UNILAC Upgrade Activities

L. Groening[1], *X. Du*[1], *P. Gerhard*[1], *M. Heilmann*[1], *M.S. Kaiser*[1], *S. Mickat*[1], *A. Rubin*[1], *A. Seibel*[1], *P. Scharrer*[1], *H. Vormann*[1], *C. Xiao*[1],

[1]GSI, Darmstadt, Germany

The motivation of the upgrade project for the more than 40 year old UNILAC is twofold. First, as stated by a dedicated report on the status of availability and reliability of the existing post-stripper drift tube linac (ps-DTL), this section is not expected to cover the life time of FAIR [1]. Second, the layout of the whole UNILAC, even if fully refurbished, cannot meet the requirements imposed by FAIR [2]. In response to this, several upgrade activities where defined. They are listed in Tab.1 together with their current status.

Table 1: UNILAC Upgrade Activities.

Activity	Status	Duration [mos]
CompactLEBT	not approved	44
RFQ-matching	80% finished	12
RFQ electrodes	20% finished	27
MEBT	not approved	44
H2-Stripper	10% finished	36
new ps-DTL FoS	5% finished	39
new ps-DTL	not approved	96
UHV controls	15% finished	36
p-DTH HF FoS	90% finished	48
ps-DTL HF	not approved	48

The CompactLEBT comprises a dedicated uranium source terminal and beam line that does not use any bending magnet thus avoiding higher order field components and dispersion. It shall be installed between the existing northern and southern source terminals. Its design is finished but the project is not yet approved.

Final beam matching into the Radio Frequency Quadrupole (RFQ) is accomplished by a quadrupole quartet. The latter has been replaced by a new device including its power converters. The installation has been finished and commissioning without beam has been completed [3]. Commissioning with beam will be within the re-start of operation in 2018.

For the subsequent HSI-RFQ a new beam dynamics layout has been worked out, which in connection with the new matching allows for more beam intensity [4]. The electrodes will be fabricated in-house in order to install them in 2019.

The section between the RFQ and the subsequent pre-stripper DTL does not allow for optimized beam transport into the DTL. A new layout offering the required operational flexibility has been designed and components are ready for procurement. However, the activity has not been approved yet.

A systematic campaign on investigating stripper media and technologies to enhance the stripping efficiency of ions behind the pre-stripper DTL was conducted in the years 2013-2016 [5]. To transfer this successful prototyping into regular operation a dedicated test stand has been constructed and commissioned [6]. The layout of the new gas supply, vacuum-, and ventilation system has been started.

The aged post-stripper DTL causes an increasing amount of down time and its design does not allow for reaching the FAIR requirements. The conceptual design of a new Alvarez-type DTL has been elaborated, evaluated by an external committee [7], and summarized into a CDR [8,9,10]. The design and construction of a first-of-series (FoS) cavity section has been started and the order for the production of its cavity mantle has been placed. Significant progress has been made in the design of the drift tubes including pulsed quadrupoles [11]. With the exception of the FoS construction, the post-stripper DTL replacement has not been approved yet.

Last year the adaption of the control system of the UNILAC UHV control system to FAIR standards has been launched. Electronic components procurement and re-cabling inside the tunnel started.

The post-stripper DTL rf-power alimentation is based on technology of the 1970s. Its upgrade has been planned and a new FoS unit was commissioned successfully on-site [12]. Except for this FoS unit the upgrade of the full system has not been approved so far.

Figure 1 summarizes the horizontal beam brilliance (current per emittance) achieved most recently, together with the FAIR requirement. Results from fully consistent front-to-end simulations based on measured beam properties at the source exit are plotted for comparison. These simulations assume that all upgrade activities were implemented.

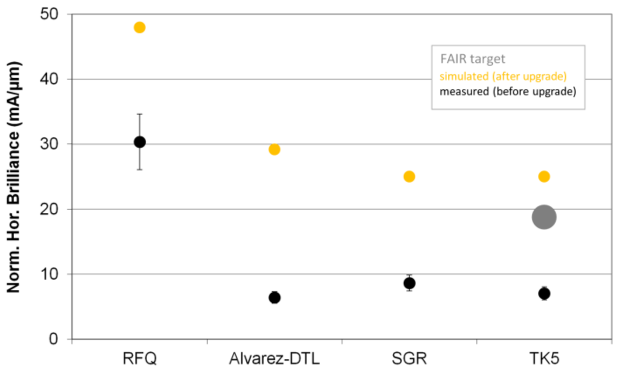

Figure 1: Horizontal beam brilliance along the UNILAC as measured in 2016 and as simulated under the assumption that all upgrade activities were accomplished.

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Experiment beamline: UNILAC-Other
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none
Grants:
Strategic university co-operation with: Frankfurt-M

UNILAC status report

P. Gerhard[1]

[1]GSI, Darmstadt, Germany

This status report overviews maintenance and refurbishment activities, upgrade measures and the preparation for the beam time 2018 at the UNILAC. Due to the general shutdown there was no beam operation in 2017.

Shutdown activities

The preparation of the GSI facility for FAIR (GaF), especially the preliminary works for the connection of the proton linac (pLinac) to the transfer channel (TK) and the construction of the pLinac building, had a major impact on the UNILAC. The TK beamline had to be completely covered with rugged plastic foils for several months to protect it from dirt and water running through the ceiling. Due to the earthmoving outside the TK building, certain sections of the building moved. Three bellows along the beamline were damaged. Alignment of the TK beamline will be necessary before the beam time 2018 starts.

Both large rotary pumps of the gas stripper pumping station suffered from degeneration of the oil and subsequent wear out. They had to undergo a general overhaul by the manufacturer. It has to be investigated if this was caused by overheating and/or extensive operation with hydrogen as stripper gas in the beam time 2016.

In July approx. 400 l of water were found in the TK foil stripper and charge state separator section TK3. A small leak in a water cooled baffle in the chamber of the first dipole TK3MV1 was identified as the cause. This leak had presumably opened some months earlier, but was not discovered, because the vacuum control system of this section was out of order. The dipole chamber was exchanged with a spare. Many beam diagnostic devices were polluted by foil residues and had to be refurbished or exchanged. The foil ladder and its drive have to be refurbished as well. This work was not finished in 2017.

The exchange of the HSI IH drift tube, with the defective quadrupole magnet triplet UH3QT5 inside, was already started in July 2016 [1]. The installation of the spare drift tube was delayed because a necessary shim was damaged during its copper plating. A new shim was ordered in February and ready for installation after copper plating in July. The installation was finished in November, but re-establishing of the vacuum is delayed to 2018 due to the damage of the stripper pumping station.

A new RF coupling loop was assembled and mounted on the 108 MHz buncher TK4BB11. This was the last action of refurbishment after a water leak of the coupling occurred in 2016 [1]. The commissioning will take place in 2018.

As a consequence of the severe breakdown of a kicker magnet power converter during the last beam time [1], a strategic refurbishment programme was developed by the EPS department. Several magnet power converters were already refurbished by exchanging aged capacitors and thyristor modules, ventilators and hoses. It was found, that capacitors are prone to aging during long shutdowns. This will be mitigated by powering all converters regularly. Additionally, direct current link voltage circuits were improved.

