# Commissioning and First Operation Experience of the New Heavy Ion Injector of the UNILAC

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## *Abstract*

A new high charge state injector for acceleration of $U^{25+}$ to 1.4 MeV/u was designed. It consists of a 14.5 GHz ECR source, a 108 MHz RFQ linac and an interdigital H-type accelerator. The installation of the injector was completed in August 1991. Commissioning and first operating experience with O, Ar, Xe ions will be reported.

## 1. Introduction

GSI extended its acceleratior facility by a synchrotron (SIS) and an experimental storage ring (ESR). Both machines are in routine operation now. The UNILAC is simultaneously used as injector for SIS and to serve the low energy physics experimental area. For efficient operating of the GSI accelerator facility, the scheme of time-share operation has been adopted for the UNILAC: beams of different ion species and currents will be extracted from two injectors and accelerated to the desired energies on a pulse-to-pulse basis. In a first step, the UNILAC poststripper accelerator was modified for time-share operation so that energy switching was possible for one ion species. This option is available since beginning of the SIS commissioning in 1989. For fast switching of ion species the new injector has been installed. The 1.4 MeV/u beam will be injected into the UNILAC poststripper accelerator alternating with the beam from the old Wideröe injector as selected by a fast switching magnet.

## 2. The High Charge State Ion Injector

The conceptual design of the high charge state injector (HLI-Hochladungsinjektor) was presented in previous publications.[1,2] It consists of an ECR (Electron-Cyclotron-Resonance) source, followed by a 108 MHz four rod RFQ tank and a 108 MHz interdigital H-type structure. The layout of the new injector and the 17 year old UNILAC injector is shown in Fig.1. Some significant parameters are given for both injectors. The compactness of the HLI demonstrates the development in ion source and accelerator technology over the last decade. The ECR source delivers the same charge states of heavy ions which are generated from the old Wideröe injector by gas stripping at 1.4 MeV/u. The beam currents are comparable or even higher than delivered by the UNILAC prestripper linac. The high charge states of the ECR source allowed a very efficient accelerator design. A 3 m long RFQ tank accelerates the ions from 2.5 keV/u to 300 keV/u. A short beam transport section, including a quarter wave rebunching cavity, provides the transverse and longitudinal matching in the IH tank, which accelerates the ions from 300 keV/u to 1.4 MeV/u with a very high rf efficiency.

The total rf pulse power of the new rf linac is only 200 kW for $U^{28+}$. Also remarkable is the designed high duty cycle of 50% at 100 Hz repetition frequency.

In 1991 all components of the HLI were installed and the comissioning has been started.

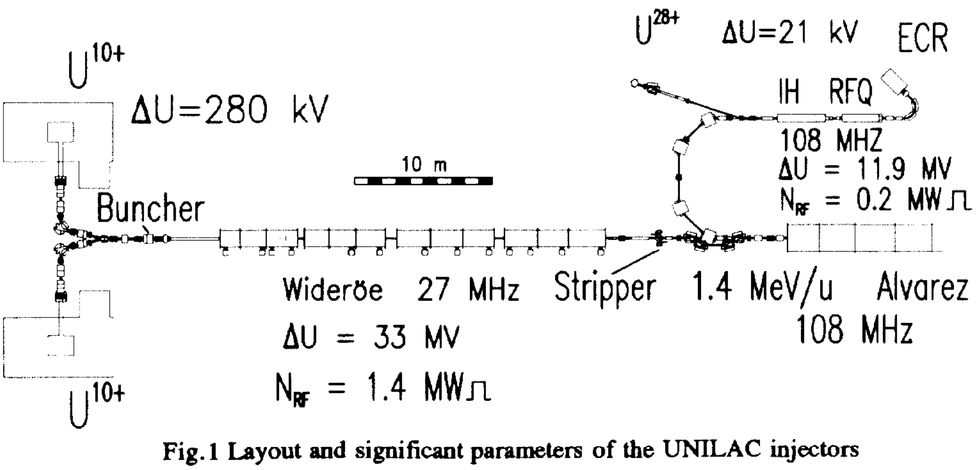

Fig.1 Layout and significant parameters of the UNILAC injectors

## 3. Commissioning of the HLI

### *3.1. ECR and LEBT*

The ECR source was built by R. Geller and his group of CEN, Grenoble. It is of the CAPRICE type and runs at the microwave frequency of 14.5 GHz. Acceptance tests at Grenoble confirmed the design intensities, e.g. 6 $\mu$A $U^{28+}$, 15 $\mu$A $Xe^{21+}$, 20 $\mu$A $Ni^{8+}$. After delivery to GSI in late 1990, the source had already been run on a test bench. Due to the limited acceptance of the analyzing magnet, the measured intensities (30 $\mu$A $Ar^{8+}$, 120 $\mu$A $O^{2+}$, 30 $\mu$A $Fe^{6+}$) were somewhat below the values reported at CEN. The operation of the source was very reliable.

