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DEVELOPMENT OF NICA INJECTION COMPLEX

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Abstract

The new accelerator complex **N**uclotron-based **I**on **C**ollider f**A**cility (NICA) is assumed to operate using two injectors: the Alvarez-type linac LU-20 as injector for light ions, polarized protons and deuterons and a new linac HILac for heavy ions. Required beam parameters will be provided using three new ion sources. First results of the ion source commissioning are presented. Status of the new fore-injector for LU-20 and HILac construction is described.

INTRODUCTION

NICA facility is aimed to perform at JINR wide program of fundamental and applied researches with 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 a corresponding injection facility. Structure and parameters of the NICA injection facility are presented in [2]. The construction of three new ion sources: SPI (Source of Polarized Ions), LIS (Laser Ion Source), Krion-6T (ESIS type heavy ion source) and two new linear accelerators: RFQ based fore-injector for the existing linac LU-20 and heavy ion linac – the HILac is planned. Status of the injection facility development is presented in this report.

ION SOURCES

The new LIS is based on commercially available Nd-YAG laser LPY 7864-2 providing output energy of 2.8 J at wave length of 1064 nm. The new laser was investigated at test bench (Fig. 1) and it was used in the Nuclotron December 2013 run for carbon ion generation.

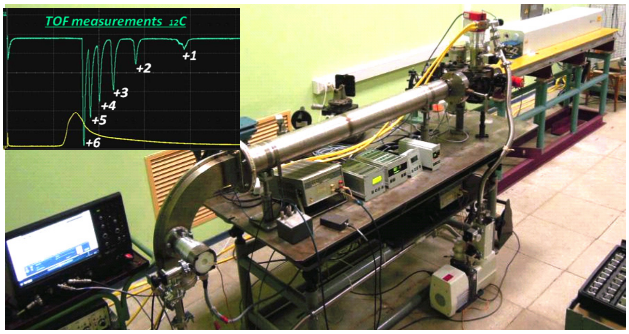

Figure 1: Nd-YAG laser at the test bench.

During the run the source and the linac operation was optimized at acceleration of C^{5+} and C^{6+} ions. The current of C^{6+} beam reach to about 1.5 mA at the LU-20 output. The pulse duration was of about 3 μs. Routinely the injector was operated in C^{5+} mode because of larger output beam current (up to 3 mA) and slightly longer the pulse duration (about 4 μs). The carbon beams were delivered to both the Nuclotron users and stochastic cooling experiments during about two weeks

Construction and assembly of Krion-6T were completed in spring 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 Au30+ ÷ Au32+ ion beams have been produced at intensity of about $6{\cdot}10^8$ particles per pulse. The required ionization time is 20 ms. The 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 existing injection facility. In May 2014 the source was installed at high-voltage (HV) platform of the LU-20 fore-injector (Fig. 2).

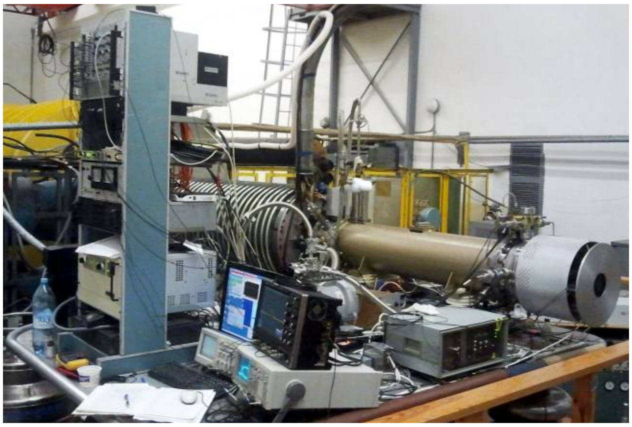

Figure 2: Krion-6T at high-voltage platform of LU-20 fore-injector.

Beam of Ar^{+16} was accelerated and extracted for users. Technological results of KRION6T commissioning are analyzed.