The cooling circuits of the single gap resonators UE1BE2 and UE1BE4 had to be rinsed. The foil stripper for the material science branch UM was revised, and SEM grids, beam current transformers and other beam diagnostic devices were checked. The data supply for the HSI magnets was adapted to allow for individual limits for low rigidity operation.

Beam time preparation

The modernisation of the UNILAC vacuum control system was delayed to 2019 due to difficult resource allocation; therefore the existing system had to be refurbished, including maintenance of the vacuum system. Defective devices (gate valves, IG and turbo pumps) were exchanged and vacuum leaks in the Alvarez cavities A2A (RF probe) and A3 (stop valve) were resolved. The pressure gauge of the gas stripper jet was fixed as well.

The UNILAC accelerator control system will remain unchanged for the time being, while all other accelerators will be controlled via the new LSA based FAIR control system from now on, including the timing system. Therefore, the synchronization between UNILAC and SIS has to be re-established. This will be tested during the dry runs.

Alignment of several sections was carried out due to the installation of new equipment (HSI LEBT) or maintenance activities (gas stripper section and HLI MEBT).

Upgrade measures

The main upgrade measure during this shutdown at the UNILAC was the installation of the new quadrupole quartet UH1QQ1 in the HSI LEBT, which started in March 2017 [2]. It required partial dismounting of the radiation shielding wall between the UNILAC tunnel and the ion source area, thereby interfering with RF tests. The installation of the magnets took much more effort than expected, mostly due to the 64 water cooled power lines, which had to be mounted properly. During commissioning of the new power converters in November, perturbing eddy currents induced in the beam pipe were discovered. Remedy has to be provided before the beam time 2018.

The upgrade of the RF gallery was continued [3] until the renewal of the air conditioning started in September. The main activities are the new high power amplifier for the Alvarez A4 transmitter and the modernisation of the Alvarez A3 transmitter and several power converters. During construction of the new ventilation building, rain water entered into the UNILAC tunnel through the roof.

The development for the replacement of the post-stripper DTL was continued, the procurement of a First-of-Series cavity section has been started [4, 5]. Testing of the new pulsed gas stripper using new low pressure gas valves was continued at a test bench [6]. As a first major

DOI:10.15120/GR-2018-1

part of the new vacuum control system, about 35 km of new cables were laid along the UNILAC and the TK. All upgrade measures are summarised in [7].

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[5] M. Heilmann, "Prototyping for the new post-stripper DTL", this report
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Experiment beamline: UNILAC-Other
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none
Grants: none
Strategic university co-operation with: Frankfurt-M

Installation of the new HSI-LEBT Quadruplet

H. Vormann, P. Gerhard, L. Groening, M. Maier, S. Mickat, C. Xiao

GSI, Darmstadt, Germany

To improve the conditions for beam operation at the High Current Injector HSI a new quadrupole quartet with larger aperture has been installed. It will increase the degree of freedom for tuning of the LEBT matching, including both existing ion source branches and the proposed third branch [1, 2].

Quadrupole Quartet Design

The quadrupole quartet (QQ) is located at the end of the HSI-LEBT (where the two ion source branches are merged), right in front of the chopper followed by the RFQ (Fig. 1).

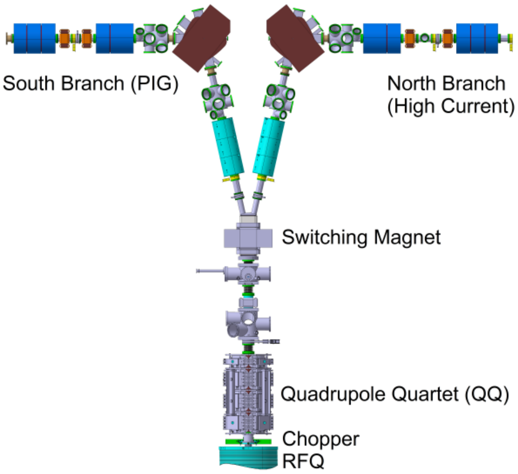

Figure 1: Sketch of the HSI-LEBT.

Based on operation experiences, the new QQ was designed with a large aperture (new: 150 mm; old: 100 mm), and optimised lengths of the single quadrupoles. The larger aperture requires high pole tip flux density (new: 0.92 T; old: 0.70 T), achieved through higher coil currents (new: 1100 A; old: 400 A), provided by high performance power supplies for pulsed operation (50 Hz, i.e. 20 ms cycles, incl. max. 15 ms ramping time and 5 ms flat top).

Power Supplies

The four new power supplies SVE25m were procured in 2015 and delivered in September 2017 (Fig. 2). They provide for a voltage of 1200 V, to ramp up to 1100 A nominal coil current within less than 15 ms.

Assembly

The procurement for the new QQ started in 2010, it was delivered to GSI in 2012 and field mapped in 2013. At that time installation did not yet start because power supplies were not available, and could not be procured soon, due to the work load for FAIR. Assembly of the QQ started in March 2017: after disassembly of the LEBT the old QQ was removed from its place in the concrete shielding wall. The new connection boxes were produced in house and installed until end of April. The new QQ was installed and provisionally aligned by the end of May. Most time consuming was the bending and brazing of the 64 coil supply tubes (copper 9x9 mm, length up to 5 m), with additional fixations. Modifications of the door lock system, the radiation protection switchboard, the cooling water supply circuits, the venting system of the ion source north terminal, and the electric mains supply were performed for the QQ assembly, as well as the installation of a new electricity sub-distribution. The LEBT beam diagnostics and steerer magnets were re-assembled with shorter distances, using space-saving vacuum tubes with integrated bellows. At the end of 2017 the assembly was almost finished (except alignment and re-cabling of peripheral devices, Fig. 3). Commissioning and SAT of the power supplies have been performed successfully in December. The tests revealed increased eddy currents on the chamber surface. Impact and counter measures are under investigation. However, the beam time 2018 can be served as foreseen.

Figure 2: Power supplies (each 2.8 m x 0.8 m x 2m) installed in the basement.

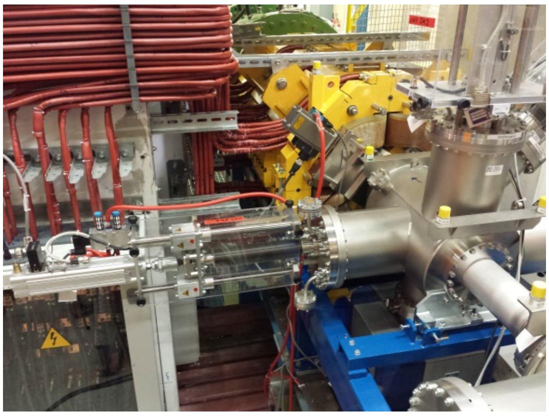

Figure 3: New QQ (yellow) installed, insulated coil supply tubes, connection boxes, beam diagnostic chambers.

References

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Experiment beamline: none
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none
Grants: none
Strategic university co-operation with: none

Site acceptance tests of the new 108 MHz, 1.8 MW power amplifier prototype and status of the RF system modernisation at the UNILAC

B. Schlitt, M. Hörr, G. Schreiber, J. Catta, T. Eiben, G. Eichler, S. Hermann, F. Lorenz, S. Petit, M. Pilz, J. Salvatore, R. Scholz, A. Windolf, and J. Zappai

GSI, Darmstadt, Germany

A substantial modernisation of the 108 MHz RF systems at the Alvarez post-stripper linac at the UNILAC is in progress to prepare the existing facility for the future FAIR operation [1, 2].

