UNILAC UPGRADES FOR COULOMB BARRIER ENERGY EXPERIMENTS

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Abstract

The GSI linear accelerator UNILAC provides heavy ion beams at Coulomb barrier energies for search and study of super heavy elements. Typical cross-sections of 55 fb require beam doses of $1.4 \cdot 10^{19}$ according to a beam time of 117 days. Several upgrades will reduce the beam time to only 16 days.

A second injection branch with a sc 28 GHz-MS-ECRIS anticipates a factor of 10 in particle intensity. By a new cw RFQ-structure all accelerator tanks are suitable for a duty cycle of at least 50 % instead of 25 % presently. Due to this, thermal power increase of 19 rf-amplifiers eased by higher ion charge states of the ECRIS is necessary. Finally the UNILAC timing system controlling 50 Hz pulse-to-pulse operation of up to six beams differing in ion species and energy has to be modified considering beam diagnostics electronics and pulsable magnets.

The front end comprising ECRIS, RFQ- and IH-structure is cw suitable and will serve as an injector for a new future sc cw-linac.

INTRODUCTION

The experiments for the SHE (super heavy elements) program at the GSI linear accelerator UNILAC are served with ion beams from the HLI (high charge state injector) comprising a 14 GHz CAPRICE-type ECR ion source, an RFQ and an IH type accelerator, and two bunchers. The ions are injected at energy of 1.4 MeV/u into the Alvarez DTL and get the final, accurately adjustable energy in the range of 5-7 MeV/u by use of several single gap resonators. All cavities are operated at 108 MHz. Additionally, the HSI (high current injector) enables the alternate injection of two further ion species beams into the Alvarez DTL as shown in Fig. 1. Therefore, the UNILAC accelerates up to three ion beams of different species on a 50 Hz pulse-to-pulse switching mode as sketched in Fig. 2. The period length of 20 ms is partitioned into 5.5 ms beam pulse and 14.5 ms for data transfer, plus magnets and rf amplifiers set up for the next pulse.

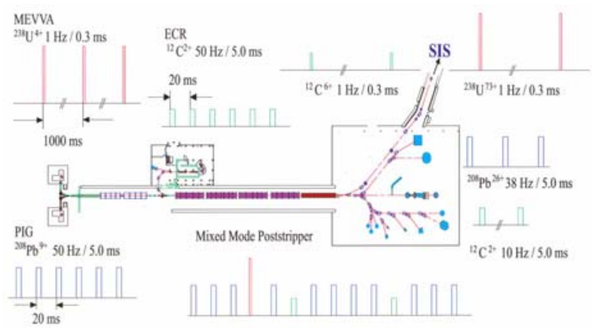

Figure 2: Example of UNILAC timing for three-beam-operation.

Considering ion source currents of 4.5 pμA, a present accelerator transmission of ~50 %, and empirical accelerator or experiment related breaks, a typical SHE beam time for cross sections of 55 fb takes 117 days [1].

UPGRADE PROGRAM

As a long term perspective the SHE program will be served by a new cw linac [2]. An intermediate program foresees an increase of the beam intensity and the duty cycle of the UNILAC to shorten the experiment runs significantly.

Second Ion Source of MS-ECR Type

The HLI will be extended by an additional new MS-ECRIS (multipurpose superconducting ECR ion source) [3]. It is designed to utilize higher magnetic fields and

