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THE NEW LIGHT ION INJECTOR FOR NICA

B. Koubek*, M. Basten, H. Höltermann, H. Podlech, U. Ratzinger,
A. Schempp, R. Tiede, Bevatech GmbH, Frankfurt am Main, Germany
A. Butenko, A. Govorov, B. Golovenskiy, D. Donets, K. Levterov, D. Lyuosev, A. Martynov,
V. Monchinskiy, D. Ponkin, K. Shevchenko, I. Shirikov, E. Syresin, JINR, Dubna, Russia
C. Kampmeyer, H. Schlarb, DESY, Hamburg, Germany

Abstract

Within the upgrade scheme of the injection complex of the NICA project and after a successful beam commissioning of a heavy ion linac, Bevatech GmbH will build a first part of a new light ion linac as an injector for the Nuclotron ring. The linac will provide a beam of polarised protons and light ions with a mass to charge ratio up to 3 and an energy of 7 MeV/u. The mandate of the Linac does not only include the hardware for the accelerating structures, focusing magnets and beam diagnostic devices, but also the LLRF control soft- and hardware based on the MicroTCA.4 standard in collaboration with the MicroTCA Technology Lab at DESY. An overview of the Linac is presented 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/u
3. a superconducting section from 13 MeV/u up to a final energy to be determined

In this paper only the Part 1 of LILac up to 7 MeV/u is 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 provides 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 up to 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 its phase transition experiments and to study spin physics on polarised particles.

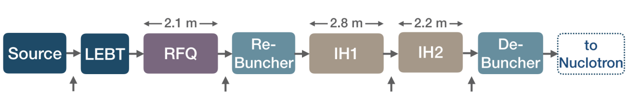

Figure 1: Scheme of the LILac cavities.

* benjamin.koubek@bevatech.com

The Linac consists of 5 cavities, an RFQ followed by a rebuncher, 2 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 0.15 % [2]. 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 9 m. A scheme of the LILac cavities is shown in Table1.

Table 1: LILac Main Parameters

Parameter	Protons	C^{4+}
Mass to Charge Ratio	1	3
Injection Energy	20 keV	60 keV
Exit Energy	7 MeV	21 MeV
Beam Current	5 mA	15 mA
Repetition Rate Limit	≤5 Hz	
Current Pulse Duration	30 μs	
RF Pulse Length	200 μs	
RF Frequency	162.5 MHz	
Transmission	≥80 %	
Full Length of the Linac	<9 m	

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 based on the MicroTCA.4 standard will be developed together with Bevatech and the MicroTCA Technology Lab at DESY.

ARCHITECTURE

Ion Source and LEBT

At the LILac two different ion sources, a laser ion source (LIS) and a source of polarised 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 [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 is split into two main 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. This channel will be similar to the existing which works at the LU-20 pre-injector.

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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 20 keV/u DC beam from the LEBT to 600 keV/u within a length of about 2 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 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 steerers and diagnostic elements. For the latter a BPM as well as an ACCT are foreseen to determine the beam position, current and bunch signal.

IH-DTL

A compact DTL section of the LILac has been designed by using the beam dynamics simulation code LORASR. 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 5.5 m.

This is due to the use of the 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 two IH cavities. The first IH tank (IH1) has two internal quadrupole triplet lenses and achieves an energy gain from 0.6 to 4.1 MeV/u, the second one (IH2) is without internal lenses and provides an end energy of 7.0 MeV/u. The transition energy of 4.1 MeV/u has resulted from beam dynamic constraints, but has also been chosen due to RF power considerations - the power demand should be balanced between IH1 and IH2.

BEAM DYNAMICS

The RFQ beam dynamics and electrode design was simulated using Parmteq. The simulations resulted in a compact RFQ with a focus on high transmission, small emittance growth and stable output emittances against changes of the input distribution from the source and LEBT.

For the MEBT and IH-DTL simulations the RFQ output distributions as provided from the RFQ beam dynamics simulations were used. The design current is 15 mA, $A/q = 3$, i.e. 5 mA for protons. Figures 2 and 3 show the results of the beam dynamics simulations with corresponding beam envelopes using the code LORASR. As for the transverse beam envelopes shown in Fig. 2, a major design issue was to provide enough safety margin between beam and aperture, with the goal to minimize beam losses.

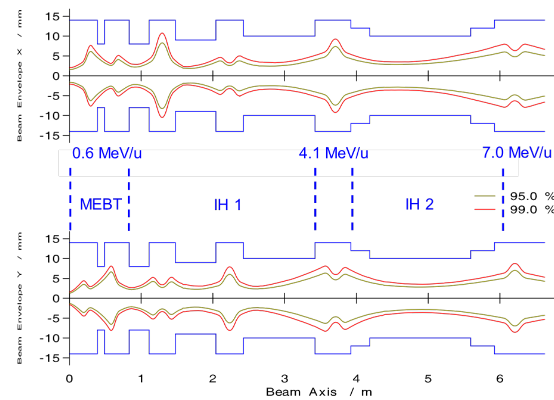

Figure 2: Transverse beam envelopes of the LILac DTL section, 15 mA, $A/q = 3$.

With increasing beam energy, the period lengths are increasing significantly and therefore also the overall section or tank lengths, respectively the distances between the triplets. This is why the beam envelopes tend to get larger towards the high-energy end of the Linac. Taking this into account, the drift tube apertures diameters were gradually increased in IH1 (from 16 to 20 mm), as well as at the tank ends of IH2 (from 20 to 24 mm). The lens aperture diameters were kept constant at 28 mm, which helps to simplify the lens mechanical design.