New 1.8 MW cavity amplifier prototype

The new 1.8 MW cavity amplifier prototype delivered by Thales Electron Devices [1–3] was commissioned successfully at GSI in 2017. The existing 1 MVA, 24 kV anode power supply of the Alvarez tank 4 (A4) RF system is used to provide the required DC power. Commercial grid power supplies are installed in a separate control rack which comprises also a fast measurement and interlock unit as well as further control elements (Fig. 1). A manual control unit developed by GSI was used for commissioning and tests. A new PLC system is currently being installed for routine operation and to allow remote control by the accelerator control system [1]. The input RF power is provided by the existing A4 driver amplifier. An existing huge coaxial transmission line switch in the output RF line is used to switch between a water dummy load and Alvarez tank 4.

Figure 1: New 1.8 MW cavity amplifier prototype during site acceptance tests at the UNILAC RF gallery plus control rack equipped with grid power supplies and control elements.

During site acceptance tests (SAT) of the new amplifier at GSI in July and August 2017 an RF pulse output power ≥ 1.8 MW and a gain factor of about 12.8 dB were reached successfully at the specified pulse length of 2 ms and a pulse repetition rate of 10 pps (Fig. 2). Tests were conducted on water dummy load as well as on Alvarez tank 4 (closed-loop operation controlling RF amplitude and phase in the accelerating cavity). The levels of harmonic and non-harmonic frequencies were well below the specified limits (< –24 dBc and < –60 dBc, respectively). Further tests were performed at a certain cavity mismatch and at intermediate pulse power levels with different pulse schemes, as well as a 2 hour test run without any trips of the amplifier. Routine operation of the new amplifier is planned on A4 tank from beam time 2018 on.

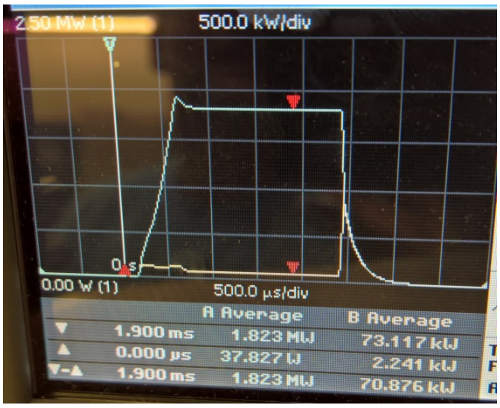

Figure 2: Forward (upper trace) and reflected RF power during closed-loop operation on Alvarez tank 4.

Modernisation of existing RF systems

The newly developed PLC system for control of the high power amplifiers [1] was installed and tested at the Alvarez 3 RF system in 2017. After successful operation of this prototype during beam time 2018 similar PLC systems will be installed at Alvarez 1 and 2. In parallel, new PLC systems to control the 1 MVA power supplies [4] were installed and tested at A1 – A3.

A new versatile microcontroller based system for resonance frequency control of the accelerating structures [4] was operated successfully at the HLI RFQ during beam time 2016. It was developed further and tested at the Alvarez tanks in 2017 and will be applied during routine operation at the Alvarez linac in 2018. Besides, first RF tests of a new digital low-level RF system (LLRF) for amplitude and phase control based on the MicroTCA.4 standard [5, 2] were conducted successfully at a laboratory test setup [6].

In parallel to the modernisation of the RF systems, a new forced-air cooling system providing air cooling for > 60 devices at the UNILAC RF gallery was installed and commissioned by external companies and by the GSI Plant & Facility Engineering department.

References

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DOI:10.15120/GR-2018-1

Experiment beamline: none
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none
Grants:
Strategic university co-operation with: none

DOI:10.15120/GR-2018-1

Status of the new post-stripper DTL

S. Mickat, L. Groening

GSI, Darmstadt, Germany

In February 2017 the GSI/FAIR directorate decided that for the new post-stripper DTL the Alvarez option will be followed exclusively. The decision towards a new Alvarez type DTL against three competitive DTL concepts was made mainly for its robust beam dynamics concept. The applied periodic particle beam dynamics provides best beam qualities for FAIR along the DTL even in case of beam fluctuations, alignment tolerances, and multi-beam operation [1].

The beam dynamics advanced in interaction with optimisations of the RF cavity design [2, 3]. A detailed error study has been worked out. The UNILAC was modelled for front-to-end simulations - from the sources to the SIS18 entrance - taking the new post-stripper DTL design and the planned UNILAC upgrade measures into account. The results confirm former predictions, that the new post-stripper DTL together with the UNILAC upgrades [4] meets the FAIR requirements.

An important milestone towards the realisation of the new post-stripper DTL was the funding of the first section of the new first Alvarez cavity as a First-of-Series (FoS) in August 2017 [5] (Fig. 1). A budget of 1.5 MEUR until 2020 was allocated for the cavity, technical subsystems and infrastructure measures. For instance, a cavity test stand for high power RF tests will be installed, which needs common media supplies for cooling water, air-pressure, electrical connections, an adequate x-ray shielding, and an RF-power supply itself. An existing 200 kW RF-amplifier can be used initially. For finalising the tests at nominal RF-power the regular amplifier of the existing Alvarez IV cavity can be used temporarily in accordance with the UNILAC beam time schedule. Negotiations on an adequate location for the test stand at the UNILAC experimental hall are ongoing.

Regarding the procurement of the FoS three main components are distinguished: the tank shell, the two end-plates, and the eleven drift tubes with integrated quadrupoles. The order for the tank section was placed in November 2017. Currently the specification of the two cooled end plates is in progress. Adaptions of the drift tube design in favour of RF-efficiency and beam dynamics were applied implying changes to the integrated quadrupole design and to the established fabrication sequence of the existing AIII and AIV drift tubes. Currently a modified fabrication and assembly sequence is tested at the on-site workshop.

These and further aspects in detail as well as the current planning towards a new post-stripper DTL are presented in a CDR, which has been published in December 2017 [6].

