COMMISSIONING OF A NEW CW RADIO FREQUENCY QUADRUPOLE AT GSI

P. Gerhard*, W. Barth, L. Dahl, A. Orzhekhovskaya, K. Tinschert, W. Vinzenz, H. Vormann, S. Yaramyshev, GSI Helmholtzzentrum f. Schwerionenforschung mbH, 64291 Darmstadt, Germany
A. Schempp, M. Vossberg, IAP, Goethe University Frankfurt, 60438 Frankfurt am Main, Germany

Abstract

As part of an intensity upgrade program, a new Radio Frequency Quadrupole (RFQ) has been commissioned at the high charge state injector (HLI), one of the two injector linacs of GSI's UNIversal Linear ACcelerator UNILAC. The main feature of this RFQ is its continuous wave (cw) operation capability. Besides, improved beam quality as well as increased beam transmission are persued.

The HLI mainly provides beam for the super heavy element research, which is one of the major physics experiments at GSI. At the Separator for Heavy Ion reaction Products (SHIP) six new chemical elements have been discovered; moreover nuclear chemical experiments with transactinides were recently performed with the TransActinide Separator and Chemistry Apparatus (TASCA). This experimental program strongly benefits from high average beam intensities. In the past beam currents were raised significantly by a number of improvements. The present upgrade program comprises the installation of a second, superconducting (sc) 28 GHz Electron Cyclotron Resonance (ECR) ion source and a new frontend (Low Energy Beam Transport (LEBT) and Radio Frequency Quadrupole (RFQ)).

For the short term, the new RFQ will raise the useable duty cycle by a factor of two, limited by the following rf cavities. The setup of the RFQ as the major upgrade of the 20 year old high charge state injector was finished in January 2010, the commissioning went on until April. This paper reports on the challenging rf and beam commissioning.

INTRODUCTION

The HLI (Fig. 1) is one of the two injector linacs of the UNILAC. It is equipped with an ECR ion source [1]. The ions are accelerated by an RFQ and IH structure and then fed into the main drift tube linac of Alvarez type. After 20 years of operation, the RFQ more and more became a bottleneck regarding high duty factor operation. For this reason, it was decided to replace the RFQ by a new one capable of cw operation. Additionally, a new 28 GHz MS-ECRIS will deliver higher beam currents and/or higher charge states [2]. The upgraded HLI will later serve as a cw injector for a new cw linac.

All parts of the new 4-rod RFQ (electrodes, stems, tuning plates, plungers and coupling loop) are directly water cooled. This results in 72 connections and vacuum feedthroughs for cooling water (see Fig. 2) in order to reduce the possibility of a leak inside the tank by placing most of the soldered connections outside of the vacuum. Every feedthrough is equipped with prevacuum sealing. Design properties of the new RFQ are given in Table 1, more can be found in [3].

* p.gerhard@gsi.de

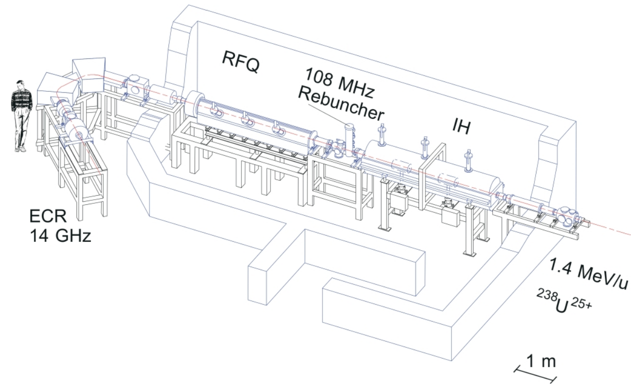

Figure 1: Overview of the high charge state injector HLI.

Figure 2: New RFQ during assembly of the water and prevacuum connections.

Schedule

The RFQ was built by NTG, Gelnhausen, Germany, and delivered to GSI in October 2009. Design, assembly, alignment and tuning was done at IAP, Goethe University Frankfurt. After final assembly of the vacuum and cooling system at GSI it was installed in a rf test bunker for preliminary high power tests. Meanwhile the old RFQ was removed and beam measurements at the matching–in position of the RFQ took place in November. In December, the RFQ was

Table 1: Design Properties of The New HLI CW RFQ

Injection / extraction energy [keV/u]	2.5 / 300
RF frequency [MHz]	108.48
A/q (cw / max.)	6.0 / 8.5
Power (max. avg. / max. pulse) [kW]	60 / 120
Intervane voltage (cw / max.) [kV]	55 / 78
Input emittance n. rms [π mm mrad]	0.1
Output emittance n. rms [π mm mrad]	0.1009
Electrode length [m]	2.0

installed in the final position, followed by rf tests until the first beam time in February 2010. After completion of all installations, the final beam commissioning of the HLI took place end of march. Regular beam time operation started end of April.

RF COMMISSIONING

During first rf power tests reasonable power levels could be reached within hours. On the second day about 16 kW avg. power were reached, when suddenly the resonance frequency shifted by 1 MHz. It turned out that one of the contact springs of the tuning plates was destroyed by impact of heat, others also showed damages (see Fig. 3). Parts of some springs did not reach the optimum contact to the stem, because some of the tuning plates were not aligned properly. Besides, operation is limited to an avg. power of 30 kW with this type of contacts. All contacts were renewed and the plates were aligned properly.

Figure 3: Burnt contacts springs.

