THE HEIDELBERG HIGH CURRENT INJECTOR: A VERSATILE INJECTOR FOR STORAGE RING EXPERIMENTS

R. von Hahn[1], M. Grieser, R. Repnow, D. Schwalm, C.P. Welsch,
MPI-K Heidelberg, Germany

Abstract

The High Current Injector (HCI) was designed and built as a dedicated single turn injector for the Test Storage Ring in Heidelberg to deliver mainly very high intensities of singly charged Li- and Be-ions for laser cooling experiments. After start of routine operation in 1999 the HCI delivered high quality beams for about 25% of the experiments with very high reliability.

Due to the experimental requirements the HCI mutated from a specialized injector to a versatile multipurpose instrument, able to deliver a large variety of atomic and molecular light ions with either positive or negative charge. In addition provisions are far advanced to implement a custom built 18 GHz high power ECR-source for the injection of highly charged heavy ions suitable for further acceleration.

This paper gives an overview of the experience gained so far and presents the status of the upgrade of the HCI.

INTRODUCTION

The High Current Injector (HCI) consists of an ion source, a 6 m long RFQ section [1] and eight drift tube structures with seven accelerating gaps [2]. Most of the components have been designed and built in house. After final construction the first phase of the accelerator was commissioned successfully in 1999 and since then the machine is routinely operated for experiments [3]. The output energy can be flexibly varied from 0.5 MeV/u (RFQ only) to 2 MeV/u (with all 7 gap resonators) and can be boosted up to 5 MeV/u using the room temperature post accelerator of the MP Tandem.

Until now the HCI performed about 10 to 15 one week beam times per year with a large variety of molecules as well as positively or negatively charged ions at the low RFQ-energy or up to the design energy of 1.7 MeV/u with the 7-gap-Linac. Although the second rebuncher is not yet available, the coupling with the post accelerator was successfully used in a few beam times.

The accelerating structures are preferably used at design velocity. After determination of the correct amplitudes and phases in several test runs with $^{4}He^{+}$-ions only linear scaling for amplitudes and magnet settings is necessary to achieve beams with good transmission for all ion species in the design range A/q Ò9.

After successful commissioning of the custom built ECR-source at its present test location, various modifications were necessary preparing the second phase of the HCI -project. The platform of the CHORDIS source power supplies was raised up to a height of 3 m to create enough space for the ECR-injection.

The charge-state separator between the HCI and the post accelerator was designed and installed. Moreover, in collaboration with the Moscow University we started to investigate the lifetimes of thin foils for additional stripping behind the HCI [4]. However the time schedule for the installation of the ECR at the HCI or at a new application is presently under discussion as changes in the future orientation of physics research at MPI-K are envisaged.

[1] robert.von.hahn@mpi-hd.mpg.de

THE RFQ

The transmission of the 6 m long RFQ consisting of two directly coupled RFQs was measured as a function of the beam intensity. Up to mass to charge ratio 4:1 the available rf power is sufficient to operate the LINAC in CW mode which is more convenient for rf- and beam diagnostics than pulsed mode operation. With higher masses up to the maximum mass to charge ratio of 9:1 the pulsed mode operation with 20 ms long pulses and a duty cycle of 25% is required. The majority of required beam times were done in CW mode.

The following figures 1 and 2 demonstrate a significant dependence on the beam intensity starting at about 500 µA in CW-mode. At low intensities a bad transmission can be attributed to larger emittances of different ion sources rather than of the RFQ.

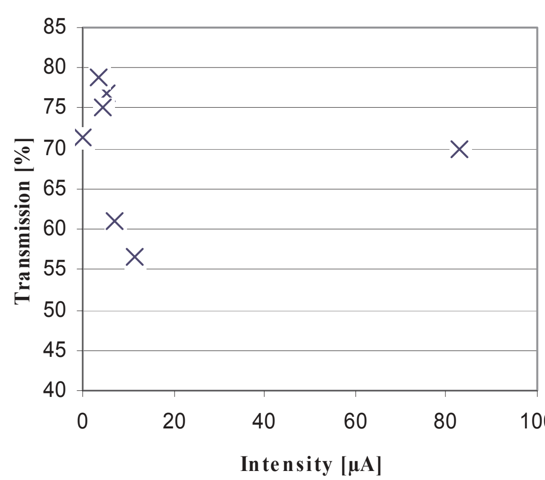

Figure 1: Transmission as a function of the beam intensity in pulsed beam operation.

