au at energy from a few hundred MeV/u up to a few GeV/u. The beams at required parameters will be delivered by two superconducting synchrotrons – the Booster (magnetic rigidity is 25 Tm) and the Nuclotron (45 Tm) equipped with an existing injector – linac LU-20 with new ion sources: SPP (Source of Polarized Particles), LIS (Laser Ion Source) [2].

As the injector for the designed Booster ring the new heavy ion linear accelerators for the $^{197}Au^{+31}$ beams with new ESIS type ion source Krion-6T (for high charge state heavy ions) is under construction. Status and the progress of the heavy ion injector for the Nuclotron Booster project are presented.

HEAVY ION SOURCE

Construction and assembly of Krion-6T were completed in 2013 and full-scale tests in reflex mode of operation had been started at a test bench. After reaching of 5.4 T of the solenoid magnetic field in a robust operation (the design value is 6 T) the $Au^{30+} \div Au^{32+}$ ion beams have been produced at intensity of about $6 \cdot 10^8$ particles per pulse. The required ionization time is 20 ms [3]. Obtained parameters are close to required for HILAc operation.

Thereafter the source was optimized for production of ions with charge to mass ratio of $q/A \geq 1/3$ in order to provide complex test of all its systems at operation on existing injection facility. In May 2014 the source was installed at high-Voltage (HV) platform of the LU-20 fore-injector (Fig. 1) and used during Nuclotron run #50 in June. The main goal for future two years is to reach the project parameters of KRION-6T for Au^{31+} beam.

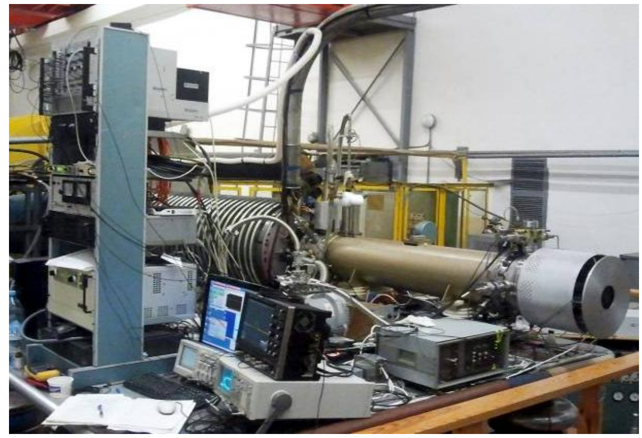

Figure 1: Krion-6T at high-voltage platform of LU-20 fore-injector. The Nuclotron Run #50.

LOW ENERGY BEAM TRANSFER CHANNEL

The ion source is situated on high-voltage platform (up to 150 kV). The LEBT channel (Fig. 2) begins from electrode with potential U0, after which a DN 250 vacuum valve is installed. In initial part of channel (IPC) the focusing electrodes with potentials U1 and U2 are located. IPC ends the tube with potential, falling off from U3 up to 0. Two solenoids, placed after initial part, form beam at the input of RFQ.

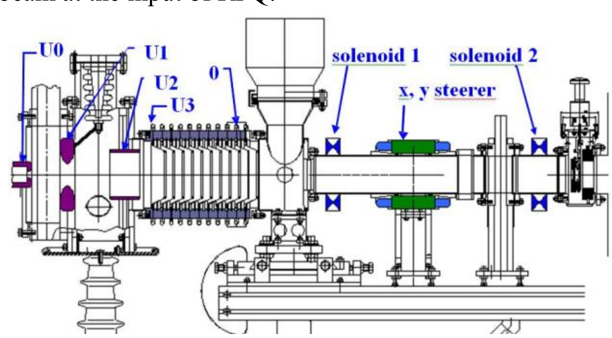

Figure 2: LEBT cannel scheme.

