STATUS AND PERSPECTIVES OF THE CW UPGRADE OF THE UNILAC HLI AT GSI

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Abstract

The High Charge State Injector (HochLadungsInjektor) HLI was commissioned in 1991 [1]. It was the first linac comprising of a Radio Frequency Quadrupole RFQ and an Interdigital H-Type cavity IH. For more than twenty years, it successfully provided essential heavy ion beams with high duty cycle for several lighthouse experiments and developments at GSI. Among them are the Super Heavy Element Research SHE, namely the experiments SHIP, TASCA, SHIPTRAP, and the heavy ion cancer therapy. Three out of the six transuranium elements found at GSI were discovered with ion beams from the HLI [2]. The ever increasing demand for beam intensity was met by the proposal of a SuperConducting Continuous Wave sc cw-Linac. As the HLI will serve as an injector for this new accelerator, a cw upgrade for the HLI was developed.

THE ORIGINAL HLI

The High Charge State Injector (see Fig. 1, and Table 1) is equipped with a Compacte A Plusieurs Résonances Ionisantes Cyclotron Electroniques (CAPRICE) ion source and a high resolution 135° spectrometer; the source was recently upgraded to slightly higher magnetic fields of 1.4 T.

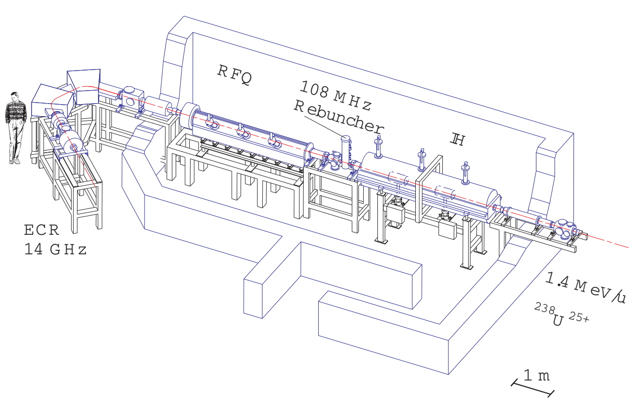

Figure 1: Overview of the HLI.

Behind the spectrometer the beam is matched to a 4-rod RFQ, which accelerates the ions from 2.5 to 300 keV/u. This is followed by a MEBT, which includes a magnetic quadrupole triplet and a doublet as well as a $\lambda/4$-buncher for transversal and longitudinal matching of the beam to the following IH cavity. The IH accelerates the beam to the final energy of 1.4 MeV/u. The beam is then transported to the UNIversal Linear ACcelerator UNILAC through a 180° bend (not shown in Fig. 1). A second $\lambda/4$-buncher provides for proper matching to the first Alvarez tank.

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Table 1: Basic Parameters of the HLI

Property	Value
Mass resolution /(Δm/m)	$3 \cdot 10^{-3}$
Beam intensity /pnA	≤1
A/z 50% d.c. (cw)	≤8.5 (6.0)
Injection energy /(keV/u)	2.5
Extraction energy /(MeV/u)	1.4
RF Frequency /MHz	108.408
Design emittance /(π·mm·mrad)	1.5 (norm.)
Total length /m	10.8

The HLI was originally designed for a duty cycle (dc) of 50% and a pulse repetition rate of 50 Hz. Most of the magnets are operated at constant current, as it was not planned accelerating different ions in parallel. Thus, the HLI can be operated with cw beam as far as the magnets are concerned, but most other devices, like beam diagnostics, and the control system are designed for pulsed operation only.

The ECR ion source is ideal for stable, long lasting beams. Due to its low material consumption, rare isotope beams can be produced very efficiently. This has made the HLI the prominent injector for medium heavy ions requested by experiments at the Coulomb barrier up to now.

CURRENT STATUS AND CW UPGRADE

With no major changes, the HLI was in routine operation and successfully providing beams for coulomb barrier experiments and injection into the heavy ion synchrotron SIS for nearly 20 years. Nevertheless, the demand for higher (average) beam intensities grew with time, and two strategies were proposed to deal with this demand: An upgrade of the source to directly increase the beam current, and an upgrade of the whole accelerator to move from pulsed to cw operation, thereby raising the duty cycle and the average beam intensity by another factor of four.

