COMMISSIONING OF NEW LIGHT ION RFQ LINAC AND FIRST NUCLOTRON RUN WITH NEW INJECTOR

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Abstract

In the frames of the NICA project development [1] the old HV fore-injector of the LU-20 linac, which was in operation from 1974, was replaced by the new RFQ accelerator in spring 2016. The first Nuclotron technological run with the new LU-20 fore-injector was performed in June 2016. During the following two runs of total duration of about 2500 hours the proton and deuteron (polarized and unpolarized), lithium and carbon beams were successfully injected and accelerated in the Nuclotron ring. Main results of the RFQ commissioning and experience of its operation are presented in this paper.

INTRODUCTION

New JINR accelerator complex the Nuclotron-based Ion Collider fAcility (NICA, Fig. 1) is aimed to deliver ion beams from protons to gold for fixed target and collider experiments. Injector of light ions, polarized protons and deuterons is based on existing Alvarez-type linac LU-20.

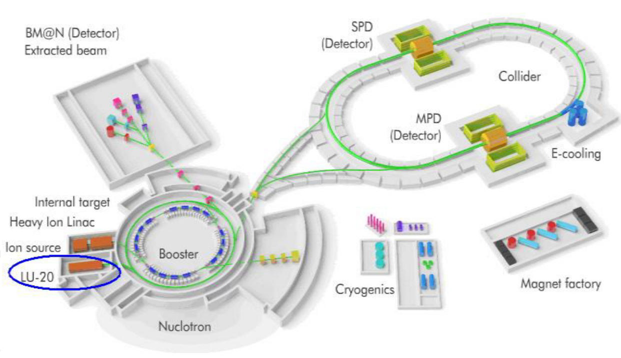

Figure 1: NICA complex. Proton, light and polarized ion linac LU-20 with new RFQ injector is marked.

Up to 2016 year, the charged particles for injecting into LU-20 linac were pre-accelerated with the electrostatic tube supplied by pulsed HV transformer with voltage up to 700 kV. The ion sources supply of up to 5 kW power placed at the HV “hot” platform was provided by feeding station consisting of motor and generator isolated one from the other with wood shaft. New Source of Polarized Ions (SPI) developed in co-operation with INR RAS (Troitsk) [2] with ultimate goal to provide over 10^{10} particles per the Nuclotron acceleration cycle requires for operation about 30 kW. To solve this problem the new fore-injector of LU-20 based on 2.2 m RFQ linac (see Fig. 2) was constructed and put into operation in 2016. Pulsed HV supply up to 120 kV (based on HV pulsed transformer) was designed and assembled to provide necessary electric potential on the ion source terminal. The ion source systems supply is provided using isolation transformer on 160 kV, 35 kWA.

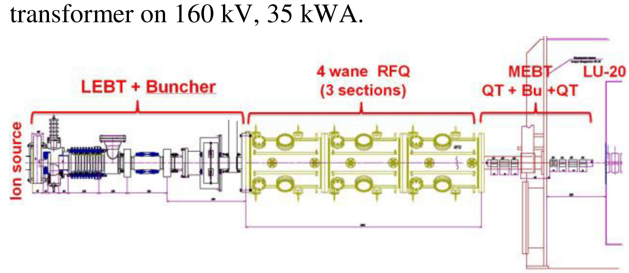

Figure 2: New fore-injector for LU-20 scheme.

The project (Table 1) was performed in collaboration of JINR, MEPhI and ITEP. The beam dynamics simulation, the RFQ resonator simulation and design as well as RF system development were carried out in 2011-2013 [3]. The resonator was manufactured in VNIITP (Snezhinsk).

Table 1: The LU-20 Fore-injector Design Parameters

Z/A	0.5	0.3
RFQ input		
Injection energy, keV	61.8	103.0
Maximum current,mA	20	10
Normalized trans. emittance, π·cm·mrad	0.2	0.15
Operating frequency, MHz	145.2	
Output		
Output energy, MeV/u	0.156	0.156
Transmission RFQ, %	≥85	≥90
$\Delta p/p$, %	≤ 4	≤ 4
Normalized trans. emittance, π·cm·mrad	≤0.5	≤ 0.5
Voltage at electrodes, kV	84	140

ISBN 978-3-95450-182-3

RESONATOR TUNING AND RF COMMISSIONING

The four-vane resonator with displaced magnetic coupling windows was chosen for the NICA RFQ design. It should operate at 145.2 MHz like the LU-20 main resonator operating frequency. The LU-20 is the Alvarez-type DTL which RF system operates in self-excitation mode. Correspondingly, the new LLRF provides appropriate frequency and phase of RF oscillations in the RFQ and buncher [4].

After manufacturing and preliminary vacuum and low-power RF tests at VNIITP the resonator was transferred to ITEP and placed in tuning hall in March 2015. Resonator was excited on operating frequency and the RF field distribution in four quarters was adjusted (Fig. 3).