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Experiment beamline: none
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none
Grants: none
Strategic university co-operation with: none

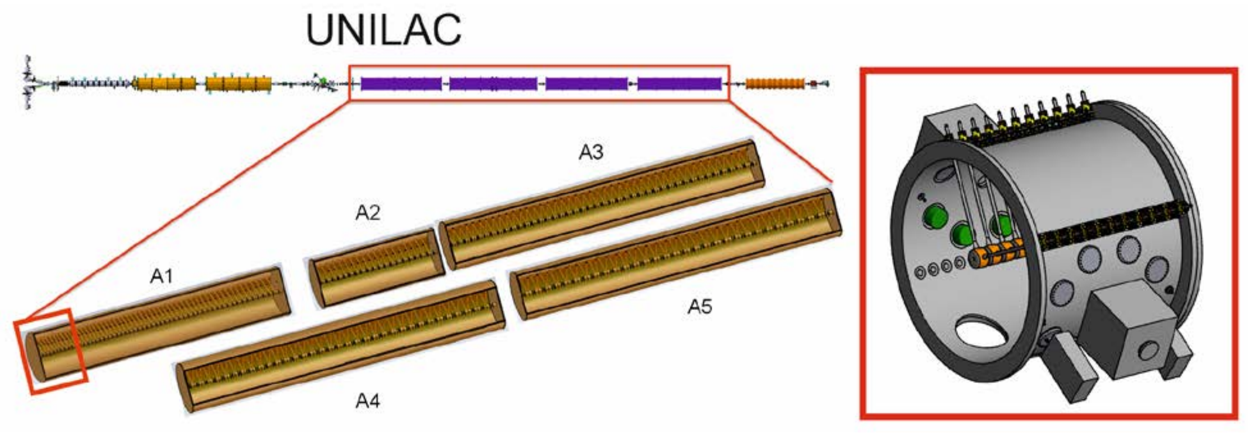

Figure 1: The new DTL design consists of five cavities (A1-A5like the existing post-stripper DTL. The first section of cavity A1 is the First-of-Series (FoS): a nearly two meters long tank section containing 11 drift tubes (right).

Cavity design activities for the UNILAC

X. Du[1], *P. Gerhard*[1], *L. Groening*[1], *and S. Mickat*[1]

[1]GSI, Darmstadt, Germany

Post-stripper DTL

The design of a completely new post-stripper DTL is part of the UNILAC upgrade program for FAIR[1]. Acceleration from 1.4 MeV/u to 11.4 MeV/u is achieved by five tanks. The new design features a homogenous surface field at the drift tube surfaces thus improving the shunt-impedance. Additionally, a new RF-field stabilization method has been developed and experimentally confirmed [2].

In 2017 the beta profile design of the DTL has been updated and improved w.r.t. further reduction of the betatron amplitude and hence the longitudinal beam quality. The results were used for the design of the transverse beam dynamics [3]. The beta profile design process has been improved by an advanced tuning algorithm for the cell lengths and by optimization of the synchronous particle energy gains per cell. The inadequate beam dynamics description caused by the generally uniform particle speed approximation was considerably updated.

According to recent simulations and measurements the design input energy was lowered from 1.393 MeV/u to 1.358 MeV/u [4]. The actual beta profile design includes this change.

Re-bunchers

The existing re-bunchers US4BB3 and US4BB4 in front of the post-stripper DTL shall provide for accurate longitudinal beam matching. For their crucial relevance of operation spare cavities need to be made available.

The RF design of the re-bunchers starts with geometric parameters adapted from existing cavities BB3. In order to match the existing pillow, the new designs use the existing outer tank radii. Table 1 lists the geometric parameters of the two re-bunchers.

Table 1: Geometric parameters of the new re-bunchers US4BB3 and US4BB4.

Parameter	BB3	BB4
Cell number	3	2
Tank inner radius	250 mm	175 mm
Tank inner length	520 mm	201 mm
Tube inner radius	27.5 mm	20 mm
Tube outer radius	32.5 mm	25 mm
Gap length	26.4 mm	16.14 mm

The spiral stems were re-designed for sufficient mechanical stability and shunt impedance. US4BB3 has two stems fixing one drift tube each. Their winded total lengths are 2.5 m thus causing the inductivity to provide for low resonant frequency using a small tank radius. These lengths together with their appropriate widths feature sufficient rigidity to prevent detuning from Lorentz forces.

In fact, the existing re-buncher US4BB3 has mechanical stability issues and the stems were reinforced by 40 mm. For the new layout, the estimated Lorentz force on the drift tube and stems is about 1.2 N, which shall be confirmed by simulations using mechanics solver [5].

Simulations with CST-MWS were performed to determine free geometric parameters to be used for further optimization of the RF-parameters. Table 2 presents the achieved RF-parameters.

Table 2: RF-parameters of re-buncher US4BB3 and US4BB4 from CST-MWS simulations.

Rf-parameters	US4BB3	US4BB4
Frequency	36.136 MHz	108.408 MHz
Total gap voltage	875 kV	350 kV
Total power loss	74 kW	13 kW
Shunt impedance	12 MOhm/m	9 MOhm/m
E_peak	49 MV/m, 6 Kilp.	22 MV/m, 2 Kilp.
Tuning range	0.5 MHz	2 MHz

Mechanical error studies on US4BB3 investigated frequency shifts due to alignment errors and fabrication imperfections. The most sensitive part in the whole cavity is the volume between the drift tubes, where the electric energy density and the surface gradients are at maximum. Simulations show that the frequency shift induced by transverse (longitudinal) drift tube shifts is 0.0175MHz/mm (0.045MHz/mm). For the drift tube thickness it is 0.11 MHz/mm. Considering the anticipated machining precision, the tuning range is much larger w.r.t. to these frequency shifts. The orders for the production of both re-bunchers have been placed, delivery is expected end of 2018.

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Experiment beamline: UNILAC-Other
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none

DOI:10.15120/GR-2018-1

First measurements of the short CH-Cavities for the cw heavy Ion LINAC@GSI

M. Basten[1], *K. Aulenbache4*[3], *W. Barth*[2,3], *M. Busch*[1], *F. Dziuba*[2], *V. Gettmann*[2], *M. Heilmann*[3], *T. Kürzeder*[2], *M. Miski-Oglu*[2], *H. Podlech*[1], *A. Rubin*[3], *M. Schwarz*[1], *S. Yaramyshev*[3]

[1]Goethe-Universität, Frankfurt, Germany, [2]HIM, Mainz, Germany; [3]GSI, Darmstadt, Germany; [4]Johannes Gutenberg-Universität, Mainz, Germany

The upcoming FAIR project (Facility for Antiproton and Ion Research) at GSI will use the existing UNILAC (UNIversal Linear Accelerator) as an injector to provide high intensity heavy ion beams at low repetition rates. As a consequence a new superconducting (sc) continous wave (cw) high intensity heavy ion Linac is required to provide ion beams above the coulomb barrier to keep the Super Heavy Element (SHE) physics program at GSI competitive on an international level [1]. The cw Linac design comprises a high performance ion source (ECR), the High Charge State Injector (HLI) upgraded for cw-operation, and a matching line (1.4 MeV/u) followed by a sc Drift Tube Linac (DTL). Presently two sc eight gap CH-cavities are under construction at Research Instruments (RI). Several intermediate RF measurements have been performed during the construction phase.

Pressure sensitivity measurements

The design of the cavity is based on eight equidistant gaps without girders and with stiffening brackets at the front and end cap to reduce pressure sensitivity. To verify the simulated pressure sensitivity with the simulations, the deformation of the cavity as well as the frequency change (Fig. 1) have been measured.