The photograph in Fig.2 shows the the source and the splitted 135 degree spectrometer of the low energy beam transport line (LEBT) of the HLI.

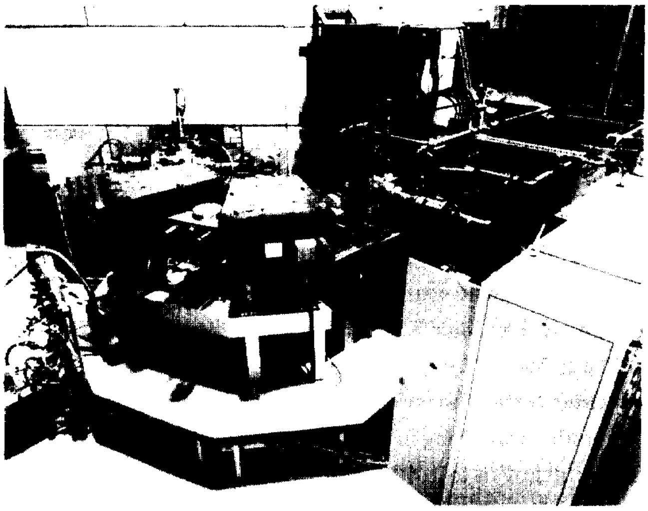

Fig.2 Photograph of the injection beam line (LEBT)

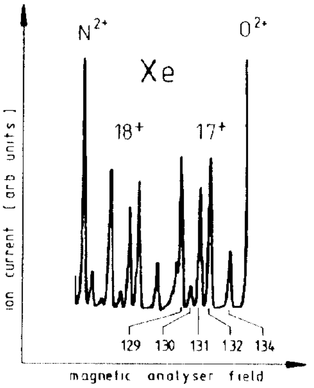

Fig.3 Mass spectrum of $Xe^{17+}$ and $Xe^{18+}$

First operation of the ECR source in combination with the LEBT was started in spring 1991 and was described in Ref. 3,4. Early measurements indicated the expected performance. The design momentum resolution of $p/\Delta p \approx 750$ could be measured with a Xe beam (See Fig.3).

From emittance measurements at the end of the LEBT, we can state that the theoretical acceptance of the following RFQ structure should be fitted very well. The magnetic triplet and the solenoid produced the required narrow beam at the RFQ entrance plane.

Most of the beam time was devoted for commissioning of the rf accelerator structures. $Ar^{8+}$ and $O^{4+}$ were normally used, He was preferred as mixing gas. Ion currents around 100 $\mu$A ($Ar^{8+}$, $O^{4+}$) have been obtained in routine operation. The long time stability of the beam is quite good for gases. Intensity oscillations in the 10-50 kHz range could be avoided by tuning of source parameters (B-field, gas pressure, microwave power). Transmission losses have been measured between the Faraday cups directly behind the source and behind the 135 degree splitpole analyzing magnet. The original extraction system was modified by insertion of special field shaping electrode in order to reduce the beam divergence. However, the transmission losses of 30-40% still occur. New emittance measurements at the exit of the ECR source showed larger values than acceptable by the transport system. As an example, for Ar a 90% emittance of 215 $\pi$•mm•mrad was measured at 1.5 mA total current and 12.5 kV extraction voltage. Beam dynamics calculations show that the effective acceptance is reduced to 160 $\pi$•mm•mrad due to mechanical changes during installation. Furthermore the beam is slightly off-axis ($\approx$ 1.5 degree). The spectrometer is sensitive to the misaligned beam, the effect on the position of the focal point can be compensated by another setting of the singlet lens, but then ions will be lost in the spectrometer chamber. A careful adjustment of the ion source chamber is necessary, work is in progress to improve the mechanical construction. In order to increase the acceptance to the design value of 200 $\pi$•mm•mrad, an extra solenoid behind the source is under discussion.

