STATUS OF THE UNILAC–UPGRADE PROGRAMME FOR THE HEAVY ELEMENT RESEARCH AT GSI–SHIP

P. Gerhard*, W. Barth, L. Dahl, K. Tinschert
Gesellschaft für Schwerionenforschung, 64291 Darmstadt, Germany
A. Schempp, IAP, University of Frankfurt, 60438 Frankfurt am Main, Germany

Abstract

For more than 30 years the heavy–element research using the velocity separator SHIP is one of the "lighthouse" experiments at GSIs heavy ion linear accelerator UNILAC [1]. The discovery of six new elements since 1981 is based on the perpetual effort to increase the beam intensity. Since the early 1990's the beam current available was raised significantly by improvements concerning the CAPRICE ion source, the LEBT and the accelerator performance. The next step is the upgrade of the RFQ accelerator, which is scheduled for 2009. The new RFQ will allow for high duty factor operation (up to 100%) and for an improved longitudinal beam quality as well as an increased beam transmission. A new superconducting 28 GHz ECR ion source will be installed later. The new source will provide increased beam intensities and simultaneously higher charge states. It will be installed in addition to the existing one; therefore a second LEBT system has to be designed and integrated. The status quo of the UNILAC upgrade programme is presented.

INTRODUCTION

The heavy ion UNIversal Linear ACcelerator (UNILAC) at the Gesellschaft für Schwerionenforschung (GSI) (Fig. 1) consists of two injectors, namely the high current injector (HSI) and the high charge state injector (HLI). Both injectors feed a common 108 MHz Drift Tube Linac

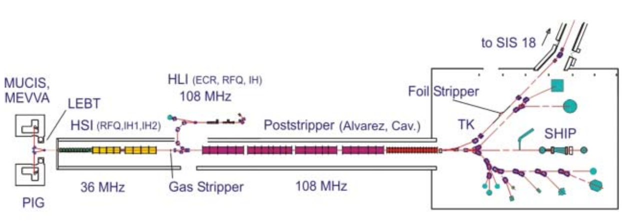

Figure 1: Layout of the heavy ion linac UNILAC at GSI.

(DTL) in a time-sharing mode at 50 Hz. The DTL is of Alvarez type and consists of five rf tanks and a subsequent single-gap resonator chain, the maximum beam energy is 11.4 MeV/u. The beam may either be transferred to the heavy ion synchrotron (SIS 18) or is delivered to the experimental hall, where the Separator for Heavy Ion reaction Products (SHIP) is located.

The beam for the SuperHeavy Element (SHE) research is mainly provided by the HLI. This injector is equipped with a 14.5 GHz Compacte A Plusieurs Résonances Ionisantes Cyclotron Electroniques (CAPRICE) ion source and a high resolution spectrometer. The beam from the Low Energy Beam Transport (LEBT) is injected into a Radio Frequency Quadrupole (RFQ) and a subsequent Interdigital H-structure (IH) accelerator (rf frequency 108 MHz), where the ions are accelerated to a final beam energy of 1.4 MeV/u [2].

UPGRADES AND STATUS

An upgrade programme consisting of three major steps was defined three years ago and is still in progress:

1. An advanced high performance Electron Cyclotron Resonance (ECR) ion source providing an increased beam current and simultaneously higher charge states,
2. a second LEBT section for transporting this beam and matching it to
3. an optimized RFQ with improved performance, operating at higher duty cycle.

Ion Source Upgrade

The largest single step of beam intensity increase is anticipated from the new Multipurpose Superconducting ECR Ion Source (MS-ECRIS). It is designed to utilize higher magnetic fields and microwave frequencies in order to achieve an increase in beam intensity of typically one order of magnitude. It will also allow for higher charge states while still extracting more ions compared to the CAPRICE source. The key parameters are listed in table 1.

The extraction energy for both sources is raised from the injection energy of the present RFQ to that of the new RFQ, i. e. from 2.5 keV/u to 4.0 keV/u . This value states a compromise between optimal ion extraction for the MS-ECRIS

Table 1: Key parameters of the present CAPRICE ion source and the advanced MS-ECRIS.

Property	CAPRICE	MS-ECRIS
Frequency /GHz	14.5	28
Axial field /T	1.3	4.5
Radial field /T	1.0…1.2	2.7

