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THE CONCEPTUAL DESIGN OF THE 7.5 MeV/U LIGHT ION INJECTOR

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Abstract

The new linac for light ion beam injection is under development at MEPhI. Such linac was proposed for acceleration of 7.5 MeV/nucleon ion beam with A/Z=1-3.5 and current up to 5 mA for proton and 0.4 pmA for light ions. The linac general layout will include two types of ion sources: ECR ion source for proton and He ions and laser ion source for ions form Li to O. Following the LEBT ions will be bunched and accelerated to the final energy using RFQ section and 14 IH-cavities. These IH-cavities will be identical (divided into two groups) and independently phased. All cavities will operate on 81.25 MHz. Results of the beam dynamics simulations and the cavities design will be presented in the report.

INTRODUCTION

Starting 2018 the new ion synchrotron complex is under development at RFNC-VNIIEF, Sarov. New complex will include booster and storage rings, two injectors LU1 (protons and light ions) and LU2 (heavy ions, designing at NRC Kurchatov Institute - ITEP) and many experimental channels. MEPhI is duty for LU1 linac which will accelerate ions from protons to oxygen up to energy of 7.5 MeV/nucleon with mass-to charge ratio A/Z<3.5.

LU1 linac will include two types of ion sources: ECR for protons and He beam and laser ion source for ions from Li to O. Both types of ion sources will be doubled to growth the reliability of the linac operation. All accelerating and bunching cavities will operate on the same frequency of 81.25 MHz. The low energy beam transport channel (LEBT) will be complex to compose beams from four ion sources. LEBT also will include buncher B1 for beams pre-bunching before the RFQ and first beam diagnostics devices block. RFQ will bunch and accelerate beam up to 820 keV/nucleon and should to provide the beam capturing coefficient not less than 90 % for all types of ions. Following RFQ section and medium energy transport line MEBT1 two groups of short 5-gaps independently feeded IH-cavities will be placed. The geometric velocity β_g will be constant for the group of cavities to reduce the linac cost. As it was shown due to the beam dynamics simulation it will be enough to have two groups of cavities with β_g=0.057 and 0.099 (six and eight cavities for the first and the second groups correspondently) to achieve the final beam energy of 7.5 MeV/nucleon. The second buncher B2 will be added to MEBT1 to control the bunch length and to chop the bunch tail. Two groups of cavities will also separated by short transport line MEBT2 includes one reserve buncher B3.

After acceleration the beam should be rotated at the angle ~40 degrees at the high-energy transport line (HEBT). After junction with the direct HEBT of LU2 the beam will start to prepare for injection into the storage ring. Note that it is planned to inject the continuous beam into the booster ring and we should to use a debuncher in HEBT for this aim

Finally, we will have 19 accelerating and bunching cavities for LU1 in total, they will operating on the same frequency of 81.25 MHz. The linac total length is about 40 m (without HEBT). All cavities will feed by solid state amplifiers.

ION SOURCES

As it was noted above LU1 linac will include four ion sources: two ECR and two laser ion sources. The key difficulty for the ECR design is the aim to generate both protons and He^{2+} ions in the same source and to have the necessary beam intensity. The operating frequency of 2450 MHz was choused for ECR due to availability of magnetrons and successful experience of its operation at MEPhI [1]. The magnet system for ECR was chosen basing on solid state magnets with mechanical motion of the sextupole trap and end rings. The simulation shows that the necessary p^+ and He^{2+} beam intensity will be achieved.

New laser ion source will be also designed basing on the old prototype operation experience. The laser ion source operates at MEPhI more that 30 years. It is used to generate different ion beams having single chatge state- and it was used to test the proposed technical solutions and to verify our analytical estimations for multi-charged beams. Unfortunately, the ion source is now equipped by low power (<450 mJ) laser, that prevents to generate multi-charged ions because this energy is lower that the

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ionization potential for the second electron. New plasma chamber was also designed to operate with different types of targets in the same session, Fig. 1. Two step motors will provide both "slow-step" motion of the target to replace the injured point and to change the target to the different material. Such design gives us the possibility to operate with eight targets.

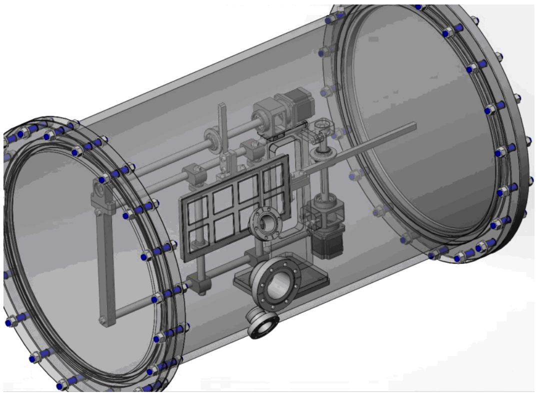

Figure 1: Discharge chamber for new laser ion (form Li to O) source.