In Fig. 3 the energy and phase width envelopes along

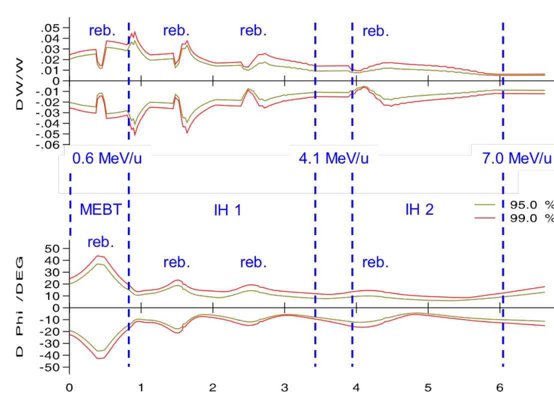

Figure 3: Longitudinal beam envelopes related to the bunch centroid, 15 mA, $A/q = 3$.

the Linac are shown, with the typical pathway for lattices based on the KONUS beam dynamics: The "jumps" in phase and energy are attributed to the redefinition of the synchronous particle energy and phase at the transitions between re-bunching and zero degree main acceleration sections.

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RF AND BEAM DIAGNOSTICS

LLRF

The Low Level Radio Frequency (LLRF) system, to control the RF fields of the accelerating cavities, is based on MicroTCA.4 standard.

The system is generator driven, thus, the RF reference adjusted in amplitude and phase with a baseband vector modulator provides the input signal to the high power solid state amplifier (SSAM).

The output power of the SSAM is measured by determining the RF signals from directional waveguide coupler. The accelerating field in the cavity is measured by the RF signals from the cavity pickups. These RF signals are directly sampled with high speed low-noise ADCs. Raw values of the ADCs are converted to I (In-Phase) and Q (Quadrature) values and decimated. Only the probe signal is used for feedback control.

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.

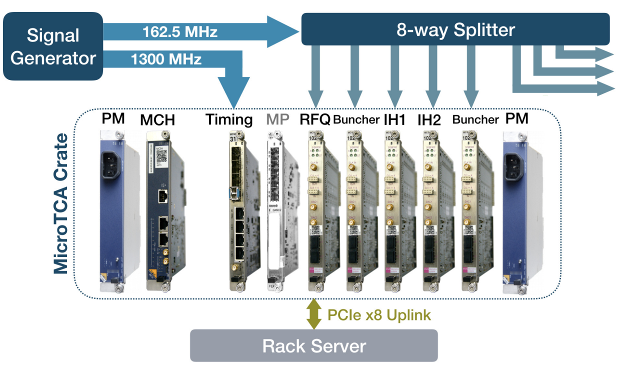

Figure 4: Layout of the LLRF system including RF master oscillator, LLRF controller channels and CPU processing unit.

The configuration of the LLRF system is shown in Fig. 4. The core components of the LLRF controller are based on the MicroTCA.4 standard. Each LLRF regulation consists of an Advanced Mezzanine Card - Rear Transition Module (AMC-RTM) pair. The RTM is an analogue RF preprocessing unit for signal filtering and signal level adjustment and includes the vector modulator, the RF interlock gate and a low-noise clock generator phase locked loop. The AMC performs the sampling of the RF signals and computes the RF field controller on the FPGA. Triggers for data acquisition are generated by a timer module (X2TIMER). The X2TIMER is connected to a 1.3 GHz reference input derived from the 162.5 MHz.

Trigger and clocks are distributed inside the MicroTCA crate over the standard AMC backplane. The CPU is an external 19" mounted rack server that is connected to the AMC modules via 8 PCIexpress Gen 3 uplink in the MicroTCA Carrier Hub (MCH). A dedicated LLRF control server is running on the CPU which allows to control and monitor the controller on the FPGA.

The crate shelf has redundant fan trays and redundant power supplies. The system is fully managed through an Intelligent Platform Management Interface (IPMI). It provides various diagnostic capabilities, remote access to the AMC-RTM modules, remote firmware upgrade and selected power cycling capabilities.

High Power Amplifier

Due to modularity, reliability and decreasing costs, also underpinned by the experience with the HILAC project [5,6], it was decided to use solid state high power amplifier for the 5 cavities. 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, 250 kW and 550 kW for the RFQ and the two IH cavities, respectively. These values may still vary in the future since final RF calculations are still in progress.

Beam Diagnostics

A set of online beam diagnostic tools is positioned along the Linac in order to provide a continuous and stable beam operation, minimising beam losses and allow to protocol beam parameters of long time operation. Since space between the accelerating devices is very limited due to beam dynamics optimisation a sufficient but minimal setup of beam diagnostic devices has been chosen.

A set of 2 current transformers (ACCTs) and 3 beam position monitors (BPMs) are foreseen for the LILac. The location of the devices is shown in Fig. 5. An ACCT as well as a BPM are located within the MEBT, a second BPM behind IH1 and a BPM and the second ACCT are positioned behind IH2. During commissioning a diagnostic bench is planned to be used in order to tune and optimise the injector but also to calibrate the on-line beam diagnostic elements.

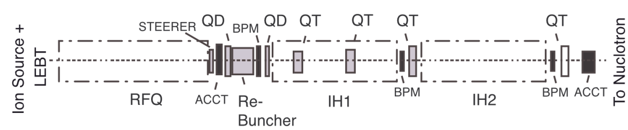

Figure 5: Location of the online beam diagnostic devices.

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