Electrostatic field inside IPC and magnetic field of solenoids are calculated by the POISSON program [4]. Optimization of channel parameters to achieve required beam parameters at the RFQ entrance was performed by MCIB04 code [5]. The code takes into account the aperture of the channel and the effects of the space charge of the multi-component beam. Two different variants of possible initial charge state spectrum of the gold beam are taken into account.

The phase planes of different charge states of the gold beam at RFQ entrance after optimization are shown

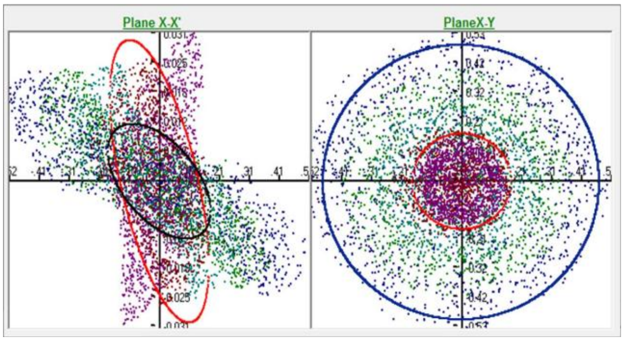

Figure 3: Phase plane and beam spot at RFQ entrance for 3.5 mA gold beam current with ions charge state spectrum from 29+ up to 32+ (different colors).

on Fig.3. The $^{197}Au^{+31}$ beam emittance and beam spot at the entrance of RFQ shown by red color, the aperture by blue one.

The proposed variant of low energy channel is suitable for transportation of $^{197}Au^{+31}$ beam from the KRION source and injection of ions in to RFQ acceptance. The $^{197}Au^{+31}$ beam rms emittance at RFQ entrance is about 10 π·mm·mrad at 3.5 mA.

STATUS OF THE HILAC CONSTRUCTION

As an injector for heavy ions into the Booster synchrotron of the NICA accelerator facility the new Heavy Ion Linac (HILAc) is under construction. The HILAc consists of three accelerating sections (RFQ and two DTL sections based on IH cavities [6]) and medium energy beam transport (MEBT). Design of the HILAc was performed by Bevatech OHG [7] and described in details in [2]. The design of RFQ - and IH - tank1 follow closely to 2 MeV/u BNL EBIS – based pre-injector [8]. IH – tank2 is added to reach a final kinetic energy of 3.2 MeV/u. The HILAc RF system includes solid-state power amplifiers and LLRF providing a joint coordinated work of all cavities.

The cavities for the NICA injector operate at 100.625 MHz. Downstream a 3.16 m long 4-Rod-RFQ there are two Interdigital H – type cavities (IH) with 2.42 m and 2.15 m outer length, respectively. The final energies are 300 AkeV for the RFQ and 3.2 AMeV for the IH-DTL. For the design A/q – value of 6.5 the sum voltage gain is 20.8 MV.

During 2013-14 all three cavities were fabricated. The material is stainless steel for the RFQ – tank, black steel for the IH – tanks and bulk E – Cu for the inner elements like 4-Rod-structure and drift tubes. The water - cooling of these structures was adapted to the low duty factor of up to $3 \cdot 10^{-4}$.

The RFQ section is prepared for shipment to JINR.

The IH1 tank is at present at the copper plating workshop and will be followed by IH2. Fig. 5 shows cavity IH1 when prepared for first RF measurements. Fig. 6 shows the measured electric field distribution of IH1 before the final machining and copper plating. Fig. 7 shows the gap voltage distribution of IH2 and a

Figure 4: The 4 – Rod – RFQ during installation work.