A reason for losses at intensities close to 1 mA might be the fact that the early codes did not work well enough for the space charge effects. The adaptation to the RFQ possibly can be improved with a solenoid instead of the quadrupole presently used.

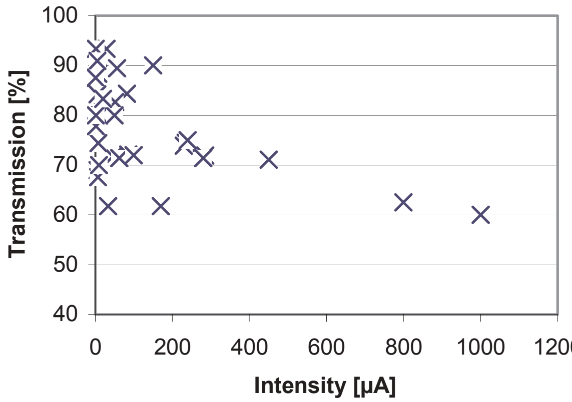

Figure 2: Transmission as a function of the beam intensity in CW operation.

OPERATION AND DEVELOPMENTS AT THE HCI

During the last years the High Current Injector (HCI) delivered a large variety of different molecular and atomic ions for experiments at the Test Storage Ring and for test purposes, Table 1. For difficult beams with very weak intensities from the ion source more prolific pilot beams were used for preparation and tuning of the required beams. The beam intensities reported in Table 1 were limited in most cases by the experiment. The reduction was achieved by a chopper in front of the RFQs or the TSR chopper.

In 2001 we started to deliver beams from a negative sputter ion source (MISS) instead of the standard CHORDIS in order to fulfil the demands for negatively charged ions. After a modification of the extraction system of the MISS to adapt it to the High Current Injector, the combination of MISS and HCI was very effective. Only two lenses have now to be switched to opposite polarity to accelerate also negative ions. In addition, newly developed sources like e.g. an ultra-cold liquid nitrogen cooled source for the preparation of rotational and vibrational cold molecules of H_3 were successfully installed.

For a D^--beam time only half of the RFQ-energy was required. This was achieved by operating the first RFQ in the standard mode and shifting the phase of the second RFQ by 180 degrees as compared to the standard phase. Thus a 1µA D^- beam of 0.5 MeV could be produced.

A variety of beam diagnostics are in use, in which beam profiles at higher intensities are determined using wire grids. The maximum power dissipation on the grid wires limits the applicable beam current to a few µA depending on the ion species and energy. To be able to observe the beam profiles also at higher currents, a beam profile monitor using residual gas ionization was developed. This device consists of two plates with an electrical field in between at a pressure of a few 10^{-7} torr. Residual gas atoms are ionized by the beam and accelerated to the segmented imaging electrode, where an arrangement of 32 collecting strips made of copper is used to detect the ions. The read out system was designed in such a way that the electronics used for the profile grids can be used with small modifications also for the residual gas monitors.

First measurements with 360 µA $^4He^+$ at an energy of 1.9 MeV demonstrated the functionality of this new system. To compare the measured beam profile of the residual gas monitor with the profile grid measurements a pulsed current of 78 µA with 1.5 ms pulse length was used. The profiles measured at the same position agreed within 0.1 mm to the measured FWHM value of the beam.