RFQ SECTION

The RFQ section will be used both for beam bunching and following acceleration up to energy of 820 keV/nucleon. It was shown that the current transmission coefficient can be increased up to 95-97 % for all types of ions by means of short low field pre-buncher installed before RFQ, Fig. 2. The beam dynamics simulation was done using BEAMDULAC-RFQ code designed at MEPhI [2-6]. The pre-buncher using also provides two times lower output energy spectrum.

The four-vane RFQ cavity with magnetic coupling windows [7] was proposed for LU1. Such type of the cavity has compact design, it is comparatively simple for tuning and such linac was successfully designed, constructed and operated as the for-injector of the JINR Nuclotron-NICA complex [8-9]. The design of the RFQ cavity is shown in Fig. 3. The total length of the cavity is about 5 m. 12 plungers will be used for the operating frequency tuning, this number is enough to shift the frequency at the wide band of ±300 kHz. The RF design of the RFQ cavity will be discussed more detail in [10-11]. All necessary simulations of the cavity are close to finish and we plan to start the manufacturing of one cavity sector next year.

IH-CAVITIES

The beam dynamics for the regular part of LU1 was studied by the combination of analytical methods and numerical simulation as it was proposed in [12-14]. As known the synchronism condition violates for such system of cavities with constant geometrical velocity and more accurate treatment of the phase slipping is necessary to achieve correct results of the beam dynamics simulation. The beam dynamics simulation shows that the regular part of the linac will consists of two groups of IH-cavities with geometrical velocities βg=0.057 (six 5-gap cavities) and 0.099 (eight 5-gap cavities) to achieve the final energy of 7.5 MeV/nucleon. Results of the beam dynamics simulation are shown in Figs. 4 and 5. Fig. 4 illustrates the slipping factor inside the groups of cavities. Longitudinal and transverse phase spaces before the first cavity, after cavities No. 6 and No. 14 are shown in Fig. 5.

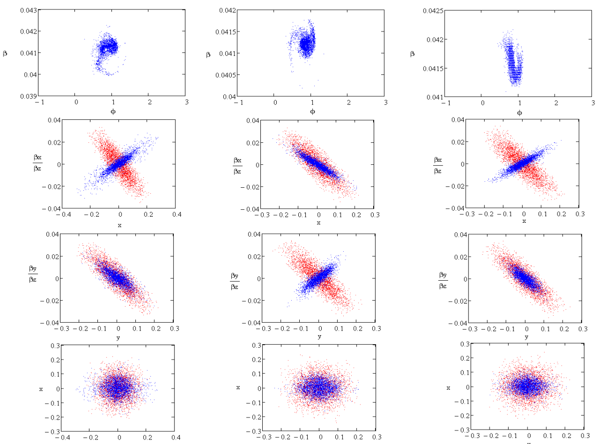

Figure 2: Beam dynamics simulation results for LU1 RFQ: A/Z=1, I=10 mA (at left), A/Z =2.0, I=1 мA (at center), A/Z=3.5, I=1 мA; all simulation were done with pre-buncher before RFQ; it are shown (top-to-bottom): longitudinal emittance, transverse emittances and the beam cross-section; all parameters are plotted by red color for the front-end of the RFQ and by blue color for the output.

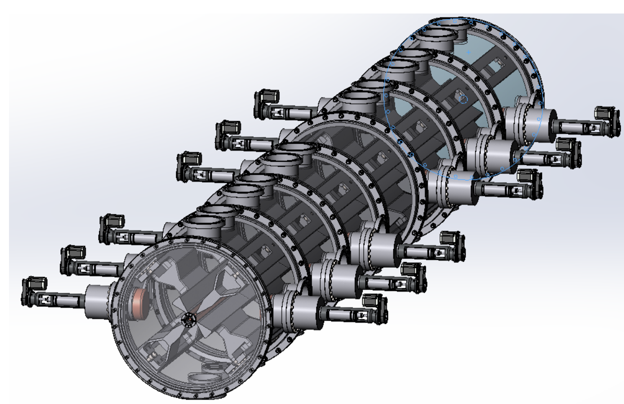

Figure 3: RFQ cavity design.

Further electrodynamics, thermal and mechanical simulations of IH-cavities were done and we start to prepare the construction of the full-scale model of first group cavity. The model of the cavity is shown in Fig. 6, it includes all necessary elements as well as vacuum and RF ports, plungers, vacuum valves, etc. Note that all mechanical tuning elements are placed inside of the cavity.

