THE HIGH CHARGE STATE INJECTOR FOR GSI

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Abstract

A new injector for acceleration of U^{28+} 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 new linac was completed in 1991. The commissioning and first operational experience confirmed the overall performance of the new injector. Remaining problems will be discussed.

Introduction

GSI extended its accelerator 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.

The Design of the High Charge State Injector

The conceptual design of the high charge state injector (HLI - Hochladungsinjector) 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 is shown in Fig.1. A summary of major injector design parameters are given in Table 1.

The ECR source was developed and manufactured at CEN Grenoble. It is an upgraded version of the 10 GHz Caprice source. The 14.5 GHz source delivers the same charge states of heavy ions which are generated from the old UNILAC injector by gas stripping at 1.4 MeV/u. The design beam currents are comparable or even higher than delivered by the UNILAC poststripper linac. The design ion for the new injector is U^{28+} at a current of 5 eμA. With up to 25 kV extraction voltage, the source can provide 2.5 keV/u beams.

Charge and mass analysis is done by a highly dispersive double magnet spectrometer. This bends the beam by 135 degrees into the rf linac. The transverse matching to the linac is done by a magnetic quadrupole triplet and a solenoid.

The rf acceleration of the ion beam starts with a 108 MHz RFQ structure. This structure captures at the low injection energy of 2.5 keV/u the full beam, bunches and accelerates it to the energy of 300 keV/u. The RFQ structure was designed and constructed by the IAP, University of Frankfurt. There, a four-rod design was developed. More details were given in previous papers[3,4].

A short beam transport section, including a quarter wave rebunching cavity, provides the transverse and longitudinal matching in the IH tank. The interdigital H-structure accelerates the beam from 0.3 to 1.4 MeV/u. This structure is used so far in several Tandem laboratories as a postaccelerator, it is characterized by a very high rf efficiency. For the UNILAC application, the radial acceptance has to be increased by at least one order of magnitude. Therefore, two thick drift tubes containing magnetic quadrupole triplets are installed. A further increase of radial acceptance is achieved by a special profile of the synchronous phase along the accelerating gaps. The main part is a zero-degree synchronous phase design. More details about the IH-structure are given in ref.[5,6].

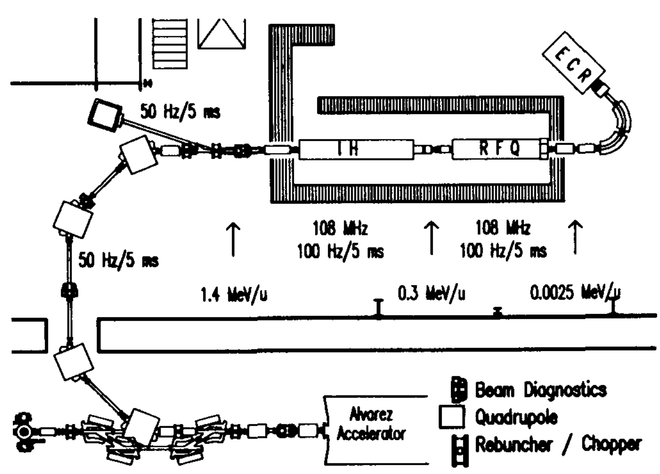

Fig.1 Layout of the new 1.4 MeV/u injector

TABLE 1
Summary of Injector Design Parameters

Source and LEBT

Ion source	ECR-type, 14.5 GHz
Charge-to-mass ratio	0.105 to 1
Extraction voltage	23.8 kV
Energy	2.5 keV/u ($\beta = 0.0023$)
Radial emittance	
(norm.)	0.46 π•mm•mrad
(unnorm.)	200 π•mm•mrad
Mass resolution	$\Delta m/m = 3 \cdot 10^{-3}$

RFQ Accelerator

Structure type	four-rod
Input energy	2.5 keV/u ($\beta = 0.0023$)
Output energy	300 keV/u ($\beta = 0.025$)
Radio frequency	108 MHz
Repetition frequency	100 Hz
Duty cycle	50 %
Max. RF power(U^{25+})	125 kW
Max. voltage	90 kV
Length	3 m
Tank diameter	0.5 m
Radial acceptance	
(norm.)	$\geq$ 0.8 π•mm•mrad
Longitud. emittance	30 π•keV/u•deg
Energy spread	± 1.0 %
Bunch width	± 0.3 ns (± 10 deg)

IH Accelerator

Input energy	300 keV/u ($\beta = 0.025$)
Output energy	1.4 MeV/u ($\beta = 0.055$)
Radio frequency	108 MHz
Repetition frequency	100 Hz
Duty cycle	50 %
Max. RF power(U^{26+})	100 kW
Max. field strength	150 kV/cm
Length	3.55 m
Shunt impedance	310 MΩ/m
Radial acceptance	
(norm.)	1.5 π•mm•mrad
(unnorm.)	60 π•mm•mrad
Longitudinal	
acceptance	150 π•keV/u•deg
emittance	70 π•keV/u•deg
Energy spread	± 0.5 %
Bunch width	± 0.3 ns (± 10 deg)

In Fig.2 the new injector is compared with the 17 years old UNILAC injector. The main differences in DC accelerating voltage, overall length, total rf power and frequency are indicated. 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. The compactness of HLI demonstrates the development in ion source and accelerator technology over the last decade.