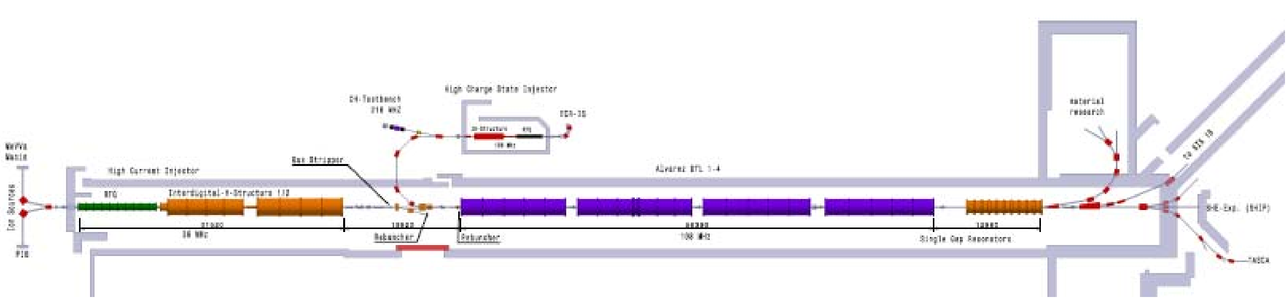

Figure 1: Scheme of the UNILAC accelerator.

microwave frequency in order to achieve an increase in beam intensity of typically one order in magnitude (see Fig. 3). It will also follow for higher charge states while still extracting more ions compared to the CAPRICE source. The core component, the sc hexapole-solenoid magnet combination, is currently in the manufacturing process. Parameters are listed in table 1.

Table 1: Key Parameters of the CAPRICE-ECRIS and the Advanced MS-ECRIS

Property	CAPRICE	MS-ECRIS
Frequency [GHz]	14.5	28.0
Axial field [T]	1.3	4.5
Radial field [T]	1.2	2.7

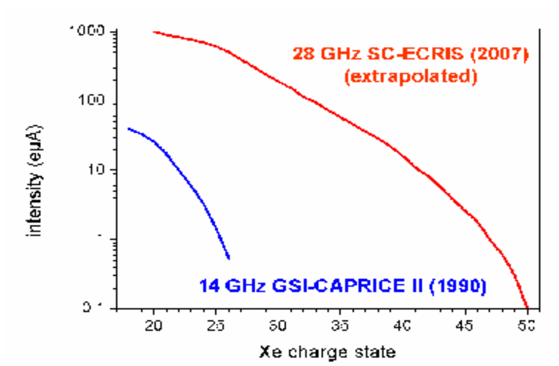

Figure 3: Xe ion beam intensities of the 14 GHz ECR and the new sc 28 GHz ECR ion source.

The extraction energy for both sources will be raised from 2.5 to 4.0 keV/u. This value states a compromise between optimal ion extraction for the MS-ECRIS and the limits of the present CAPRICE ECR.

Beam Analysis and LEBT

The two ion sources will be connected to the RFQ by separated spectrometers and LEBTs as shown in Fig. 4. Realization is foreseen until 2012 together with the installation of the MS-ECRIS.

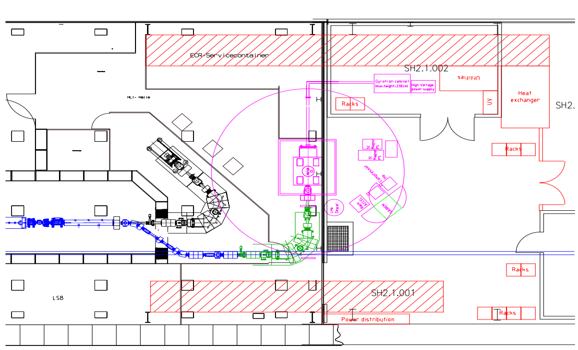

Figure 4: LEBT and spectrometer layout for two ECR branches.

One of the two ion sources can feed the HLI while the other one is used for development tasks, e.g. generating metal ions as ^{50}Ti, Pb, or U, or will be prepared for another ion species beam for the upcoming beam time.

New CW Capable RFQ

In 2010 a new cw capable 4-rod RFQ [4, 5] was installed. Main parameters are shown in table 2. The maximum pulse power of 120 kW of the reused amplifier is sufficient for 50 % duty cycle for the actual maximum beam rigidity (U^{28+}). Expected higher charge states from the MS-ECRIS allow for cw operation later. By a moderate cooling power upgrade of the IH tank and its rf plungers the entire HLI becomes cw capable and will be used as 1.4 MeV/u stage for the future cw linac.

