LILac ENERGY UPGRADE TO 13 MeV

B. Koubek*, S. Altürk, M. Busch, H. Höltermann, J. Kaiser, H. Podlech, U. Ratzinger,
M. Schütt, M. Schwarz, W. Schweizer, D. Strehl, R. Tiede, C. Trageser
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
A. Brunzel, P. Nonn, H. Schlarb, DESY, Hamburg, Germany

Abstract

In the frame of the NICA (Nuclotron-based Ion Collider fAcility) ion collider upgrade a new light ion LINAC for protons and ions will be built in collaboration between JINR and BEVATECH GmbH. While ions with a mass-to-charge ratio up to 3 will be fed into the NUCLOTRON ring with an energy of 7 MeV/u, protons are supposed to be accelerated up to an energy of 13 MeV using a third IH structure. This energy upgrade comprises a third IH structure, a dual-use Debuncher cavity as well as an extension of the LLRF control system built on MicroTCA technology.

INTRODUCTION

In the frame of the NICA ion collider project [1] a new light ion frontend Linac (LILac) for polarised particles, protons and ions with a mass-to-charge ratio 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 for protons only
3. a superconducting section from 13 MeV/u up to a final energy to be determined

As Part 1 is under progress [2], work on Part 2 has already started and will be described in this paper.

The above described LINAC will be located in LU20 hall at JINR. The changed setup of the cavities compared to [2] is shown in Fig. 1.

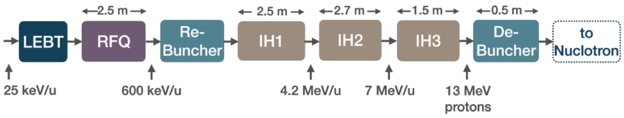

Figure 1: Scheme of the LILac cavities.

The upgraded Linac consists of 6 cavities, an RFQ followed by a Rebuncher, 3 IH-DTL structures and a Debuncher as shown in Fig. 1. It is operating at 162.5 MHz with a repetition rate of 5 Hz and a duty cycle of 0.1 %. The main parameters of the LILac are summarised in Table 1. The length of the Linac containing the cavities, the beam diagnostic devices and focusing magnets, yet excluding the Debuncher will be realised within a length of about 12 m. A scheme of the LILac cavities is shown in Fig. 1.

Table 1: LILac Main Parameters

Parameter	**Protons**	**C^{4+}**
Mass-to-charge ratio	1	3
Injection energy	25 keV	300 keV
Exit energy	7/13 MeV	84 MeV
Beam current	5 mA	10 mA
Repetition rate limit	≤5 Hz	
Current pulse duration	30 µs	
RF pulse length	200 µs	
RF frequency	162.5 MHz	
Transmission	≥80 %	

An initially planned use of two Debuncher has been revised and lead to the development of a two-in-one Debuncher solution. This Debuncher can serve ions at 7 MeV as well protons at 13 MeV without sacrificing efficiency. Additionally, it reduces costs and complexity for this Linac by adding only one additional water cooling circuit and one RF system. The LLRF system based on MicroTCA standard offers great flexibility for this energy upgrade. The modular system makes it possible to expand the system with one card set consisting of an analog and a digital card.

IH3

Beam Dynamics

It was intended to fit the post accelerator cavities for protons into the linac in such a way, that the beam transport of the 7 MeV/u beam was properly solved as well as the proton post acceleration up to 13 MeV - by the same two quadrupole triplets in front and behind this cavity. This led to a very compact cavity with only 11 gaps. The effective voltage gain of 5 MV/m is a safe value for IH-type structures. The beam diagnostics (4-knob-probe and current transformer) are well matched to the cavity end flanges.

RF Design

IH3 of the LILac has the purpose to serve as an energy upgrade for proton beam operation up to 13 MeV. The cavity consists of eleven gaps and due to the rather high energy for an IH, which leads to large cell lengths, it was decided

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* benjamin.koubek@bevatech.com

to reduce the end gap lengths and additionally implement "pockets" at the inner part of the IH entry and exit (see Fig. 2). Thus, the total length can be kept to a reasonable measure. Furthermore, the width of the middle frame is increased compared to IH1 and IH2 in order to reduce the otherwise increased height of the upper and lower tank lids. The tuning of the cavity is performed by a centred plunger with a trapezoid body attached to it. Hereby the frequency can be adjusted by 300 kHz while moving the tuner by 20 mm.