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

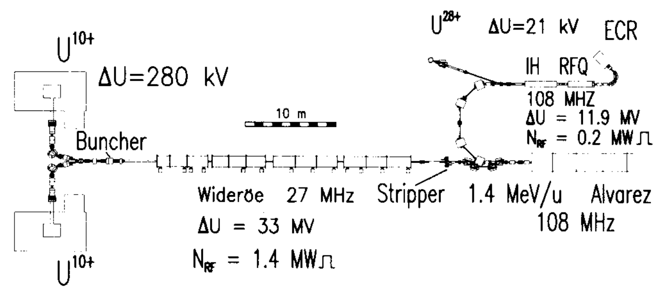

Fig.2 Comparison between the new injector and the 17 years old UNILAC injector

Commissioning and First Operational Experience of the HLI

ECR and LEBT

First commissoning of the ion source and the low energy beam transport section was described in ref.[7,8,9]. Acceptance tests at Grenoble confirmed the design intensities of the ion source, e.g. 6μA U^{28+}, 15 μA Xe^{21+}, 20 μA 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 μA Ar^{8+}, 120 μA O^{2+}, 30 μA Fe^{6+}) were somewhat below the values reported at CEN. The operation of the source was very reliable.

The photograph in Fig.3 shows the source and the splitted 135 degree spectrometer of the low energy beam transport line of the HLI. First operation of the ECR source in combination with the LEBT was started in spring 1991. 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.4). Due to the second order correction of the split pole spectrometer, deterioration of the phase space did not occur.

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.

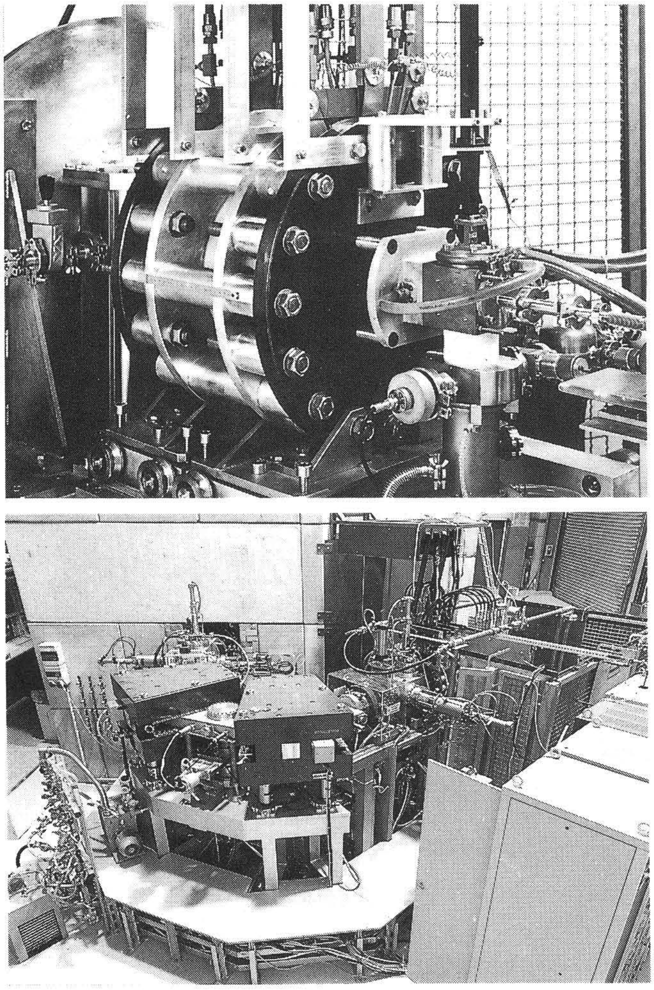

Fig.3 Photograph of the ion source and the injection beam line (LEBT)

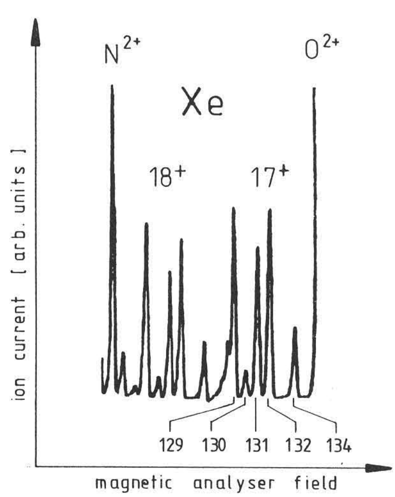

Fig.4 Mass spectrum of natural Xe^{17+} and Xe^{18+}

The magnetic triplet and the solenoid produced the required narrow beam at the RFQ entrance plane.