Table 2: Design Properties of the New HLI RFQ

Injection / extraction energy [keV/u]	2.5 / 300
RF frequency [MHz]	108.408
A/q (cw / 50 % duty cycle operation)	6.0 / 8.5
Power (max. thermal / 50 % pulse) [kW]	60 / 120
Intervane voltage (cw / max.) [kV]	55 / 78
Input emittance norm. rms [mm·mrad]	0.1
Output emittance norm. rms [mm·mrad]	0.101
Electrode length [m]	2.0

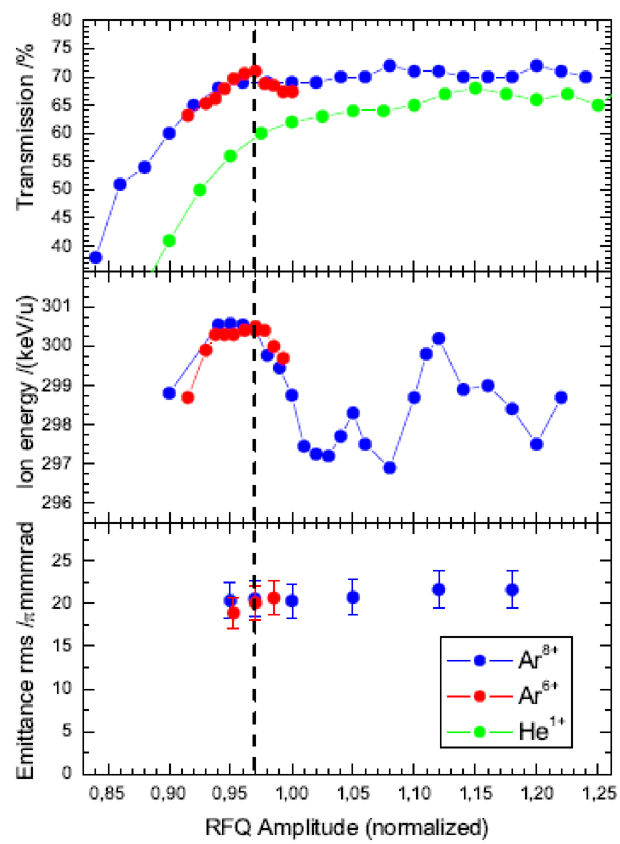

Figure 5: Results of RFQ commissioning with Ar and He beam. Transverse emittance (bottom), beam energy (middle), and transmission (top) as function of the RFQ voltage. Dashed line indicates working point.

During commissioning in March 2010 a beam transmission of 72 % was achieved and the power consumption was measured as predicted. Sparking disappeared after rf and vacuum conditioning. The new RFQ meets its specifications and serves in routine operation. The input beam energy is preliminarily limited to 2.5 keV/u to avoid extraction voltage breakdowns of the CAPRICE ECRIS. The RFQ rods will be replaced by new already designed rods for an input energy of 4 keV/u with commissioning of the new MS-ECRIS.

RF Amplifier Duty Cycle Raise

The main challenge towards a duty cycle of 50 % for medium heavy ions acceleration (e.g. ^{70}Zn) is the amplifier upgrade of the 108 MHz Alvarez DTL section and the single gap resonator chain as shown in Fig. 6.

Figure 6: RF 108 MHz amplifier gallery.

According to different mass over charge ratios and different duty cycles during multi beam operation, the appropriate anode voltages are 24 kV or 18 kV, respectively. Additionally, individual matching of the amplifier output cavity for best efficiency is necessary. In principle this is not possible presently for pulse-to-pulse operation, but can be developed and applied for scheduled long-term beam times. Furthermore the fact of beam load of up to 400 kW/tank caused by high intensity beams of the HSI has to be considered.