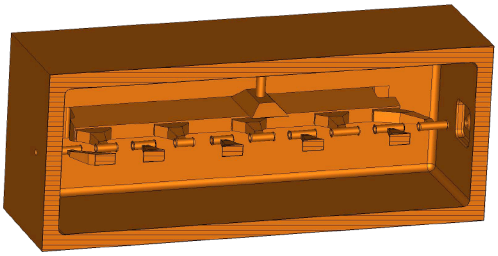

Figure 2: Cross sectional view of the IH3 RF-model.

Intertank Section

After the IH3 an intertank section (ITS3) comprising a phase probe, a quadrupole triplet and an ACCT (AC current transformer) will be built, followed by a Debuncher after a drift of about 3 m.

Magnets For transverse focusing of the beam, compact quadrupole magnets are used to ensure a smooth beam envelope. In total, the beamline will contain two doublets including a steerer and three external triplets in the intertank sections as well as three internal triplet lenses in IH1 and IH2. Each singlet is optimised longitudinally, minimising the total length of the triplets and will be operated with a maximum magnetic gradient of up to 65 T/m. A concept is applied which allows to keep the total drift short by use of large diameter flanges and bellows put around the outer singlet cores.

Beam Diagnostics Along the LILac beamline four "in-air" ACCTs will be installed over the vacuum chamber. The ACCTs coming from company Bergoz Instrumentation will measure the intensity of the charged particle beam. The output signal is directly proportional to beam current and guarantees a precise waveform measurement of the macropulses with minimal droop and noise.

The phase probes will be developed by BEVATECH. They are required for a precise tuning of RF phase and amplitude of the RFQ and IH structures. Four phase probes along the beamline are foreseen to achieve the designed performance and high injection efficiency by adjusting longitudinal beam parameters such as a beam energy and bunch length at the entrance of the Nuclotron. Apart from this, the phase probes are used during commissioning and setup of the linac to verify the correct beam energy by a time of flight measurement (TOF) using the signals of two pick-ups in a well-known distance.

DEBUNCHER

Initially, it was planned to use two Debunchers, one for 7 MeV/u ions from IH2 and one for 13 MeV protons from IH3. In order to reduce the number of systems on that Linac a two-in-one Debuncher solution was investigated.

Beam Dynamics

To have one cavity for the 7 MeV/u as well as for the 13 MeV beam leads to the consequence of a two gap cavity. The drift for both beams has to be adequate for an effective de-bunching. Fig. 1 shows the array of the cavities. At the Debuncher the 7 MeV/u as well as the 13 MeV beam have a phase width of below 80°, see Fig. 3. That is adequate to reach the specified energy widths for synchrotron injection.

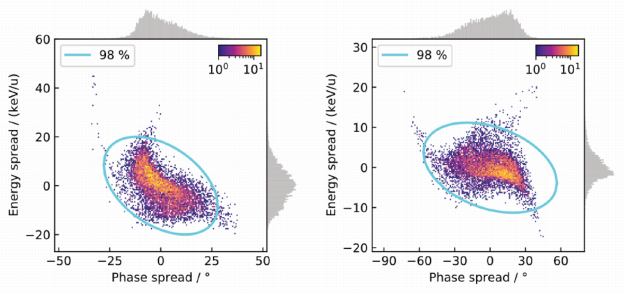

Figure 3: Simulated longitudinal particle distribution of the 13 MeV beam (left) and 7 MeV/u beam (right) behind the LILac Debuncher.

RF Design

The RF design of the 2-gap Debuncher is based on a spiral-shaped stem whose inductance significantly reduces the inner radius of the cavity. In order to improve field deflection inside the drift tube the period length is increased to $3\beta\lambda/2$. Initially, two buncher versions have been investigated. As one solution two 4-gap Debunchers could be used, one for 7 MeV/u $A/q = 3$ particles and one for 13 MeV protons. The other approach was a dual-use Debuncher with two gaps could be used. It was decided to go with the dual-use Debuncher for this project because it offers a compact solution that also reduces the number of systems in the accelerator chain at the cost of a higher power consumption. The cavity consists of a cylindrical tank with two lids made of copper plated stainless steel.

The inner drift tube is mounted at the spiral arm while the outer drift tubes are fixed at the lids.