* p.gerhard@gsi.de

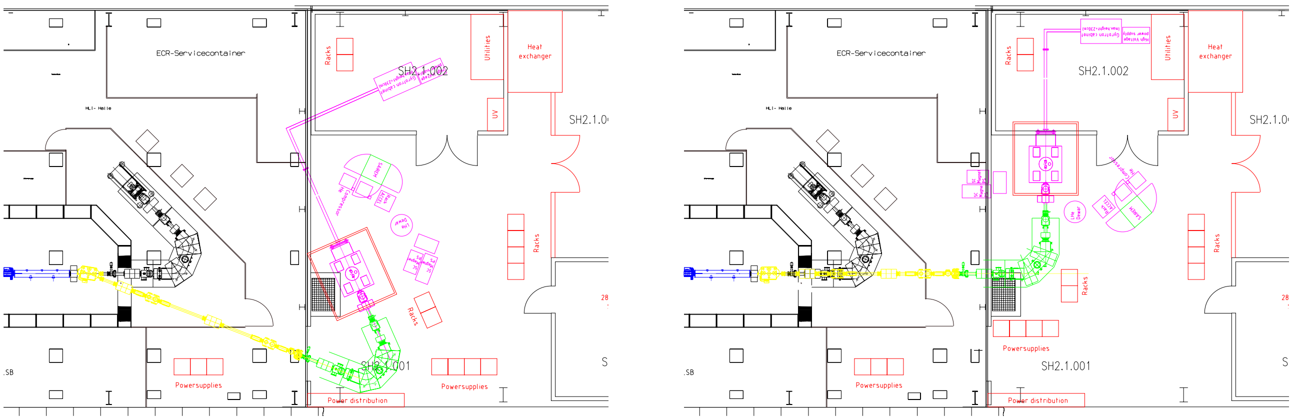

Figure 2: Design studies for the HLI upgrade. Black: Environment and present ECR with 135° spectrometer; blue: RFQ; magenta: 28 GHz MS-ECRIS with microwave generator and supplies; green: new 135° (left) and 90° (right) spectrometer; yellow: beam transport line with switching magnet; red: radiation protection for the ion source, electronic racks, power supplies, utilities etc.

and the limits of the present extraction system.

The construction of the mechanical parts of the MS-ECRIS has been accomplished including some design revisions. However, due to the sophisticated handling of the magnetic forces, the manufacturing of the magnet system has experienced significant delay. During the quench training it was able to operate in stand alone mode up to 100% of the nominal field, but when hexapole and solenoidal coils were energized together they did not reach 50% [3]. This unexpected behavior has to be investigated.

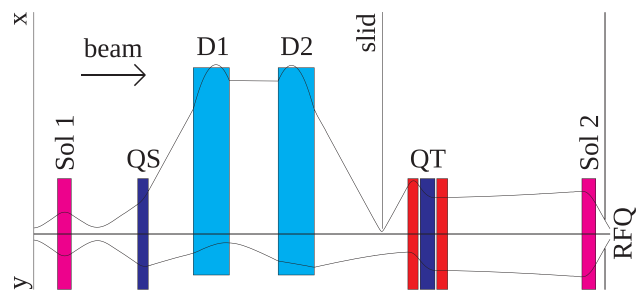

Figure 3: MIRKO beam optics of the LEBT following the present CAPRICE ion source (ε=300 π·mm·mrad).

Second LEBT

A second LEBT branch and a switching magnet in front of the RFQ are required in order to operate the existing and the new ECR source in parallel. Two designs for the beamline are shown in Fig. 2. The new ion source together with the spectrometer have to be placed in a second, adjacent building. After the charge separation the beam has to be delivered to the RFQ by approximately 8 m of beam transport line. One design goal is to preserve the present LEBT. The first option (left) is to circumvent the existing spectrometer and connect the new LEBT with one switching magnet from the side. Another possibility (right) is to place the new LEBT above the existing one and connect it by two vertical dipoles. This improves the accessibility of the whole area and saves 2 m of beam transport line. Both layouts care for sufficient separation between the old and new ECR source to allow for maintenance of one source while the other is operated. Radiation protection and separation of the 28 GHz microwave generator from the superconducting source have to be considered.

Advanced beam dynamics of both solutions will be studied in the next months, a MIRKO calculation of the present LEBT is shown in Fig. 3. The focusing section behind the ion source will be similar to the present one, which facilitates a solenoid and a quadrupole lens in front of the spectrometer. For the latter one could use the 135° split dipole spectrometer as in the present LEBT, which has a resolution of $\Delta m/m = 1.3 \cdot 10^{-3}$ but limited acceptance. A 90° spectrometer would relax the layout of the beamline significantly. It would also open up the possibility to enlarge the acceptance, which makes sense because of the enhanced RFQ performance, and the MS-ECRIS would allow for a reduced spectrometer resolution. This key issue has to be investigated carefully. Because of the long drift distance, the new LEBT design should be achromatic, whereas the chromaticity of the present spectrometer is not corrected. One also has to keep the quadrupole apertures reasonably small.

Especially the design of the switching magnet and the matching to the RFQ is under consideration. Today the beam is matched to the RFQ using a solenoid. Matching to the new RFQ is improved due to an optimized input radial matcher in the RFQ, which will allow for a larger beam spot and smaller angles. This reduces the aperture necessary for the focusing elements and makes the use of quadrupoles feasible. Focusing by a solenoid has to be compared with quadrupole lenses in order to find the optimal solution. The LEBT layout and the magnet design has to be completed until end of this year. The area where the new source and

LEBT are to be mounted will be available in late 2010.