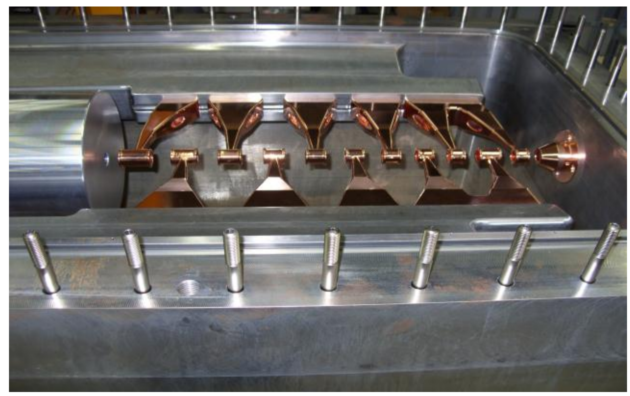

Figure 5: IH1 cavity prepared for first RF measurements.

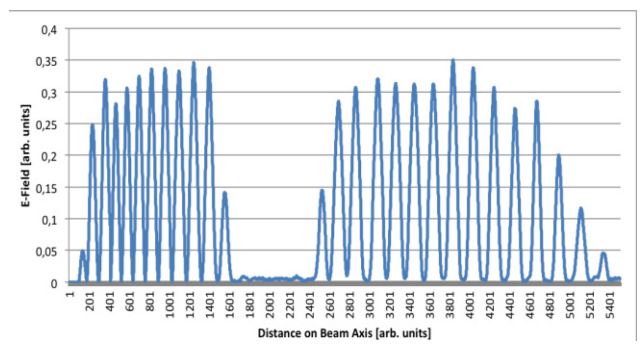

Figure 6: E - field distribution along the beam axis of cavity IH1.

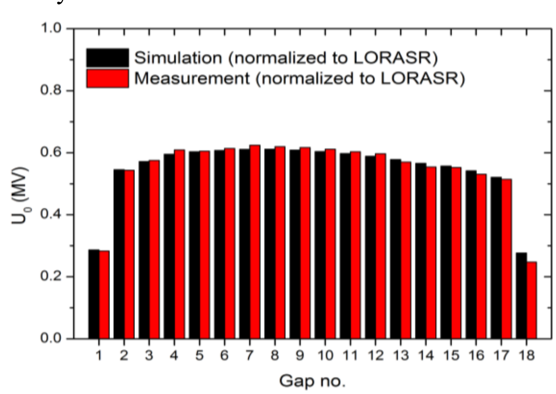

Figure 7: Gap voltage distribution along cavity IH2 and comparison with LORASR simulations

ISBN 978-3-95450-142-7

comparison with the design values used in LORASR beam simulations.

Only the fine - tuning at the very end will allow to reach the voltage distribution anticipated for beam dynamics calculations.

The RF amplifiers with output levels of 4kW (two units for MEBT - rebuncher and debuncher in the synchrotron transfer line), 120 kW (RFQ) and 340 kW (2 units for IH1 and IH2) are solid state amplifiers. The 120 kW unit was tested successfully in powering a cavity with adequate Q – value. The test has been performed up to an output level of 150kW to provide additional reserve. The 340 kW amplifiers are under fabrication and will pass similar tests before being delivering.

The transverse beam focusing along the linac will be provided by two quadrupole doublets as well as by two quadrupole triplets. All lenses are under fabrication. The first quadrupole triplet will be installed within IH1. It will match two subsequent KONUS drift tube sections. The second one is located between IH1 and IH2.

The aperture of all quadrupoles is 27 mm. There are only two different lengths of quadrupole singlets with identical cross section, built from laminated steel.

The matching section between RFQ and IH-DTL consists of two quadrupole doublets and of a 4 gap rebuncher. The rebuncher is the coaxial quarter – wave – type.

Capacitive pick – up probes as well as current-transformers are the diagnostic elements along the linac. They have been delivered already.

Shipment of the RFQ and first RF amplifier to JINR is scheduled for this autumn.

LOW LEVEL RF SYSTEM

LLRF system of HILAc was developed by ITEP (Fig. 8). A single-board reference generator G produces five generally independent sinusoidal signals (exciting three accelerating cavities, rebuncher and debuncher).