MS-ECRIS

About ten years ago, an international project was started to develop a high performance ion source using the concept of electron cyclotron resonance. This source was called MS-ECRIS [3]. It was intended to install it as a second source in front of a new LEBT branch at the HLI. Key feature of the source was a strong confinement by higher magnetic fields, produced by sc magnet coils. The aim was to reach higher charge states and at the same time deliver more ions to the accelerator. In 2007, the magnet system was tested for the first time, and quenches occurred when both coils were

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powered simultaneously to around 40% of the nominal value. Since then, several attempts and upgrades to the coil system have been made to increase this value, but no improvement could be achieved. Thus, the project recently had to be canceled, and the HLI operates with the existing CAPRICE until an alternative source will be evaluated and obtained.

First CW Upgrade: RFQ

In 2009 the HLI was equipped with a new 4-rod RFQ. This was intended as the first step of an upgrade of the whole linac [4] towards cw operation. It was initially designed to fit to the MS-ECRIS, but was redesigned as this project was delayed at that time, with an optional upgrade later. It turned out that the beam dynamics performed well, but the mechanical and thermal design of the structure was not able to meet the high requirements [5]. After an upgrade of the rf contacts of the tuning plates, operation up to 30 kW average power is now possible, while the design power for cw operation is 60 kW.

During commissioning, strong modulations of rf signals, like the reflected power, were observed (see Fig. 2). This

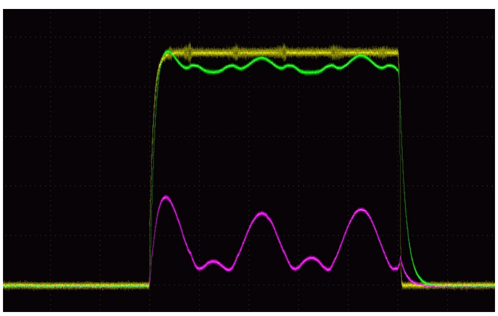

Figure 2: Modulation of the RFQ rf signals, caused by vibrations of the rods.

phenomenon was already known from the first HLI RFQ. It is attributed to mechanical vibrations of the structure. Later it was discovered, that operation at higher amplitudes is only possible for certain rf pulse lengths (at 50 Hz pulse repetition rate). Otherwise, the reflected power gets too high. It was verified by in situ investigations with a laser vibrometer [6], that mechanical vibrations of the rods are excited by the rf pulses. This leads to modulations of the rf field and deteriorates the beam quality substantially at high rf amplitudes. Operation is limited to moderate amplitudes with respect to the design values and requires a high degree of experience in operation. Due to fast and strong response of the structure to changes of the thermal load, cw operation is also not possible.

For the time being the HLI is still used as injector linac for medium heavy ions like ^{12}C, ^{40}Ar and ^{48}Ca with high duty cycles, and sometimes for rare heavy ions like ^{124}Xe.

Full CW Upgrade

The following describes the known measures necessary in order to turn the HLI into an injector linac capable of cw operation.

RF Cavities A thermally and mechanically improved RFQ will be build, but the other cavities have to be upgraded as well. Both bunchers are only capable of 50% dc due to their limited cooling. A new design for one of the bunchers is presently under development in the frame of the cw demonstrator project (see below).

The IH cavity in principle should be cw capable, but the plungers get too close to the drift tubes already at the present duty cycle due to the thermal load. This affects the field distribution and will not be tolerable at 100% dc. The proposed countermeasure is to build a new top shell.

Low Level RF and Power Amplifiers The existing low level rf is not suitable for cw operation. Since it was built on-site, a careful survey and consideration of possible alternatives has to be done.

All present rf transmitters are based on tubes. Their average power will not be sufficient for cw operation. The lower power systems for the bunchers may be replaced by solid state transmitters. The high power transmitters for the RFQ and the IH will again be tube based systems.

Beam Diagnostics and Control System The complete beam diagnostics, especially the electronics, are based on and designed for pulsed operation. Some parts, like beam current transformers, may be ordered from the shelf for cw operation, while for others this may not be the case and a considerable amount of development might be necessary. The same holds true for the control system.

CW LINAC

Nearly all beams from the HLI are accelerated to ion energies between 3.6 and 11.4 MeV/u by the UNILAC. On the other hand, the UNILAC is foreseen as the main injector linac for the FAIR project, which requires a short pulse, high brilliance beam. Therefore, an upgrade program for the UNILAC is running which, as a side effect, will reduce the dc of the UNILAC from 25 to 1%. With this, the cw upgrade of the HLI only makes sense if a new, cw capable linac is build, and this is what has already been proposed. The benefit is, that the two accelerators, the UNILAC and the cw linac, can independently be optimized for their specific tasks. Figure 3 shows the proposed integration of the cw linac into the existing facility at GSI.