Table 1: Beams delivered by the HCI

Beam	Energy [MeV]	Intensity [µA]
$^1H^-$	0.5	0.6
$^4He^+$	7.67	30
$^2D_2^+$	6.56	3
$^1H_2^+$	3.1	30
$^2D_3^+$	1.4	0.25
$^9Be^+$	4.5	0.3
$^2D^-$	1	1
LiH_2^-	4.5	0.1
$^7Li^-$	5.6	0.2
$^1H_3^+$	1.46	10
LiH_2^-	4.3	0.08
HD^+	1.5	5
D_2H^+	2.4	5
D_2H^+	5.3	5
$^4He_2^+$	4	0.0003

THE ECR

In preparation of phase II of the High Current Injector, a state of the art 18 GHz-ECR-Source, Fig. 3, for the production of highly charged ions was bought and installed on a test bench. The test bench consists of the source itself, a solenoid and a double focusing magnet to resolve the ion source spectra.

During the acceptance tests at the manufacturer we achieved stable operating conditions at the maximum voltage of 36 kV and reproduced the ion intensities from the specifications (Table 2).

Table 2: Design specifications of the ECR

Ion	Mass	Charge	Intensity [eμA]
Ar	40	11^+	80
Xe	129	25^+	10
Pb	208	33^+	3

In 2002, all infrastructure work of the test bench was finished and we could start to operate the source in order to reproduce the design parameters and gain experience for routine operation. As a first step we run the source in the gas mode operating with H, He, N, O and Ar. A versatile new scan and analysis routine was very convenient to evaluate the complex ion spectra delivered from the ECR.

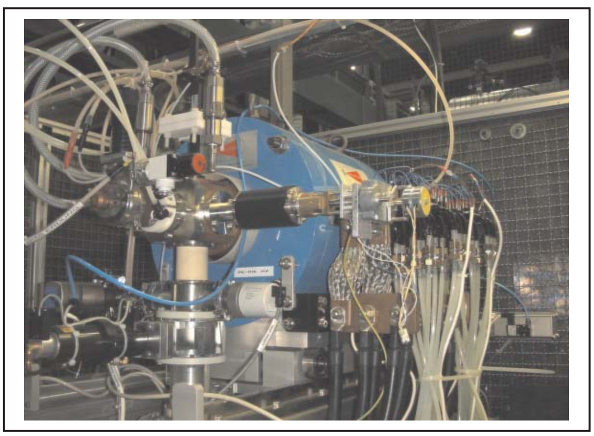

Figure 3: Photograph of the ECR ion source.

A typical spectrum of Argon is shown in Fig. 4. The source was optimized for Ar^{8+} resulting in a current of 400 μA in this charge state. The maximum charge state of Ar was Ar^{11+} up to now.

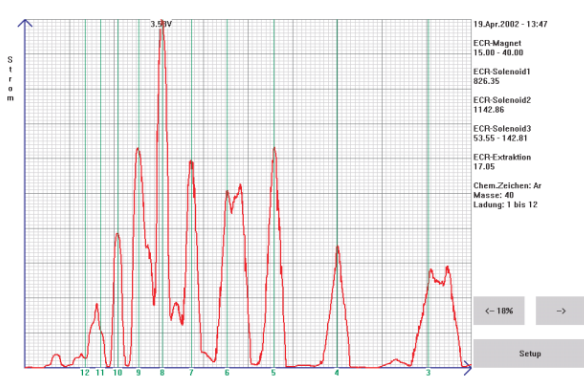

Figure 4: Spectrum of an Argon beam with 17 kV extraction voltage.

Though basically operational the ECR still has to be adapted to the spatial restrictions and the optical requirements of the HCI injection system. The design consists of the ECR, a singlet, an 180° bender and a triplet to focus the beam into the RFQ-section.

A stripper will be required in phase II to increase the ionic charge before further acceleration in the post accelerator. To separate the charge states, a separator system consisting of 4 identical 45 degree bending magnets has been designed and built. Allowing for edge angles of 22.5 degree these magnets are rectangular magnets and fulfill the requirement that the dispersion after the separator is zero. The magnets are already adjusted in the beam line and are routinely in use to determine the beam energy.

CONCLUSION

The principle of two directly coupled RFQs was successfully proven for the first time. Since 1999 the HCI is a very stable and reliably running machine in spite of permanent changes of ion species or required energy.

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