Most of the beam time was devoted for commisioning of the rf accelerator structures. Ar^{8+} and O^{4+} were normally used, Helium was preferred as mixing gas. Ion currents around 100 μA (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 220 π•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 π•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 the ions will be lost in the spectrometer chamber. A carefull adjustment of the ion source chamber is necessary, work is in progress to improve the mechanical construction. In addition, work is going on to improve the emittance of the source.

RF Linac

The photographs in Fig.5 show the RFQ and IH tank. The arrangements of electrodes in the RFQ tank and also the drift tubes of the IH tank are also shown.

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.6 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 rf level for the RFQ and IH is shown in Fig.7. The beam measurements 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.

Low level measurements of the RFQ structure are reported in ref.[10,11]. Beam tests confirm the design shunt impedance. For the IH tank the rf power is about 20 % higher. Optimization of the field distribution should reduce the rf power.

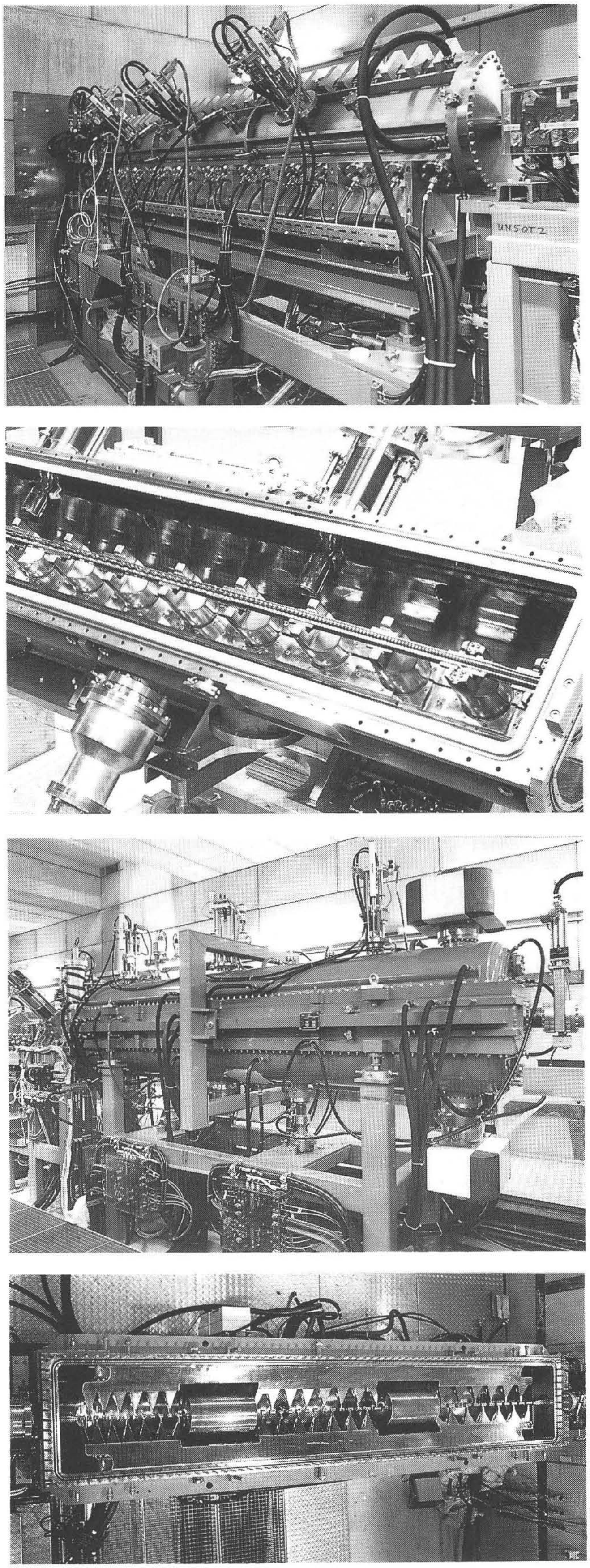

Fig.5 Photographs of the RFQ and IH structure

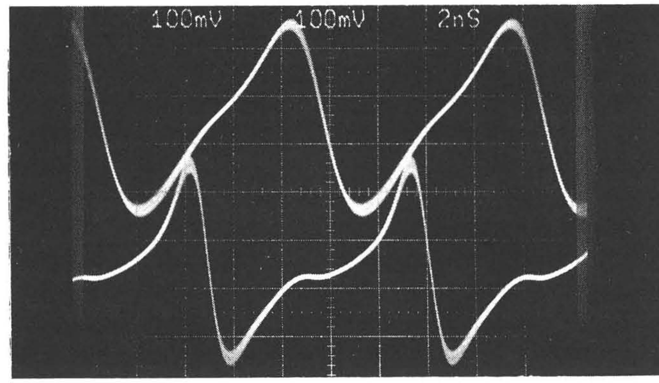

Fig.6 Bunch signals behind the RFQ (upper trace) and IH

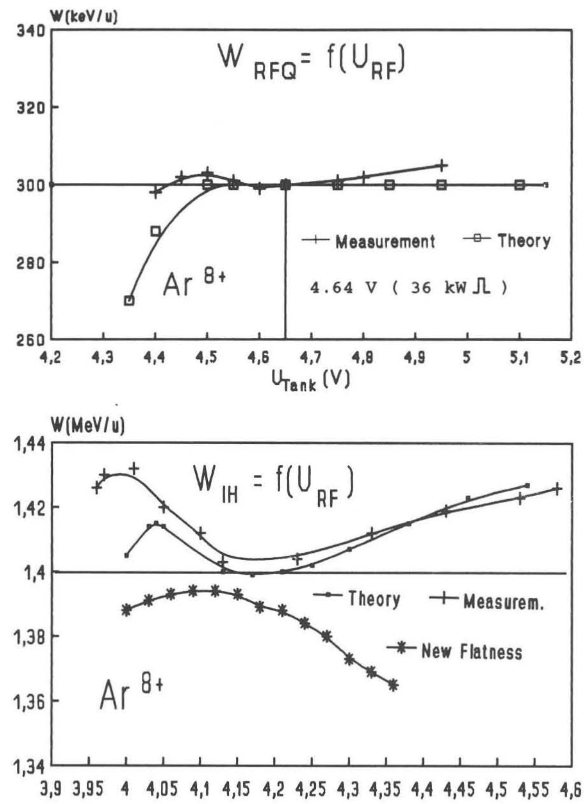

Fig.7 Output energy of the RFQ (upper) an the IH tank as function the rf field level.

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 35-40% of the theoretical value could be reached during the commissioning phase. Also the beam is about one degree off-axis. Computer studies and beam experiments have been started in order to understand the behavior of the RFQ structure. The field asymmetry of the end cells is below 20 %, this effect cannot explain beam the loss.