Due to the low duty cycle a power coupler in air is used. A ceramic cup separates the coupler from vacuum, which reduces costs and complexity of the power coupler. The ceramic cup is positioned as close as possible to the spiral arm mounting in order to achieve a high magnetic field. To control the frequency during operation a dynamic piston tuner is mounted opposite of the spiral-arm flange, allowing a frequency adjustment of about ±150 kHz.

LLRF

Overview

The Low Level Radio Frequency (LLRF) system is based on MicroTCA.4 standard. It is designed to provide amplitude and phase stabilities for the accelerating cavities of $\leq 0.2\,\%$ and $\leq 0.1^\circ$ respectively. Apart from this it integrates a tuner server to ensure the frequency stability of the cavity by controlling the motor piston tuners. The output power of the solid state high power amplifier as well as the field level inside the cavities is measured by RF signals from a directional coupler and the pickup antennas of the cavities. 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. The configuration of the LLRF system is shown in Fig. 4.

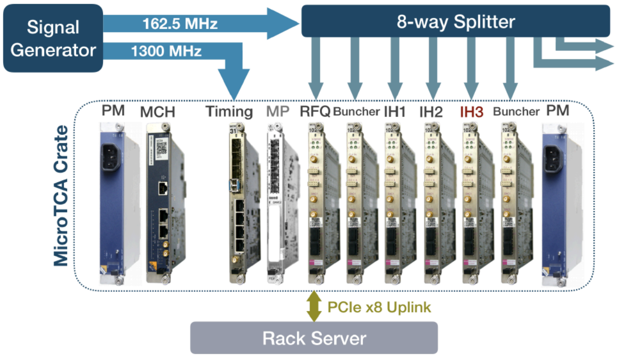

Figure 4: Layout of the LLRF system: RF master oscillator, LLRF controller channels, CPU processing unit and extended with the additional IH3 card.

Each LLRF regulation consists of an Advanced Mezzanine Card - Rear Transition Module (AMC-RTM) pair, shown in Fig. 5. The RTM is an analogue RF pre-processing 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 control system can be integrated into a higher level timing system or interlock system.

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.

Extension for IH3

The MicroTCA crate offers twelve available card slots for the X2TIMER and the 5 AMC-RTM card pairs to control the five cavities.

This means the remaining slots can be used for additional cavities or perspectively for data acquisition for diagnostics as example. For the upgrade of one cavity, the IH3, one card set consisting of an RTM and an AMC digitiser card can simply be added. Limitations are basically given by the number of available slots and the power consumption of the cards by means of the provided power supply.

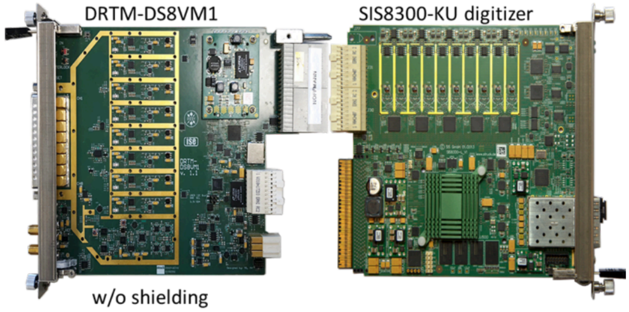

Figure 5: RTM-AMC pair for the regulation of a single cavity. Left: the RF pre-processing module (RTM). Right: the AMC digitiser.

OUTLOOK

The beam dynamics design as well as the rf design of the cavities has been finished. At present the manufacturing of the cavities is in progress. The LLRF system is under development and testing. For the upgrade of IH3 the additional cards have to be added to the modular system and adjustments for the server software have to be applied.

REFERENCES

[1] A. V. Butenko *et al.*, “Development of NICA Injection Complex”, in *Proc. 5th Int. Particle Accelerator Conf. (IPAC’14)*, Dresden, Germany, Jun. 2014, pp. 2103–2105. doi:10.18429/JACoW-IPAC2014-WEPRO067

[2] B. Koubek *et al.*, “The New Light Ion Injector for NICA”, in *Proc. 29th Linear Accelerator Conf. (LINAC’18)*, Beijing, China, Sep. 2018, pp. 362–365. doi:10.18429/JACoW-LINAC2018-TUPO017