To find the limits of the Alvarez DTL and single gap resonators rf amplifiers under the conditions of a 50 Hz sequence of long pulses with medium amplitude (m/q = 6.5) and 1 Hz intermediate short pulses (m/q = 8.5) the amplifiers were tested and the behavior of the tanks was monitored. Reliable operation was possible up to a duty cycle of 8 ms / 50 Hz with the compromise of an anode voltage of 24 kV. Similar results were measured for the single gap cavity amplifiers. Tank cooling kept stable, the plungers reached nearly inner end positions. As a consequence, most of the required ion species (m/q ≤ 6.5) for the SHE program can presently be offered with a duty cycle of 40 %. Lower m/q values expected by the MS-ECRIS enable accordingly longer pulses up to 50 %.

But, the remaining time of 10-12 ms within an operation period length of 20 ms is not sufficient for data transfer and setting up rf amplitudes and magnet field strengths for an intermediate short pulse beam. Therefore, empty interim pulses have to be inserted before the short pulse beam to provide the necessary switching time of 14.5 ms. Finally, the efficient beam on target time for a duty cycle of 40 % sums up to 48 Hz · 8 ms = 384 ms/s instead of 253 ms/s presently and even 480 ms/s for duty cycles of 50 % for light ion beams. Hence, the gain in "beam on target time" amounts to a factor of 1.5-1.9.

Nevertheless, cost estimations for improvements of the rf amplifiers for stable 10 ms / 50 Hz operation for m/q ≤ 8.5 were done. The main issues are amplifier upgrades by high performance tube stages, modifications of the anode power supplies and the low level rf devices. Including all additional expenses the costs are approximately 5 M€ excluding GSI man power [6].

CONCLUSIONS AND OUTLOOK

The SHE experimental program is an essential task of the GSI research activities taking a significant part of the available beam time at the UNILAC. Considering a conservative estimation of a beam intensity gain of a factor of 5 by the MS-ECRIS and a duty cycle gain of 1.5, the expected shortening of the beam time from 117 to only 16 days for a dose of $1.4 \cdot 10^{19}$ particles according to cross-sections of 55 fb is easily performable. The effort for that comprises mainly the development and installation of the MS-ECRIS with a dedicated LEBT also giving redundancy to the existing CAPRICE ECRIS. The accelerator rf power limitation of a duty cycle of 40 % for m/q ≤ 6.5 becomes obsolete due to the higher charge states of the MS-ECRIS beams.

An invest of 5 M€ for rf amplifier upgrades induces significant advantage only for highest m/q ratios and was rejected. The future development now focuses on a SHE dedicated cw linac. The existing cw capable HLI can be reused for acceleration to 1.4 MeV/u. The subsequent acceleration stages will be achieved by sc CH-cavities [7].

REFERENCES

[1] S. Hofman et al., Heavy Element Research at GSI-SHIP, EXON-2004, Peterhof, Russia (2004).

[2] W. Barth et al., UNILAC-Upgrade Program for the Heavy Element Research at GSI-SHIP, EPAC, Edinburgh, Scotland, Great Britain (2006).

[3] K. Tinschert et al., Ion Beam Production from Rare Isotopes with GSI ECR Ion Sources, ECRIS08, Chicago, USA, MOPO-14, P. 97 (2008).

[4] A. Schempp, An Overview of Recent RFQ Projects, LINAC, Victoria, BC, Canada, MO302, P. 41 (2008).

[5] P. Gerhard et al., Commissioning of a New CW Radio Frequency Quadrupole at GSI, IPAC, Kyoto, Japan (2010).

[6] W. Vinzenz, Internal Note, Conditions for a 50 % duty cycle rf operation, May 2008.

[7] S. Mickat et al., The Superconducting CW-Linac-Demonstrator at GSI, LINAC10, Tsukuba, Japan (2010), theses proceedings.