### *3.2 RF Linac*

The photograph in Fig.4 shows the RFQ and IH tank in the concrete cave. First ion acceleration with $Ar^{8+}$ beam took place in June 1991 in the RFQ structure, and later in August in the IH tank. In Fig.5 the bunch signals of the capacitive probes, positioned behind each tank, demonstrate the stable acceleration. The energy was measured with high accuracy by the time-of-flight method using two capacitive probes. The output energy as function of the rf level for the IH is shown in Fig.6. RFQ measurements will be reported in a seperate contribution of this conference.[5] The measurments are in good agreement with computer simulations. The design energy of 300 keV/u for the RFQ and 1.4 MeV/u for the IH structure could be confirmed. In case of the IH tank, the output energy could be lowered to the required injection energy of 1.39 MeV/u into the Alvarez section by changing the field distribution by the three plungers.

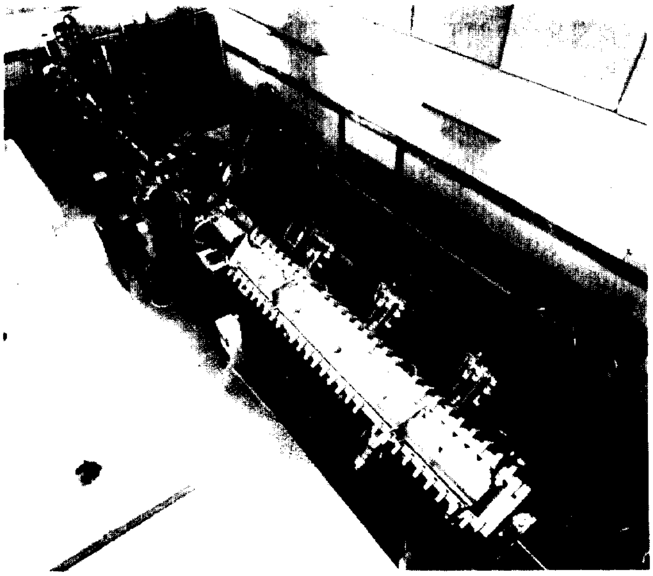

Fig.4 Photograph of the new rf linac (in front RFQ)

Fig.5 Bunch signals behind the RFQ (upper trace) and IH (lower trace), 2 ns/div.

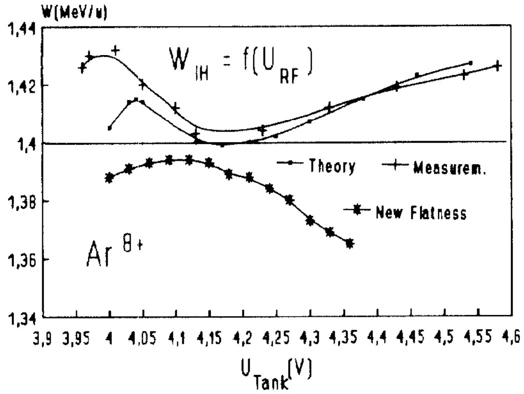

Fig.6 IH output energy as a function of rf field level

The measured rf power set-points confirmed the design shunt impedance of both structures. Field levels for $U^{25+}$ (ca. 125 kW for each tank) were easely reached at 25% duty cycle without sparking problems . At 50% duty cycle, 30 kW average rf power has been tested up to now. At the RFQ tank, rf amplitude modulations have been observed starting at ~45 kW peak power. Extensive investigations indicate that mechanical stability of the rods has to be increased. At present the tank field can be stabilized by the rf amplitude control.

The beam transmission of the RFQ was lower than predicted by computer simulations - not more than 40-50% of the calculated value could be reached. Also the beam is about one degree off-axis. The sources of beam losses could not be determined up to now. The transmission of the IH tank was in the very first run ~85%. We expect full transmission with optimized longitudinal and transverse intertank matching. The measured quality in transverse and longitudinal phase space at 1.4 MeV/u was in agreement with the calculated beam properties. At lower transmission no significant emittance growth was observed. A first test of the dual beam option now available was performed with a 15.4 MeV/u $Ni^{14+}$ beam injected into the SIS and 11.4 MeV/u $O^{3+}$ beam in the UNILAC experiment hall in March 1992.

## 4. Conclusions

The commissioning of the HLI confirmed the overall performance of the ECR-RFQ-IH combination. Remaining problems need further development.

The HLI offers new possibilities for the GSI accelerator complex. As the ECR source can deliver high intensity pulsed beam in the so called "after-glow mode", both injectors can be used for UNILAC, SIS and ESR beams. As the according beam lines can be pulsed, also SIS- and ESR-experiments can use different ion species.

## 5. References

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