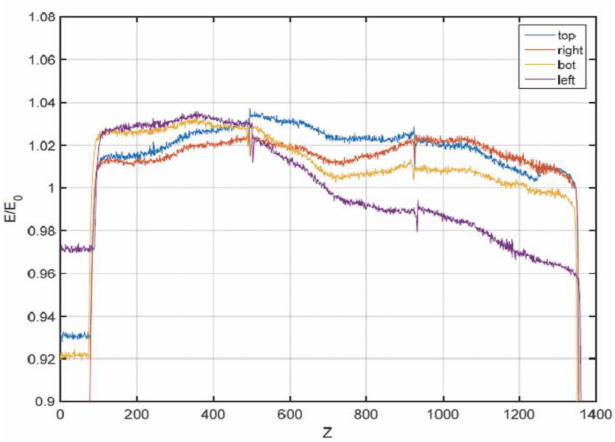

Figure 3: RF field amplitude deviation (< 2%) in four quarters of RFQ resonator.

RF power load was the next step in tuning. It was realized easily and about 380 kW was feed into RFQ resonator (~340 kW is necessary for carbon ions C^{4+} acceleration). Multiple RF sparks on the same place were not observed but training of multipactor was necessary and it was done. Vacuum of $(8\text{-}9)\cdot 10^{-8}$ Torr was achieved after RF commissioning. The resonator was filled by dry nitrogen, transported to JINR and installed in test position in LU-20 injector hall (see Fig.4).

COMMISSIONING AT JINR

In injectors hall the RFQ resonator was equipped by all RF, tuning and vacuum components which were dismounted for the transportation. High power RF system was also assembled at projected place and the resonator was pumped and loaded by the RF power.

Further, the laser ion source, HV fore-injector (up to 120 kV) and LEBT (two focusing solenoids, two steerers and beam diagnostics box) were mounted to the linac support, tested and the deuterium beam was injected into RFQ. The magnetic separator with a special vacuum chamber for smooth angle changing was installed at the RFQ output to measure the beam spectrum for different *Z/A*. At the end of separator a special set of collectors and slits for the beam registration were installed.

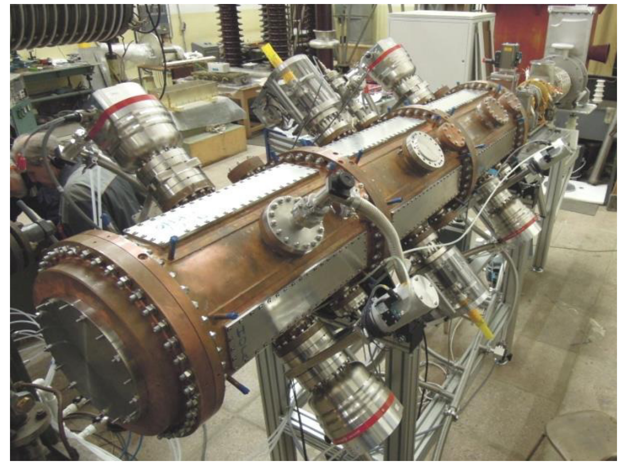

Figure 4: RFQ linac with RF and vacuum components installed on resonator on test area at JINR (Nov. 2015).

The system was calibrated using of H^+, D^+ and carbon beams, which were generated by laser ion source using different targets and accelerated by 63 kV in accelerating tube. The first beam was successfully accelerated in RFQ linac 10-12 Dec. 2015. Measured spectrums for both deuterium and carbon ion beams are presented in Figure 5, the beam current is about ~10 mA for the deuterium beam and ~5 mA for the carbon one.

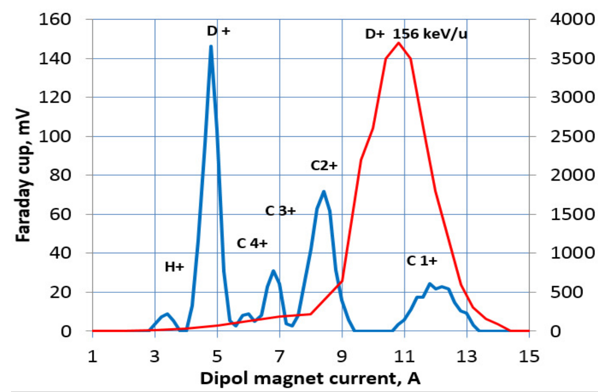

Figure 5: Measured spectrums for ions from the LIS with deuterated polyethylene target, HV = 63 kV (blue) and accelerated up to 156keV/u in RFQ deuterium beam (red).

Good agreement of simulation and experimental results was observed for accelerated/non-accelerated carbon and deuterium beams. The current transmission coefficient through the RFQ is close to 80 % that agreed with projected value.