The SPI is aimed to increase the intensity of the polarized beams (proton, and deuteron) up to the level of 1010 particles per pulse. The source consists of two general parts: atomic beam source (ABS) and plasma

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ionizer. The ABS was assembled and tested first at INR of RAS (Moscow). After successive test it was transported to the JINR where the SPI was assembled completely (Fig. 3). Optimization of the SPI operation regimes is in progress now.

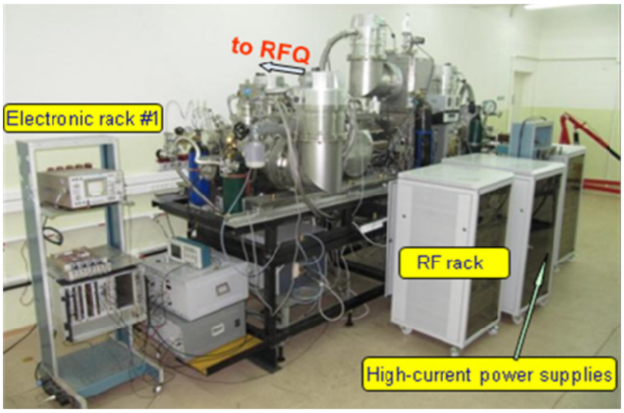

Figure 3: SPI at the test bench.

The first run of the SPI operation at the Nuclotron dedicated to polarized deuteron beam production and acceleration is scheduled for 2015 after commissioning of the new RFQ pre-accelerator for LU-20.

LU-20 FORE-INJECTOR

Presently the charged particles to be injected into LU-20 are pre-accelerated with the electrostatic tube supplied by pulse transformer voltage up to 700 kV. The ion source supply of up to 5 kW power placed at the HV "hot" platform are provided by feeding station consisting of motor and generator isolated one from the other with wood shaft. The new fore-injector will be based on RFQ and electrostatic tube as pre-accelerator between RFQ and ion sources. DC voltage up to 150 kV will be used to provide necessary electric potential. The ion source supply will be provided via 160 kV/35 kWA isolation transformer. Technical design of the new fore-injector performed in collaboration with ITEP (Moscow, Russia) was completed in 2012.

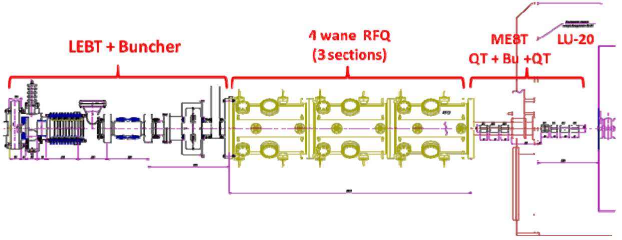

Figure 4: New fore-injector for LU-20 scheme.

The HV supplies and divider transformers have been delivered to JINR. Modulator and RF amplifier for the RFQ are constructed and being tested on equivalent load at ITEP. Manufacturing of the RFQ is at final stage at enterprize in Snezhinsk-city (Russia). Commissioning of the fore-injector is scheduled for 2015. Moreover, the LU-20 operation with the new fore-injector requires a low-level RF (LLRF) system that should provide accurate RF phase matching between the LU-20 and the RFQ-buncher assembly (the buncher is a small cavity located between the RFQ and LU-20). The LU-20 is the Alvarez-type DTL, which RF system works in self-oscillation mode. Correspondingly the LLRF (Fig. 5) provides appropriate frequency and phase of RF oscillations in the RFQ and buncher.

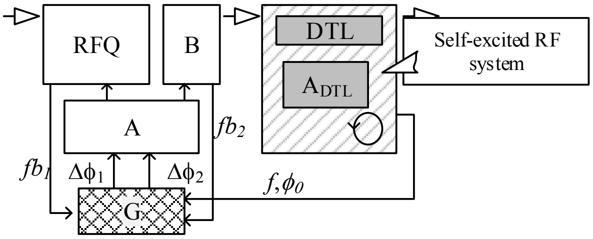

Figure 5: Structure of LLRF for LU-20 based injector. B-buncher, A-RF power amplifiers, RFQ, DTL – linear accelerators, G – LLRF part.