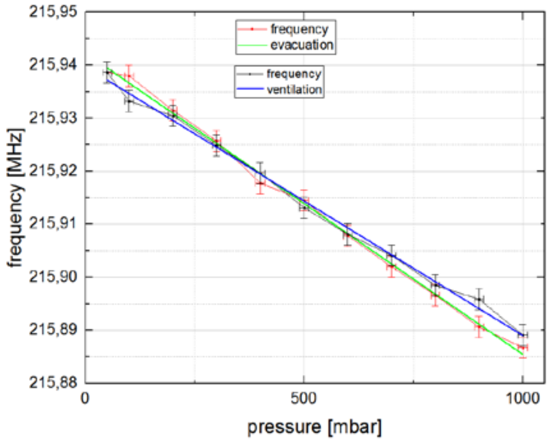

Figure 1: Measured pressure sensitivity during evacuation and ventilation of the cavity

Taking the change in ε_r into account we measured a pressure sensitivity of approx. $\Delta f = (-6.74 \pm 1)$ Hz/mbar during evacuation and approx. $\Delta f = (-12.87 \pm 1.1)$ Hz/mbar during ventilation. The simulated pressure sensitivity was approx. $\Delta f = +4.61$ Hz/mbar. In contrast to the simulation the frequency goes down during the evacuation process. This means we have more deformation in regions with high electric fields that in regions with high magnetic fields. The measured deformation however was lower than simulated. We measured the deformation on three different spots with fine dial indicators and all of them showed less deformation than expected from the simulations with CST. Nevertheless the pressure sensitivity is significantly lower compared to the first CH-structure of the demonstrator. As a consequence stable operation at the resonance frequency can be confirmed.

Frequency measurements during thermal shrinking

The frequency change induced by thermal shrinking of the cavity has been compared with CST simulations. The cavity was positioned in a metal tub and cooled with liquid nitrogen. 6 temperature sensors were placed along the cavity to evaluate the average temperature of the cavity. The frequency change depending on the average temperature (Fig. 2) have been evaluated.

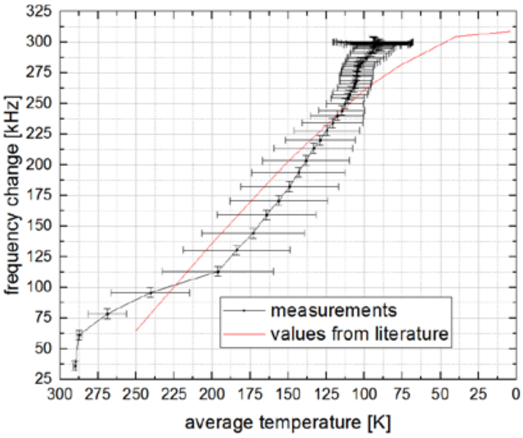

Figure 2: Measured frequency change depending on the average temperature of the cavity

The measured frequency change at an average temperature of 95 K was approx. 14% more than expected by deformation values from literature. It seems that the gradient in the average temperature along the cavity is mainly responsible for this discrepancy. We covered roughly half of the cavity with liquid helium while the top of the cavity became more than 20 K warmer than the bottom of the cavity. To provide high acceleration gradients a well prepared surface is indispensable. The BCP-treatment etches several µm from the inner surface of the cavity. As a consequence the frequency increases. Taking all influences on the resonance frequency into account, we can now perform the final BCP to reach the design frequency of 216.816 MHz. BCP is scheduled for February 2018, the first cavity will be delivered in March 2018, the delivery of the second cavity may follow approx. 2 months later.

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Prototyping for the new post-stripper DTL

M. Heilmann, X. Du, L. Groening, M. Kaiser, S. Mickat, C. Mühle, V. Srinivasan’*

[1]GSI, Darmstadt, Germany

The final design describes the First-of-Series (FoS) Alvarez-Cavity-section of the first tank being part of the new post-stripper DTL of the UNILAC [1]. The FAIR experiments have new requirements to the linac and a high availability is important for the new main operational injector [2]. In the first step the FoS-cavity (Table 1) has an input energy of 1.36 MeV/u with 11 drift tubes (including quadrupole singlets) in a total length of 1.9 m and a diameter of 2 m with an operation frequency of 108.4 MHz [3,4]. The drift tubes will have a new shape profile at the end plates. The single layered quadrupole singlets inside the drift tubes are pulsed with 10 Hz and will have a maximum field gradient of 51 T/m. The new drift tube design combines the new shape profile with the transverse and longitudinal installation space of the magnet. The FoS Alvarez-cavity will be part of the first section of the new Alvarez DTL. It shall be operated at nominal RF- and magnetic fields prior to procurement of the series. After low level measurements at the test stand the Alvarez-prototype will be conditioned and operated with high RF power.

Mechanical Integration

The tank is under construction at the company VA-TEC. The next tendering for the main components is planned for the two end plates and after that for the drift tubes (including magnets). For RF coupling a well-established coupler-type will be used. The RF-power test stand is planned to be ready at the end of 2018 (Fig. 1).

The drift tube prototype is under technical development together with the GSI-mechanical workshop (MeWe) and the magnetic design is being finalized by the GSI-department "Normal Conducting Magnets" (Fig. 2).

Table 1: Parameters of the Alvarez-Prototype

Parameter	Unit	Value
Frequency	MHz	108.408
A/q		≤8.5
Max. beam current	mA	16.5
Synchronous phase	deg.	-30
RF-pulse length	ms	2
RF pulse repetition rate	Hz	10
Input energy	MeV/u	1.36
Output energy	MeV/u	1.67
Gaps	#	12
Gap length	mm	40.5-44.6
Drift tubes	#	11
Drift tube length	mm	109.9-121.0
Drift tube diameter	mm	180.0
Aperture	mm	30.0
Tank diameter	mm	1952.6
Tank length	mm	1880.5
Q-Factor		82000

The drift tube design was simplified so that all components can be built at GSI and just the magnets must be stocked as spare parts.

The pulsed quadrupole singlet lens design is based on a single layer winding concept. The new Alvarez-DTL (A1-A5) will have seven different groups of quadrupole magnets; each of them has its own aperture, effective length, and gradient.

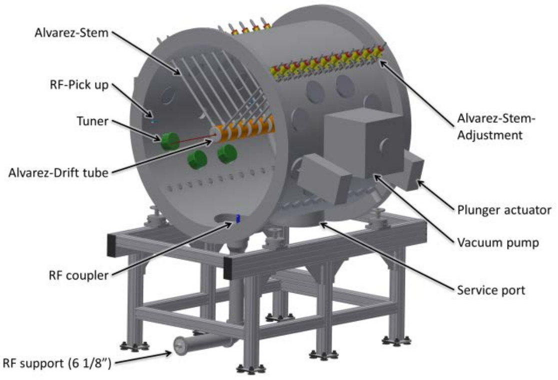

Figure 1: CAD-model of the post-stripper DTL. The FoS-tank has a length of 1.9 m and 11 drift tubes. The adjustment concept will be the same as in the existing Alvarez. The plunger actuator will have a range of 250 mm at the FoS-Alvarez-Cavity-section and the tuners are of 100 mm in length with a diameter of 180 mm.

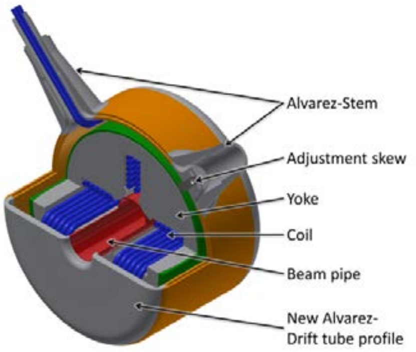

Figure 2: Alvarez-drift tube prototype with the new shape profile and an aperture of 30 mm. Inside of each drift tube is a pulsed quadrupole singlet magnet with a gradient of 51 T/m and an effective length of 99.5 mm.