RFQ Upgrade

A new RFQ with an improved performance was designed (Tab. 2). The main feature is the operating with a high duty cycle of 50% for the maximum mass–over–charge ratio (A/z). This was already the design goal for the present RFQ, but could not be reached in practice [4], and after 17 years of extensive use the limit for 50% d.c. operation[1] is A/z≤6. The new RFQ will allow for cw operation for A/z≤6. It is intended to use the HLI in the future as an injector for a proposed cw linac dedicated to UNILAC experiments especially like SHIP [5].

Table 2: Basic parameters of the present and the new RFQ

Property	Present	Upgrade
Injection energy /(keV/u)	2.5	4
Extraction energy /(keV/u)	300	300
RF Frequency /MHz	108.5	108.5
A/z (cw)	—	≤6.0
A/z (50% duty cycle)	≤ 8.5	≤ 8.5
Design emittance /(π·mm·mrad)	215	200
Max. av. power /kW	70	70
Shunt impedance /(kΩm)	200	150
Intervane voltage /kV	80	55
Cavity length /m	3.0	2.0

The second main design feature is an improved beam transmission, which turned out to be insufficient with the present RFQ due to an inadequate estimate of the beam emittance. A beam dynamics design for the new RFQ, optimized for the beam provided by the new MS-ECRIS, had been proposed by M. Vossberg et al. [6]. The calculated beam transmission is better than 90% for a design emittance of 200 π·mm·mrad and beam currents up to the design value of 5 mA, for lower currents as expected from the MS-ECRIS in routine operation it reaches 100%.

The existing RFQ rf amplifier with a maximum average output power of 70 kW will be reused in order to save money. The length of the RFQ tank therefore had to be reduced from 3.0 m to 2.0 m to allow for the high duty cycle operation. The injection energy was increased from 2.5 to 4 keV/u in order to fit the optimized extraction energy of the new MS-ECRIS.

The tank (Fig. 4) will be built from one piece of steel and is now under construction. The resonant structure is implemented as a four–rod–RFQ. The four electrodes will be held by 14 stems, the whole structure is directly water cooled. The RFQ will be delivered to GSI in March 2009, commissioning is scheduled for mid 2009.

[1] This is the highest duty factor feasible with the existing accelerator chain and would require a general overhaul of the rf systems. Simultaneous high current operation as specified for FAIR would require an additional large upgrade measure for all UNILAC rf systems.

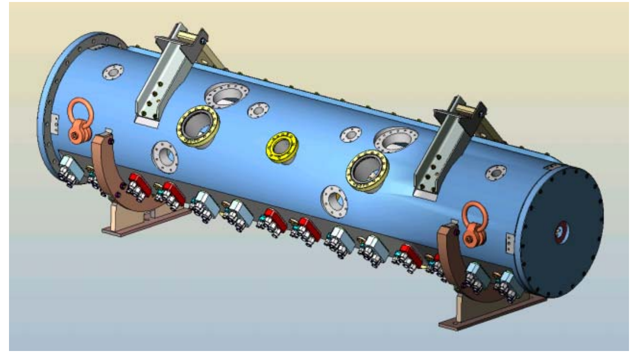

Figure 4: Sketch of the new HLI–RFQ tank [7].

SUMMARY & OUTLOOK

In order to increase (average) beam intensities for the heavy–element research at GSI, an upgrade programme consisting of three steps is in progress. The first step will take place in 2009 by replacing the old RFQ accelerator by a new one with improved beam transmission and duty factor capabilities. The main upgrade will be a new ion source of ECR type. It is expected to deliver about one order of magnitude higher beam intensities and to allow the use of higher charge states. The time schedule for the MS-ECRIS is not fixed by now. In order to use the new source in parallel to the CAPRICE ion source operated now, a second LEBT branch is in the design phase. Its commissioning is expected for 2011. In order to make use of the higher duty factors upgrade measures for all Alvarez rf systems are proposed, and additionally upgrades for the magnet power supplies and the control system would be required. A dedicated cw linac for the heavy element research is proposed.

REFERENCES

[1] S. Hofmann and G. Münzenberg, The discovery of the heaviest elements, Rev. Mod. Phys. 72, 733 (2000)

[2] N. Angert et al., Commissioning and First Operation Experience of the New Heavy Ion Injector of the UNILAC, EPAC1992, Berlin, Germany (1992)

[3] G. Ciavola et al., these proceedings

[4] J. Friedrich et al., Performance of the GSI HLI-RFQ, EPAC1992, Berlin, Germany (1992)

[5] W. Barth et al., UNILAC–Upgrade Programme for the Heavy Element Research at GSI–SHIP, EPAC2006, Edinburgh, UK (2006)

[6] M. Vossberg et al., these proceedings

[7] J. Häuser, NTG, Gelnhausen, Germany, private communication