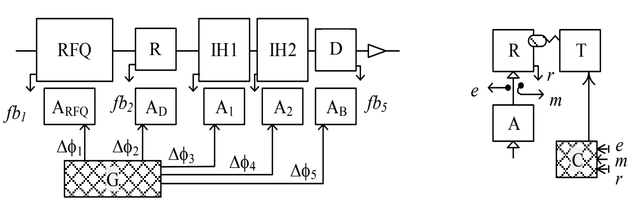

Figure 8: Structure of the HILac LLRF system.

In normal operational mode those signals have a common frequency and a predetermined phase difference between channels. Feedback signals fb1…fb5 may be used for additional stabilization of phases (and amplitudes in the case of A or AB-class amplifiers A_i). Figure's 8 right side shows a resonant frequency control loop, implemented for each resonator of the HILac. Detuning is determined using the relation between the signal from the resonator r and the forward wave signal calculated as combination of properly scaled electric and magnetic components of EM-field in the RF feeding line u= e+m.

Figure 9 shows a simplified structure of the multichannel reference generator G. Sinusoidal signals produced by precisely in-time adjusted DDS microchips. Basic parameters, like the frequency tune word (FTW), amplitude and phase are written to DDS's registers by ARM microprocessor. Same microprocessor receives the measured data in form of amplitude and phase arrays using one of direct memory access channels. This allows performing of slow feedback and a general system monitoring. Buffered raw data from any of eight channels of the ADC is also available for testing purposes. An ADC, working in IF mode digitizes the control signals of the resonators with a rate of 34.6MSPS per channel. Detector Det filters incoming data, decimates and calculates an amplitude and phase of control RF signals. This data is available for subsequent analysis and for fast feedback loop based on the digital controller C.

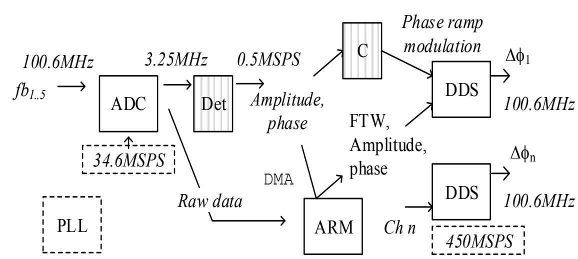

Figure 9: Simplified structure of the reference generator.

CONCLUSION

The new heavy ion source Krion-6T of the NICA injection facility was constructed and operated in specific regimes at the existing accelerator complex. It should rich the design parameters within two years. Construction of the new linear accelerator HILAc is in the final stage. The beginning of their first stage of commissioning is planned on the end of this year.

REFERENCES

[1] G. Trubnikov et al., "Heavy ion collider facility NICA at JINR (Dubna): status and development", Proceedings of ICHEP'12, Melbourne, Australia.

[2] A.V. Butenko et al, "Development of the NICA injection facility", Proceedings of IPAC2013, Shanghai, China.

[3] D.E. Donets, et al., "Physics research and technology development of electron string ion sources", Rev. Sci. Instrum. 83, 02A512 (2012).

[4] F.C. Iselin and J. Niederer, The MAD Program, CERN/LEP-TH/88-38, Geneva, Switzerland, 1988.

[5] V. Aleksandrov, N. Kazarinov, V. Shevtsov, Multi-Component Ion Beam code–MCIB04, Proc. XIX Russian Particle Accelerator Conference (RuPAC-2004), Dubna, Russia, 2004, p.201.

[6] U. Ratzinger, "A low beta RF linac structure of the IH – type with improved radial acceptance ", Proceedings of LINAC 88, Newport News, Virginia, USA, CEBAF-Report-89-001, p. 185.

[7] www.bevatech.com.

[8] J. Alessi et al., Commissioning of the EBIS – Based Heavy Ion Pre-injector at Brookhaven, Proc. of the LINAC 2010 Conf., Tsukuba, Japan, p. 1033.