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[3] X. Du et al. (this report).

[4] A. Rubin et al. (this report).

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* m.heilmann@gsi.de

DOI:10.15120/GR-2018-1

Experiment beamline: none
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none
Grants: none
Strategic university co-operation with: none

DOI:10.15120/GR-2018-1

Brilliance and error study for the new post-stripper DTL

A. Rubin[1]*, X. Du*[1]*, P. Gerhard*[1]*, L. Groening*[1]*, S.Mickat*[1]

[1]GSI, Darmstadt, Germany

The GSI UNILAC has served as injector for all ion species since 40 years. Its 108 MHz Alvarez DTL providing acceleration from 1.4 MeV/u to 11.4 MeV/u. It has suffered from material fatigue and has to be replaced by a new section [1]. The design of the new post-stripper DTL is developed at GSI [2]. The beam dynamics simulations for the new model were done for 238U28+ using the TraceWin code. Five Alvarez tanks with four inter-tank sections provide 100% transmission and low emittance growth (about 5% transverse and 7% longitudinal rms emittance growth for the FAIR case) [3].

Error study for the new Alvarez DTL

Error studies for the new Alvarez DTL were done taking into account machine and beam errors (Tab. 1), which are independent and uniformly distributed within given intervals. All cases revealed 100% transmission.

Table 1: Machine and beam errors:

Quadrupole x,y displacement	± 0.15mm
Quadrupole x,y,z rotation	± 1°
Gap voltage	± 1%
Gap phase	± 1°
Initial energy	± 0.5%
Input emittances	± 15%
Input beam mismatch	± 10%
Input current	± 15%

The average additional rms emittance growth caused by machine and beam errors is about 26%. The detailed investigation shows that the 1st tank is the most sensitive to the errors. The main reason for additional emittance growth is quadrupole rotation around the beam axis (Fig.1). Limiting the quadrupole rotation in tank A1 to ±0.5° while keeping it at ±1° in A2-A5 leads to 13% of mean emittance growth for the whole machine.

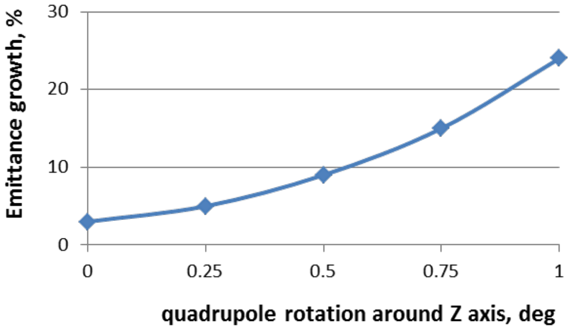

Figure 1: Mean additional emittance growth as a function of the quadrupole rotation around beam axis.

Brilliance analysis at SIS18 input

In order to estimate the beam brilliance behind the DTL a virtual collimator line was constructed. After four quadrupole triplets and four collimators the beam has a well defined total emittance. The horizontal acceptance of the synchrotron SIS18 to be filled by the DTL is 0.8 mm mrad (total, normalized). The collimators width is chosen such that the beam emittance behind the virtual collimator line leaves a margin for additional growth until injection into the SIS18 of 10% or 30%. The transmission through the collimators line allows to estimate the expectes current into the SIS18 acceptance. This investigation was done without machine (DTL) and beam errors as well as with errors. The position of the data on the 3D Pareto front [4] assuming emittance growth along the transport channel is shown in Fig. 2. The current in case of no DTL errors (13.2 mA) corresponds to suitable injection losses below 5%. With DTL errors it drops to 12.2 mA. Reduction of the assumed emittance growth along TK to 10% shifts the corresponding point for the case with DTL errors (13.2 mA again) towards the preferable region.

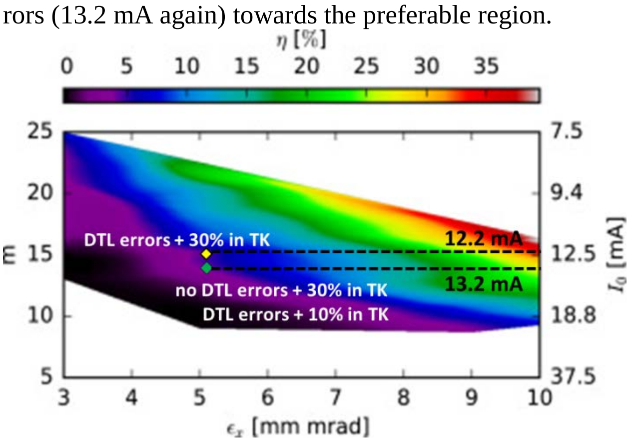

Figure 2: The 3D Pareto front from an optimization of multiplication factor, loss, and emittance with the data achieved behind new DTL assuming emittance growth in the transport channel to SIS18 [4].

References

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Experiment beamline: UNILAC-Other
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: none
Grants: none
Strategic university co-operation with: none

DOI:10.15120/GR-2018-1

First results at the pulsed gas stripper test stand

P. Scharrer[1], M. Maier[1], W. Foosang[2], P. Gerhard[1], K.P. Horn[1], M. Schweda[1],

[1]GSI, Darmstadt, Germany; [2]Faculty of Science, Chiang Mai University Chiang Mai 50200, Thailand.

The pulsed gas stripper for the UNILAC was developed and tested in beam times 2013 to 2016 [1]. An increase of the stripping efficiency into the FAIR design charge state of U^{28+} of up to 65% has been achieved using a H_2 target (instead of a N_2 target). Injector valves, commonly used for liquid fuel in combustion engines, were used for the gas injection (liquid valve).

In recent beam times in 2016, this valve type showed a serious flaw in prolonged operation, resulting in frequently arising interlocks from the pumping system. Therefore, a new valve type, designed to be used with gaseous media, was chosen to allow for using the pulsed H_2 gas stripper for UNILAC standard operation. Before commissioning of the new valve type with beam during the upcoming beam time, an offline test stand was built to characterize the new valves (gas valve) and compare their performance with the previously used liquid valve type.

Valve test stand

One of the most important parameters for the pulsed H_2 gas stripper is the applied target thickness, as it defines the resulting charge state distribution [2]. The optimal back-pressure for U^{28+} operation in previous beam times using liquid valves was 7.5 MPa. The gas valves can only be operated with back-pressures below 1.2 MPa, but have an increased opening aperture. The main question being addressed was, if the required target thickness can be achieved using the new gas valve type.

A simplified design was chosen for the test stand setup. At the UNILAC, the target thickness is usually determined as an effective value using the measured energy loss of the beam [1]. At the test stand, the pressure in the chamber behind the gas valve as well as the gas flow through the valve, are measured to evaluate the valve performance.