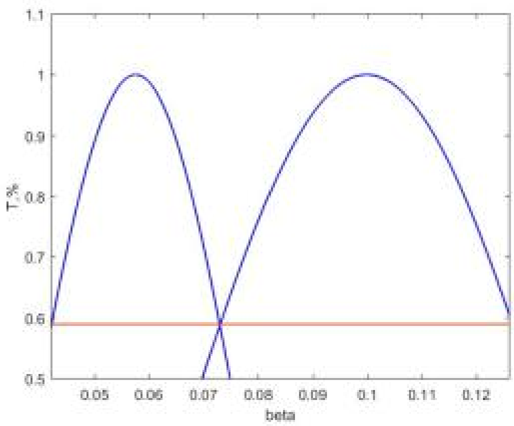

Figure 4: Slipping factor for the regular part of LU1, it includes 14 IH-cavities divided into two groups

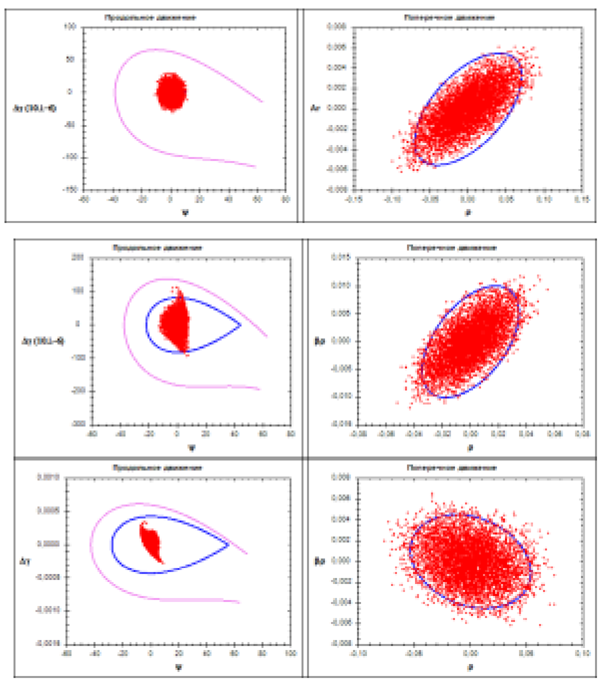

Figure 5: Beam dynamics simulation results for the regular part of LU1; longitudinal and transverse phase spaces are shown before the first cavity, after cavities No. 6 and No. 14.

BEAM TRANSPORT CHANNELS

LU1 will include four main beam transport channels (LEBT, MEBT1, MEBT2, HEBT) and 12 short channels between IH-cavities (with quadrupole doublets). The beam dynamics simulation for the transport channels shows that we can use one type of pulse quadrupoles for all channels and the maximal necessary gradient will be not higher than 22 T/m. The pulse regime provides us the low operation power and gives us possibility to use lenses without water cooling of coils. Channels will also include five dipoles, three in LEBT to join beams generated by four ion sources and two in HEBT. Please find the information about beamlines and magnets in [15].

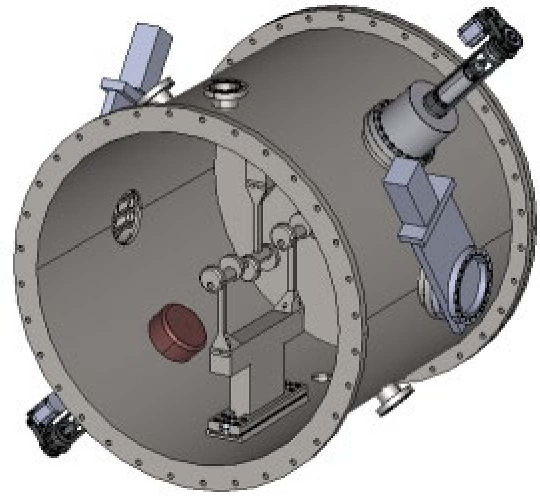

Figure 6: IH-cavity design.

VACUUM, CONTROL, DIAGNOSTICS

LU1 will be equipped by all necessary systems as well as vacuum, power, diagnostics, control, mechanic supports, etc. The vacuum system for LU1 is discussed in [16]. The control system of the new VNIIEF synchrotron complex is planned to build using high-level platform TANGO, but local control system for LU1 will be much more simple and will include data server and control server as well as control racks for all linac systems. Beam diagnostics is now a key point for successful accelerator commissioning and operation. It is planned that LU1 will include four main diagnostics blocks located in LEBT, MEBT1, MEBT2 and HEBT. We plan to use slit grids, paper port and Allison scanner to control the beam emittance and a bunch shape monitor also (all these components will be developed at INP RAS). Also we plan to use ~15 beam position monitors and ~18 current transformers to control the current parameters along the linac.

CONCLUSION

New injector LU1 is now under development for VNIIEF synchrotron complex under R&D. Such linac will accelerate light ions from protons to oxygen up to energy of 7.5 MeV/nucleon. Main features of LU1 were discussed in the paper as well as the beam dynamics simulation results. Cavities (RFQ, IH type and bunchers) preliminary design is close to finish today and we hope that tests of RFQ and IH-cavity prototypes will start next year.

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