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 the lower transmission no significant emittance growth was observed.

In April/May 1992 the new injector delivered over a six-week period $^{18}O^{3+}$ to the UNILAC. The operation was very stable and reliable. Unfortunately, a further reduction in the transmission in the RFQ section was observed - only about 20 % could be reached. An inspection of the electrode inside the RFQ tank showed a surprisingly large misalignment of the four rods, the position errors were in the range up to ± 0.8 mm. The check of the alignment was stimulated by computer simulations.[12] The studies indicate that position errors should not exceed ± 0.1 mm. We assume that the cooling of the electrodes is not sufficient at the high duty cycle.

After the realignment beam measurments has been carried out. In Fig.8 the transmission as a function of input emittance is shown before and after the realignment - the improvement is evidently. Because the alignment is still not perfect the design transmission of 100 % at the input emittance of 200 π•mm•mrad cannot be reached. A redesign of the RFQ electrodes has been started.

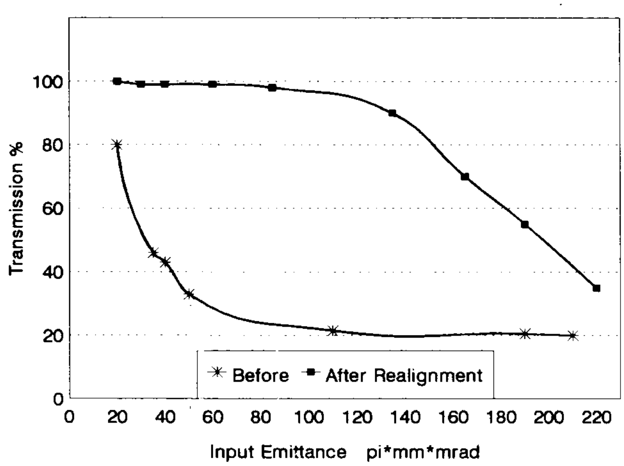

Fig.8 Beam transmission at different input emittances before and after realignment

Conclusions

The commissioning of the HLI and the first operational experience confirmed the overall performance of the ECR-RFQ-IH combination. A redesign of the RFQ structure is necessary. In autumn of this year uranium beam will be accelerated through the whole system. We are expecting successfull operation.

Acknowledgements

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