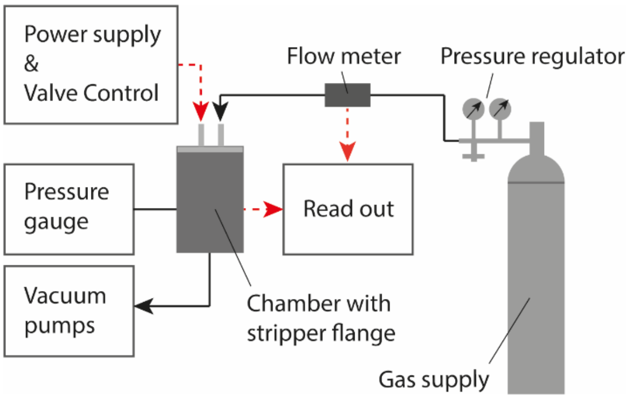

Figure 1: Scheme of the current test stand setup.

The setup of the test stand is shown in Fig. 1. The valves are mounted on the original flange of the pulsed gas stripper [1] on top of the chamber. To mount the smaller gas valves, the valve adapter was redesigned and built in-house. The vacuum chamber is connected to a pumping system, featuring two roots vacuum pumps and a rotary pump. Due to safety reasons, the operation with H_2 gas is not possible at the test stand. Instead, He and N_2 gas are used for test purposes. Additionally, a new valve control system was commissioned, which allows for more flexibility in adjusting the valve parameters and provides better compatibility with the UNILAC control system. The main assembly of the setup and first measurements were done in the framework of the summer student program.

Measurements

In Fig. 2, the measured pressure in the chamber is shown as a function of the back-pressure using He gas for both valve types at 1 ms opening time. Both valves reach similar gas pressures inside the chamber, operating in their respective range of back-pressure. This behavior is confirmed by measurements of the gas flow and suggests that a similar target thickness can be obtained in the UNILAC gas stripper using the new gas valves.

However, the gas flow measurements at varying opening times also show that the conductance of the gas supply system is insufficient to feed the gas valves. This results in unreliable flow measurements at longer opening times, which are important to determine the optimal opening sequence of the valves when synchronizing the gas injection with the beam pulse timing. A new stripper flange with a higher conductance has been designed and is currently manufactured. Together with an improved gas supply system it will be tested in 2018.

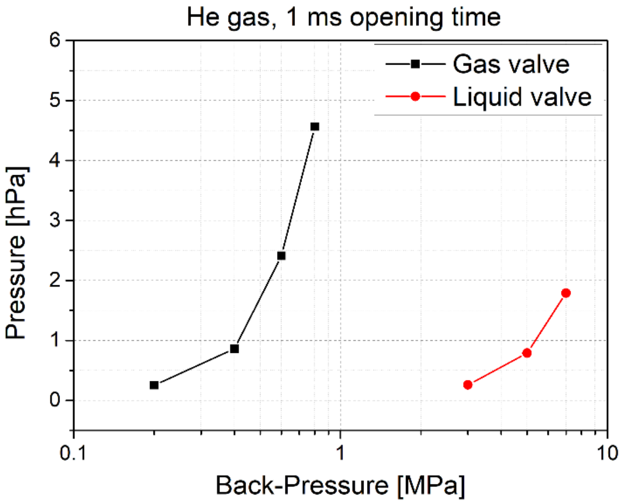

Figure 2: First measurements comparing the pressure inside the chamber with both valve types.

References

[1] P. Scharrer et al., Phys. Rev. Accel. Beams 20 043503 (2017).

[2] H. D. Betz, Rev. Mod. Phys. 44 3, p. 465-539 (1972).

DOI:10.15120/GR-2018-1

Experiment beamline: none
Experiment collaboration: none
Experiment proposal: none
Accelerator infrastructure: UNILAC
PSP codes: 170100312
Grants: none

DOI:10.15120/GR-2018-1

Development of an IH-type linac for the acceleration of high current heavy ion beams

*H. Hähnel**, U. Ratzinger, R. Tiede*

Institut für Angewandte Physik, Goethe Universität, Frankfurt, Germany

An efficient and compact linac design proposal for the UNILAC poststripper based on H-mode cavities and KONUS beam dynamics has been developed at IAP Frankfurt in the last few years [1, 2]. It features five RF-cavities with high shunt impedances of $Z_{eff} = 90 - 152\ M\Omega/m$. In combination with the short period length of $L_p = \beta\lambda/2$, another main benefit of H-mode linacs, the total length of the proposed poststripper linac is 22.8 m.

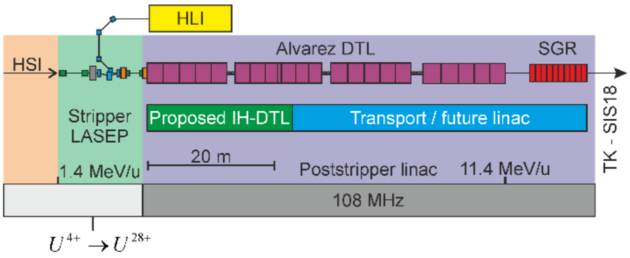

Figure 1: Sketch of the existing UNILAC poststripper section with the dimensions of the proposed IH-DTL linac.

Beam Dynamics / Focusing

By utilising the KONUS beam dynamics concept, a linac design with long IH-type cavities and a total of only seven quadrupole triplet lenses for the whole linac was possible. Based on a two-stage constant phase advance approach, the emittance growth of the linac was minimized to just above 25 % in the transverse planes. The careful design of the longitudinal beam motion in the KONUS lattice resulted in high longitudinal beam quality with only 10 % emittance growth (as shown in Figure 2). Design simulations were performed with a waterbag input distribution. For the reference beam (15 $mA\ U^{28+}$), full beam transmission is achieved.

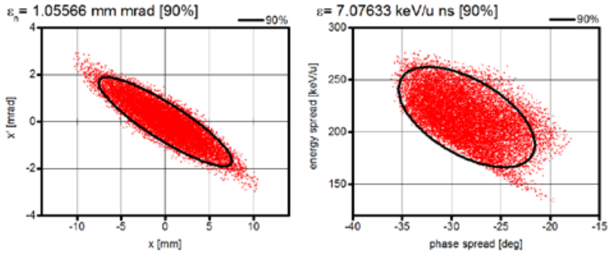

Figure 2: Particle distribution at the exit of the IH-DTL poststripper linac from LORASR simulations with $5 \cdot 10^6$ macroparticles. Transverse (left) and longitudinal (right) planes are shown.

Error Studies

To judge the real-world performance of the proposed linac, extensive error studies were performed. In these studies, realistic and even excessive machine errors ranging from misalignment of components to fluctuations of machine settings were investigated [1]. For realistic tolerance values, the linac performance was almost unchanged with additional emittance growth for all cases in the range of only 1-2 %. In combination with a developed steering strategy, the total beam losses of even the worst case could be reduced to 0.03 %. Beam losses in the case of realistic tolerance almost vanished to only $6 \cdot 10^{-8}$.

Fieldmap Calculations

Recent beam dynamics calculations using realistic 3D-fieldmaps of the electromagnetic field in the first two cavities (= four KONUS sections) were performed using the TraceWin code (see Figure 3). The results are in good agreement with LORASR simulations. With TraceWin, an even lower transverse emittance growth is predicted.

