ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-WEPLH15

LIGHT ION INJECTOR FOR NICA

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Abstract

The Nuclotron ring of the NICA project will get a new light ion injector linac (LILac) for protons and ions with a mass to charge ratio up to 3. The LILac will consist of 2 sections: A 600 keV/u RFQ followed by an IH-type DTL up to 7 MeV/u, and a postaccelerator IH cavity for protons only - up to 13 MeV. A switching magnet will additionally allow 13 MeV proton beam injection into a future superconducting testing section. The pulsed Linac up to 7 MeV/u and including the post-accelerator for protons up to 13 MeV will be developed in collaboration between JINR and BEVATECH GmbH. The technical design of that Linac is discussed in this paper.

INTRODUCTION

In the frame of the NICA ion collider upgrade [1] a new light ion frontend Linac (LILac) for polarised particles, protons and ions with a mass to charge ration of up to 3 will be built. Behind the ion source and LEBT, LILac will consist of 3 parts:

1. a normal conducting Linac up to 7 MeV/u
2. a normal conducting energy upgrade up to 13 MeV protons
3. a superconducting section from 13 MeV/u up to a final energy to be determined.

In this paper the Part 1 and Part 2 of LILac up to 7 MeV/u and 13 MeV for protons are discussed. This normal conducting Linac will be built in collaboration between JINR and BEVATECH GmbH.

The Linac will be located in LU20 hall at JINR and provide a beam energy of 7 MeV/u to be injected into the Nuclotron ring for further acceleration as a first stage of the project. Protons and light ions with a mass to charge ratio of up to 3 will be used for either fixed target experiments to study baryonic matter or will be injected into the NICA collider ring for hadron matter and phase transition experiments and to study spin physics on polarised particles [2].

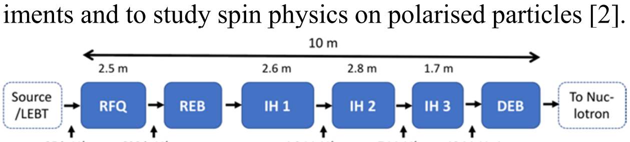

Figure 1: LILac cavity scheme.

The Linac consists of 6 cavities, an RFQ followed by a re- buncher, 3 IH-DTL structures and a de-buncher as shown in Fig. 1. It is operating at 162.5 MHz with a beam repetition rate of 5 Hz and a duty cycle of 0.1% [3]. The main parameters of the LILac are summarised in Table 1. The length of the Linac comprising the cavities, the beam diagnostic devices and focusing magnets but excluding the de-buncher will be realised within a length of below 10 m.

Table 1: LILac Main Parameters

Parameter	Protons	C^{4+}
A/Q	1	3
Injection Energy	25 keV	300 keV
Exit Energy	13 MeV	84 MeV
Beam current	5 mA	15 mA
Rep. Rate Limit	≤ 5 Hz	
Current Pulse Duration	30 µs	
RF Pulse Length	200 µs	
RF Frequency	162.5 MHz	
Transmission	≥ 80%	
Length of the Linac	≤ 10m	

Each cavity will be fed by a dedicated high power solid state amplifier to provide the corresponding power for the accelerating fields in the cavities. The LLRF control soft- and hardware is realized in the MicroTCA.4 standard will be developed together with Bevatech and the MicroTCA Technology Lab at DESY based on the LLRF system from XFEL.

ARCHITECTURE

Ion Source and LEBT

For LILAC two different ion sources, a laser ion source (LIS) and a source of polarized ions (SPI), will be used. From the LIS it is planned to receive light ions, while the SPI will generate polarised and non-polarised protons and deuterons [3]. The ion sources are placed on a high voltage terminal (up to 150 kV) [4]. The LEBT channel with a length of about 1.8 m consists of 2 parts: The first part is an electrostatic section with ion optics and an electrostatic tube, and the second part uses two magnetic solenoids with a maximum magnetic field of 1.2 T. The LEBT channel is currently under redesign.

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RFQ

A 4-rod type RFQ is the first RF accelerating structure of the Linac. It accelerates, focuses and bunches the continuous 30 keV/u DC beam from the LEBT to 600 keV/u. Due to a new extraction energy of the ion source the RFQ beam dynamics design had to be changed to accept the higher injection energy of 25 keV/u. Also the RFQ design has been improved to provide better longitudinal emittance and comes now to a length of 2.5 m. The cavity will be made of copper plated stainless steel, while the inner structure - the electrodes (rods), the stems and tuning plates - will be machined from solid copper. To ensure a stable operation in terms of field and frequency the RFQ will be equipped with one passive and one active piston tuner.