In February 2016, the old HV fore-injector accelerator tube was dismounted and the new RFQ fore-injector was installed on the LU-20 axis. All the systems of the accelerator were assembled, aligned and commissioned again. The new HV platform 15 m^2 for the SPI was constructed.

Two triplets of quadrupoles for the MEBT line were designed, manufactured and assembled with vacuum system between the RFQ and LU-20 resonator. All magnets of LEBT and MEBT lines are powered by pulsed power supplies with a special control system, which were designed and assembled in JINR.

ISBN 978-3-95450-182-3

The first deuteron beam from the laser source was accelerated in LU-20 with new fore-injector in March 2016 [5] with transmission factor up to 20% through the whole injector.

NUCLOTRON RUNS

During May 2016, the SPI was transferred and mounted on the HV terminal platform of the new fore-injector (see Fig. 6).

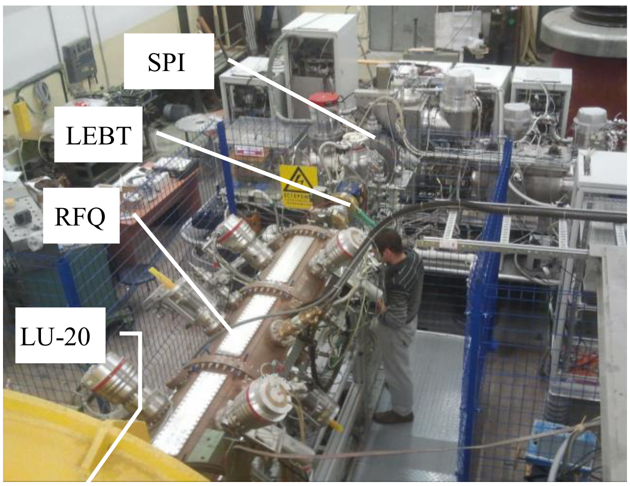

Figure 6: Source of Polarized Ions mounted on the HV terminal and RFQ connected to the LU-20

In June 2016, the first technological Nuclotron run with the deuteron beam from the new fore-injector and SPI was provided. During that run all the main systems of the ion source and injector were commissioned and put into operation.

The run dedicated to experimental investigations in spin physics (with polarized deuterons) was started 26 of October 2016 and its total duration was more than 1500 hours. Average intensity of the polarized deuteron beam was about 5-7·10^8 particles per cycle (Fig. 7) and during the run performed in February-March 2017 it was increased up to 2·10^9 ppc. In this run the acceleration of polarized proton beam from SPI as well as the lithium and carbon beams from the laser source was provided.

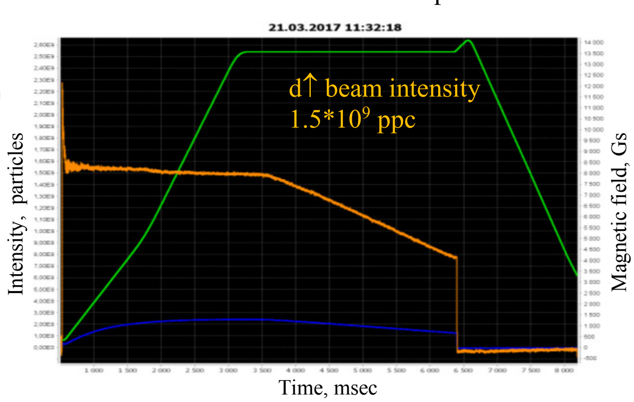

Figure 7: Cycle diagram for polarized deuteron beam during acceleration and slow extraction: orange line - intensity, green line - main magnetic field.

CONCLUSION

After four years of intensive discussions, simulations, construction and manufacturing the new RFQ linac for LU-20 injection complex upgrade was installed in the Nuclotron injector's hall at JINR and put into operation. Proton, deuteron, lithium and carbon beams were successfully accelerated in new fore-injector. Stable and safety operation of the LU-20 with new RFQ and SPI during three Nuclotron runs was demonstrated. The proton and deuteron (polarized and unpolarized), lithium and carbon beams were successfully injected and accelerated in the Nuclotron ring. To obtain designed capture efficiency of the beam in LU-20 the buncher in MEBT line is foreseen. Such cavity was designed, manufactured and tested. Presently it is installed at MEBT and under preparation for the nearest Nuclotron run scheduled for autumn of 2017.

Figure 8: LINAC team during commissioning of the RFQ and the SPI.

ACKNOWLEDGEMENTS

We would like to thank all Institute of Technical Physics (Snezhinsk) specialists which are take part in resonator manufacturing and personally I.V. Mamaev, K.A. Klykov, M.Yu. Naumenko and G.N. Ostashkov.

We also would like to thank MEPhI TechnoPark and personally A.N. Petrovsky, A.P. Korotkova and S.S. Korotkov for the organization support.

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