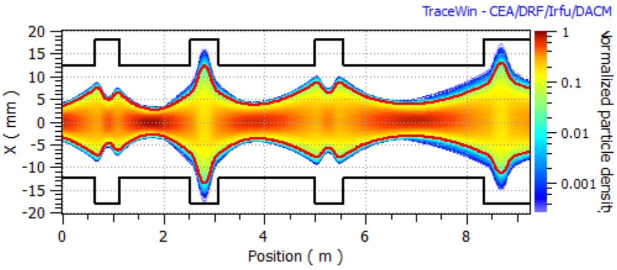

Figure 3: Transverse beam envelope from beam dynamics calculations with cavity fieldmaps calculated from the CST cavity models.

These results in combination with the aforementioned error studies clearly hint towards satisfying real-world performance of the proposed poststripper linac design.

Acknowledgements

We appreciate the collaboration within the UNILAC upgrade program at GSI (W. Barth, L. Groening, et al.).

References

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[2] H. Hähnel et al., 2017 J. Phys.: Conf. Ser. 874 012047

Accelerator infrastructure: UNILAC
Grants: BMBF 05P15RFRBA
Strategic university co-operation with: Frankfurt-M

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* Contact: haehnel@iap.uni-frankfurt.de

Investigations on KONUS beam dynamics using the pre-stripper drift tube linac at GSI

C. Xiao, X.N. Du, and L. Groening

GSI, Darmstadt, Germany.

Interdigital H-mode (IH) drift tube linacs (DTLs) based on KONUS beam dynamics are very sensitive to the rf-phases and voltages at the gaps between tubes. In order to design these DTLs, a deep understanding of the underlying longitudinal beam dynamics is mandatory. The report presents tracking simulations along an IH-DTL using the PARTRAN and BEAMPATH codes together with MATHCAD and CST. Applying the existing geometrical design, rf-voltages, and rf-phases of the DTL were re-adjusted. In simulations this re-optimized design can provide for more than 90% of transmission of an intense 15 emA beam of $^{238}\mathrm{U}^{4+}$ keeping the reduction of beam brilliance below 25%. Details can be found in [1].

Single particle tracking

In the MATHCAD code the electric field on axis (r = 0) of each cell is solved using:

$$\mathrm{E_z(z,r,t)} = -\cos(\omega t + \varphi_0) \sum_{m=1}^{M} \mathrm{E_m I_0}(\mu_m r) \sin\left(\frac{2\pi mz}{\Gamma}\right),$$

where $\mathrm{I_0}$ is the Bessel functions of zero and first order, ω is the angular frequency of the field, r is the radial coordinate, and φ_0 is the phase at the gap at t = 0. Typically the number of Fourier harmonics is M = 30.

$$\mu_m = \frac{2\pi}{\lambda}\sqrt{\left(\frac{m\lambda}{\Gamma}\right)^2 - 1},\ \Gamma = l + 2g + d,\ \ \mathrm{E_0} = \frac{U}{g}.$$

Each DTL cell comprises a front half tube, gap, and end half tube. Lengths of front tube, gap, and end tube are defined as l, g, and d, respectively. The inner radius of the tube is a and the electric field along the gap is obtained from

$$\mathrm{E_m} = \frac{4\mathrm{E_0}}{\mathrm{I_0}(\mu_m a)} \frac{\pi m(l+g)}{\Gamma} \frac{g}{\Gamma} \frac{\sin\left[\frac{\pi m(l+g)}{\Gamma}\right]}{\frac{\pi m(l+g)}{\Gamma}} \frac{\sin(\frac{\pi mg}{\Gamma})}{\frac{\pi mg}{\Gamma}},$$

U is the integral voltage along the whole cell. The single particle starts moving at z = 0.

The reference particle vector function is defined as:

$$\mathrm{Z(t,z)} = \begin{bmatrix} z \\ \frac{dz}{dt} \end{bmatrix} = \begin{bmatrix} z \\ \beta c \end{bmatrix},$$

with βc as velocity. Starting at t=0 and z=0

$$Z(0,0) = \begin{bmatrix} 0 \\ \beta_0 c \end{bmatrix}.$$

The derivative DZ is

$$\mathrm{DZ(t,z)} = \frac{\mathrm{dZ(t,z)}}{\mathrm{dt}} = \begin{bmatrix} \beta c \\ \frac{\frac{q}{m_0}}{\sqrt{1-\beta^2}} \mathrm{E_z(z)}\cos(\omega t + \varphi_0) \end{bmatrix}.$$

$E_z(z,t) = E_z(z)\cos(\omega t + \varphi_0)$. This differential equation is non-linear and cannot be solved analytically. MATHCAD provides several routines to solve systems of ordinary differential equations. Each one uses a different integration algorithm and takes the same arguments. The Bulirsch–Stoer method (a very robust method which some prefer over Runge–Kutta) is applied solving derivative DZ and the results are written as matrix F.

$$F = Bulstoer\left[Z(0,0), t_i, t_f, s, Dz(t,z)\right],$$

where $Z(0,0)$ is the vector with initial conditions, t_i and t_f are the starting and ending points of the integration, s is the number of integration steps, and $DZ(t,z)$ is the vector containing the differential equations. At each step

$$F_1 = t_n, F_2 = z_n, F_3 = \beta_n c, \quad n = 1,2,\cdots s,$$

$F^{1,2,3}$ indicates column 1, 2, and 3 of matrix F. The parameters of effective voltage, time transition factor, and rf-phase of each gap can be calculated according to the above MATHCAD routine and imported into BEAMPATH and PARTRAN codes to perform the beam dynamics simulations with space-charge effects.

Multi-particle tracking

A realistic particle distribution at the exit of the HSI-RFQ (radio frequency quadrupole) is imported and non-linear space-charge forces are considered in the tracking simulations.

A more accurate method for calculation of rf-phases, effective voltage, and time transition factor parameters has been developed basing on the single particle tracking through the one-dimensional electric field-map, and these parameters were imported into PARTRAN code. On the other hand, BEAMPATH code has been applied to simulate the IH-DTL. Corresponding twofold particle distributions at the exit of the IH-DTL are shown in Fig. 1

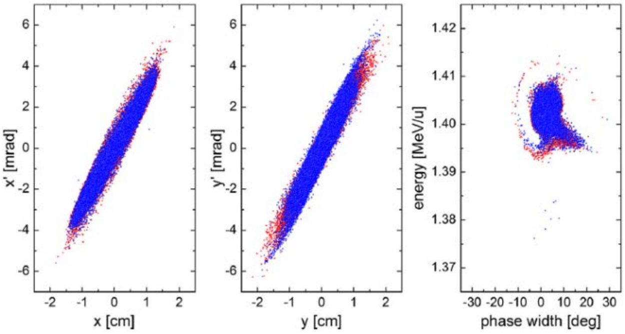

Figure 1: Particle distributions at the exit of the DTL simulated with PARTRAN (blue) and BEAMPATH (red).

Self-consistent beam dynamics of this IH-DTL optimized with the t-code BEAMPATH can provide for more than 90% of transmission of the $^{238}\mathrm{U}^{4+}$ beam with 15 emA at the design energy of 1.4 MeV/u. These results could be reproduced very well with PARTRAN using realistic TTF parameters, measured gap voltages, and upgraded rf-phases taking into account unequal lengths of front and end half tubes.

Reference

[1] C. Xiao et al., Nuclear Inst. and Methods in Physics Research, A 887 (2018) 40–49.