MEBT

The medium energy beam transport section provides a proper beam matching from the RFQ into the first IH-DTL structure. A standard concept was applied, consisting of two short quadrupole doublet magnets for the transverse beam matching with 2 magnetic steerers attached and a two gap Re-buncher cavity in the centre. It resulted in a rather compact layout - only about 0.8 m in total - but with enough space reserved for on-line beam diagnostic elements. For the latter a beam position monitor, BPM, as well as an ACCT are foreseen to determine the beam position, bunch signal and beam current.

IH-DTL

A compact DTL section of the LILac has been designed by using the beam dynamics simulation codes LORASR and validation in Tracewin. A beam energy gain from 0.6 MeV/u to 7.0 MeV/u for the design particle with a mass over charge ratio $A/q = 3$ is obtained within a Linac length of about 7 m. A post accelerator for protons with an energy of 13 MeV adds up to a total Linac length of 10 m.

Beam dynamics design uses KONUS beam dynamics, which allows for multi gap cavities and a small number of transverse focusing elements. These are powerful magnetic quadrupole lenses (doublets or triplets), which can be integrated into the cavities or placed as external elements in between the resonators.

The DTL consists of three IH cavities. The first IH tank (IH1) has two internal quadrupole triplet lenses and achieves an energy gain from 0.6 to 4.2 MeV/u, the second one (IH2) has one quadrupole triplet and provides an end energy of 7.0 MeV/u. The third IH Tank is a post accelerator for protons only with an end energy of 13 MeV and no internal lens. As beam diagnostic elements each structure will be followed by a BPM and where applicable an additional current transformer to measure transmission.

BEAM DYNAMICS

RFQ

After the LEBT exit the beam is injected with 25 keV/u into the RFQ with an acceptance of 0.4 mm mrad. The constraints for the design were: (1) to accept the input emittance and energy, (2) to be as long as necessary but as short as possible, (3) the power loss should be within the range of 250 – 300 kW (including safety margins).

The new design of the RFQ accelerates a 15 mA beam (A/q = 3) up to 600 keV/u. within about 2.5 m. It has negligible transverse emittance growth emittance and provides a transmission of above 87 %. The beam dynamics design was made using Parmteq and the electrode design was cross checked by Toutatis tracking simulations. These simulations agree well with an almost identical longitudinal particle distribution. The beam output distribution is of the Toutatis simulation is shown in Fig. 2. At the moment the RFQ's rf and mechanical design is in its final phase.

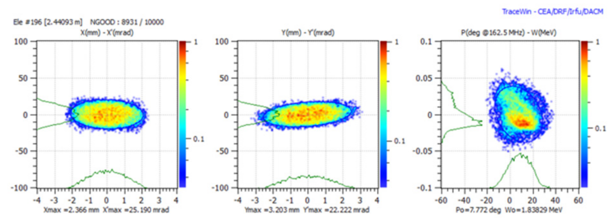

Figure 2: Toutatis/TraceWin beam output distribution of the LILac RFQ.

Table 2: Main Parameters of the LILac DTL Part

Cavities		
Main Components	1 Rebuncher (REB), 2 IH-DTL (IH1, IH2) 1 post-accelerator IH-DTL (IH3)	
Number Of Gaps	2 (REB); 31 (IH1); 24 (IH2); 11 (IH3)	
Tube Inner Diam. [mm]	20 (REB); 16 – 20 (IH1); 20 (IH2); 20 (IH3);	
Eff. Gap Volt. [kV]	80 (REB); 120 - 500 (IH1, IH2); 200 - 750 (IH3)	
Cavity Effective length [m]	0.2 (REB); 2.6 (IH1); 2.8 (IH2); 1.4 (IH3)	
Magnetic quadrupole triplets		
Effective Length [mm]	140 (QD in MEBT) 320 (QT)	
Eff. Gradients [T/m]	57.0 – 62.0 for QD 49.0 – 62.0 for QT	
Aperture Diam. [mm]	34	
Beam parameter		
Design Current C^{4+} [mA]	15	
	RFQ out	IH3 out
$\varepsilon_{n,98\%\ transv.}$ [mm·mrad]	1.7	2.4
$\varepsilon_{rms\ transv.}$ [mm·mrad]	0.29	0.36
$\varepsilon_{98\%\ long.}$ [keV·ns]	6.7	10.1
$\varepsilon_{rms\ long.}$ [keV·ns]	0.77	1.05