The reference is taken from the self-oscillation RF system that feeds the DTL and transformed to signals of the same frequency and predefined phases. Due to the self-excitation mode, the oscillation frequency of the DTL RF generator is not provided with stable reference source and may vary from pulse to pulse. Therefore, the exact frequency and phase of the RF field in DTL becomes known to the control system to tens of microseconds later than the beginning of the excitation. To guarantee a timely response of the reference generator the embedded FPGA-based DSP implements a direct digital synthesizer built in fast phase locked loop. The electronics is built on proven architecture combining a moderate performance FPGA and lightweight ARM microprocessor for flexible set-up and communication purposes.

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) and medium energy beam transport (MEBT). Design of the HILac was performed by Bevatech OHG [3] and described in details in [2]. The design of RFQ - and IH - tank1 follow closely to 2 MeV/u BNL EBIS – based pre-injector [4]. IH – tank2 is added to reach a final kinetic energy of 3.2 MeV/u. The HILac RF system includes transistor amplifiers and LLRF providing a joint consistent work of all cavities.

The cavities for the NICA injector operate at 100.625 MHz. Besides 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 keV/u for the RFQ and 3.2 MeV/u for the IH-DTL. For the design A/q – value of 6.5 the sum voltage gain is 20.8 MV. All three cavities have been fabricated in 2013. The material is stainless steel for the 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 2 permille.
All RFQ components were delivered and final alignment and tuning is currently done at Bevatech. The IH1 tank is at present in the GSI Darmstadt copper plating shop and will be followed by IH2. Fig. 6 shows RFQ cavity with electrodes.

Figure 6: The 4 – Rod – RFQ during installation work.

The electric field distributions of IH1 and IH2 were measured before the final machining and copper plating.
Nevertheless, the only fine - tuning at the very end will allow to reach the voltage distribution anticipated for beam dynamics calculations.

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 [5].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 of the coaxial λ/4 – 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 summer.

The LLRF system of HILAC was developed by ITEP (Fig.7). A single-board reference generator G produces five generally independent harmonic signals (to control three accelerating cavities, buncher and debuncher).

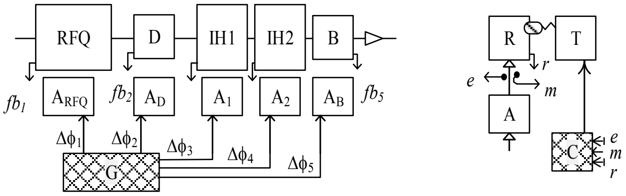

Figure 7: Structure of the HILac LLRF system.

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 for A and AB-class amplifiers A_i). Fig. 7 right shows a resonance 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.

A simplified structure of the generator G is shown in Fig. 8. Sinusoidal signals are generated by precisely 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 slow feedback and general system monitoring. The 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.

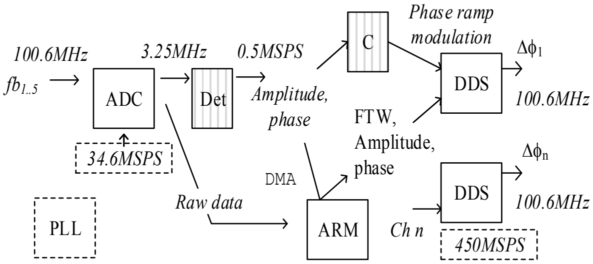

Figure 8: Simplified structure of the reference generator.

CONCLUSION

The new ion sources of the NICA injection facility are constructed the LIS and Krion-6T was operated at existing accelerator complex, test of the SPP is in progress at test bench. Construction of new linear accelerators is in the final stage. The beginning of their commissioning will be started in this year.

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