The cw linac is based on a new type of rf accelerating cavities, namely superconducting crossbar H-Mode cavities [7]. Together with a new concept of the gap structure, in total nine sc CH-cavities will allow for flexible acceleration of the beam to energies between 3.5 and 7.3 MeV/u. This energy range is adapted to the requirements of most of the experiments that are now served by the UNILAC. The transverse focusing will be done by solenoids between the cavities.

Status of the CW Demonstrator

As the sc CH-cavities are a new technology, it was decided to build a demonstrator unit first. This project is called *sc*

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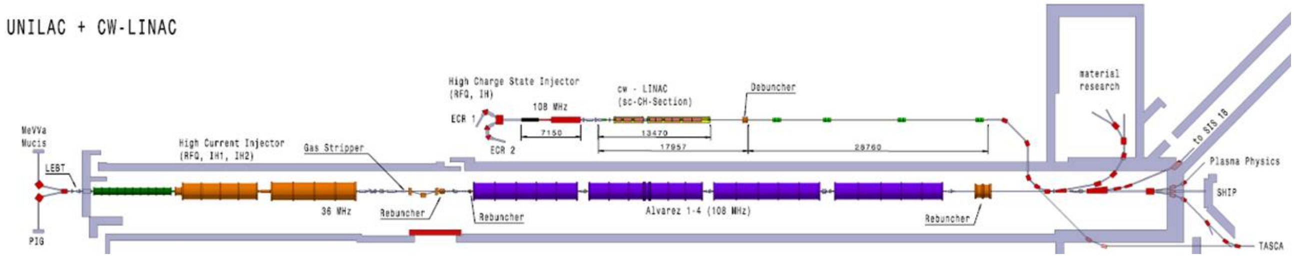

Figure 3: Present proposal for the integration of the cw linac at GSI.

cw-Linac Demonstrator. A test stand is being built behind the HLI. The concrete bunker is already set up (see Fig. 4), wherein a cryostat housing the cavity and a beam line will be placed.

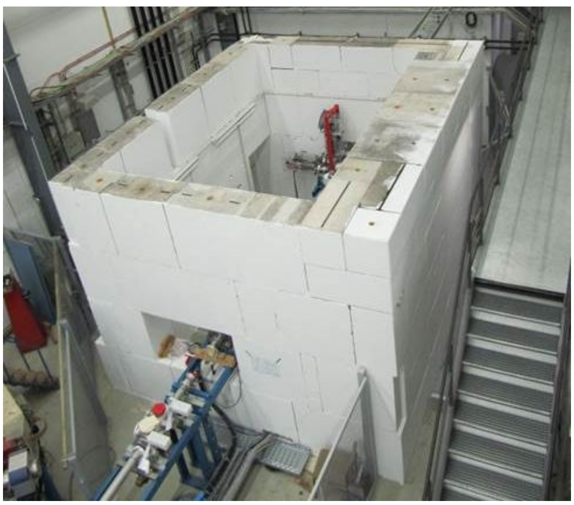

Figure 4: View on the sc CH-demonstrator test bunker and beamline.

Two sc solenoids and one sc CH-cavity (see Fig. 5) have been ordered, as well as the cryostat.

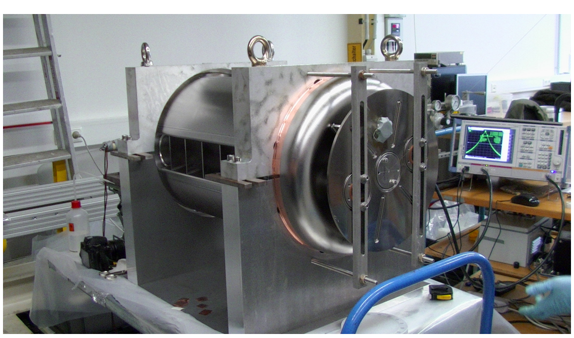

Figure 5: The first sc CH-cavity during manufacturing.

A detailed report on this project was given in this conference series [8]. The cryostat is expected to arrive at GSI in September, the first tests with beam are planned in 2016. Later, these devices will be used as the first section of the cw linac.

As the availability of this technology is essential for the cw linac project, all other upgrade activities are on hold until the first tests have been conducted successfully. The proposal for the next step, an advanced demonstrator consisting of five cavities, is already prepared [9].

SUMMARY & OUTLOOK

The high charge state injector is a very innovative and effective extension for the UNILAC. Today, it is an indispensable injector linac for many experiments at GSI, but the limitations become more perceptible. Increasing demands for higher beam intensities initiated upgrades for the source and for cw capability of the HLI. Both projects were not successful so far, while the road map to achieve these goals is clear. At the moment, all activities are concentrating on the performance demonstration of the sc CH-cavity which is planned for next year.

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