North American Particle Acc. Conf. NAPAC2019, Lansing, MI, USA JACoW Publishing
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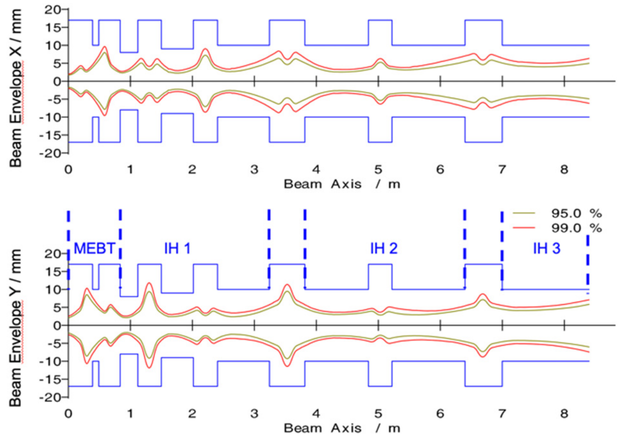

Figure 3: Transverse beam envelopes RFQ exit to IH3 exit.

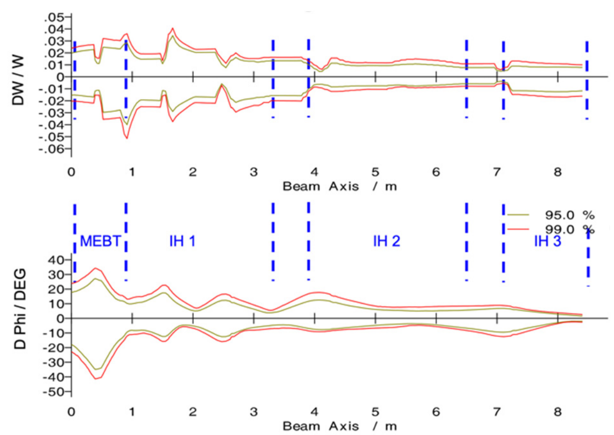

Figure 4: Longitudinal beam envelopes RFQ exit to IH3 exit.

MEBT and IH-DTL

A compact DTL section of the LILac linac has been designed by using the beam dynamics simulation code LORASR. The linac is based on the 'KONUS' beam dynamics concept, which allows for multi gap cavities with a small number of magnetic quadrupole lenses (doublets or triplets). In Fig. 3 and Fig. 4 the transverse and longitudinal beam envelopes from RFQ exit to IH3 exit are shown and the positions of the main linac components are indicated. The corresponding linac component and beam parameters are listed in Table 2.

Figure 3 shows a transversally well matched beam with small envelope oscillations. The quadrupole triplet channel is clearly visible and there is enough safety mar-gin between beam and aperture (in blue). The DTL part of the LILac DTL has been designed with 100% transmission using the simulated RFQ output distribution. Machine error studies will be performed next, in order to define the rf stability and alignment tolerances.

The longitudinal beam envelopes (Fig. 4) also show stable behaviour with small oscillations particularly at higher energies and small output energy and phase spreads. The emittance growth (see Table 2) is well below to what was achieved by previous KONUS designs.

RF AND LLRF

RF Power Amplifier

It was decided to use solid state high power amplifier for the 6 cavities due to modularity, reliability and decreasing costs, also underpinned by the experience with the HILAC project [5]. The power budget was planned considering the cavity RF losses, beam loading and a 30 % power margin. It was estimated to use 10 kW amplifier for the buncher cavities, 300 kW and 600 kW for the RFQ and the IH cavities 1 and 2, and approximately 300 kW for IH cavity 3. These values may still vary in the future since final RF calculations are still in progress.

LLRF

The Low Level Radio Frequency (LLRF) system, to control the RF fields of the accelerating cavities, is based on MicroTCA.4 standard. The electronic cards for all 6 cavities fit into one crate with 9 units height.

The system is generator driven, thus, the RF reference adjusted in amplitude and phase and with a baseband vector modulator provides the input signal to the high power solid state amplifier (SSAM). For accelerator operation, the cavity field gradients and phases can be user defined where the stability of the fields is ensured through digital real-time fast feedbacks programmed in Field Programmable Gate Arrays (FPGAs). The cavities frequency is measured and readjusted on demand through motor tuners with a LLRF system for each cavity.

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