In the first long rf commissioning period all conditioning and tests were restricted to the power limit of 30 kW. Both high amplitudes and short pulses as well as high duty cycles and lower power levels were applied, limited by the raise of the vacuum pressure. The highest rf power was reached after beam commissioning, when the RFQ was operated with up to 24 kW avg. resp. 98 kW pulse power, and duty cycles between 10 and 40%. Afterwards the tank was opened, one partly damaged contact was found and the contacts were renewed again.

The recommissioning of the HLI was performed with a low mass–to–charge ratio beam only. It was followed by another period of rf conditioning. During this 90% of the maximum pulse power and 50% of the avg. design power could be reached. After two days of successful conditioning, again one contact spring was completely burnt, while all other contacts seemed to be unaffected. After this it was decided to have all contacts replaced by a different type which is considered to be more robust. Since then the RFQ has been operated at a maximum of 90 kW pulse power and 23 kW avg. power without further problems.

A major issue of the RFQ are modulations of the reflection in the rf pulse, which became visible during the rf commissioning. The reflected power changes in the order of up to 10% (see Fig. 4). The free ends of the rods are excited by the rf pulse and vibrate mechanically, changing the rf matching at a rate of about 500 Hz. This problem can be handled by choosing specific pulse lengths were the excitation of two consecutive pulses cancels out, at the expense of free pulse length availability.

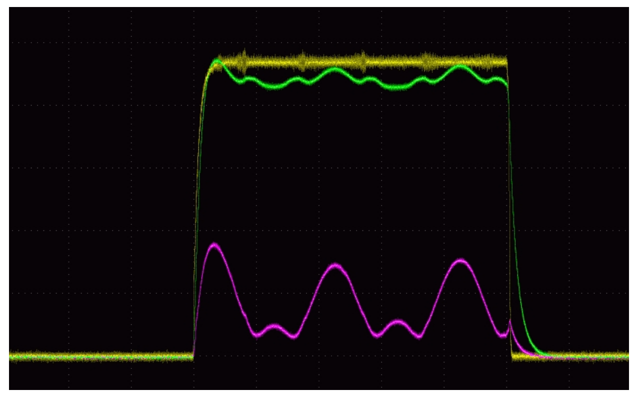

Figure 4: RF measurements of the new RFQ. The tank signal (yellow), forward (green) and reflected (magenta) power are shown. The amplitude was 55%, which corresponds to 45 kW pulse power. The pulse length was 5 ms, duty cycle 25%.

Another problem arises from the quick response of the structure to changes in thermal load. Because of the direct cooling the resonance frequency changes very fast, which implies a fast plunger control. If the plungers move too fast, though, they tend to overshoot the optimum. Substantial effort was made to find a reasonable setting, still changes in amplitude have to be applied carefully.

BEAM COMMISSIONING

The beam commissioning of the new RFQ was performed in three steps. The first step covered measurements of the beam before entering the RFQ. A beam emittance measurement device was installed behind the matching solenoid. One full week was spent mainly on emittance measurements with $^{40}Ar^{5+,7+,8+,9+}$ at two different beam energies. Some results are shown in Fig. 5.

The second step was the beam commissioning of the RFQ. The same emittance measurement device and additional diagnostics were installed behind the RFQ. Using $^{40}Ar^{6+,7+,8+}$, extensive measurements of the beam parameters (transversal emittance, energy, transmission, bunch shape) of the RFQ were conducted. Investigations on the

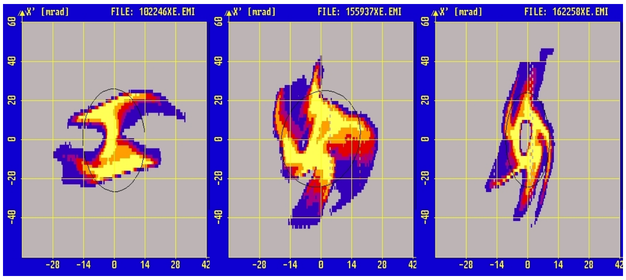

Figure 5: Typical measured beam emittances of Ar^{7+}@2.5 keV/u (left, middle) and Ar^{8+}@4 keV/u (right) in front of the RFQ.

optimum matching of the beam to the RFQ were also performed. As the main result, a proper working point at reasonable rf power could be established, which confirms the theoretical prediction. The expectations regarding transmission and beam quality could be verified. Some important results are shown in Fig. 6.

The last step of the commissioning was carried out after the RFQ was put into its final position. It comprised the confirmation of the results for the RFQ after repair, transversal and longitudinal matching and optimization of the beam for the complete high charge state injector linac and definition of the new default settings for all beam line components.

All beam times during the commissioning went without major problems, and all results were in agreement with the expectations. This also holds true for the first beam time, which could be operated routinely.

SIMULATIONS

The emittance measurements in front of the RFQ were used for simulations of the beam–matching to the RFQ acceptance. A 4D particle distribution was created from the measured emittances and calculated backwards to a point before the last matching magnets. Calculations for different distances between the matching solenoid and the RFQ show only weak dependence of the matching on the distance, which is in agreement with the experimental findings. In support of these simulations, the solenoid was dismantled and a field mapping was carried out to have full information about the magnetic properties. Further investigations of the RFQ are planned.

CONCLUSION AND OUTLOOK

As expected, the rf commissioning of the new HLI 4-rod RFQ was challenging, and high average rf power lead to three breakdowns of the structure. Conditioning and operation also turned out to be time consuming and complicated. Within the tight schedule of the shutdown, it was possible to achieve a successful beam commissioning and the RFQ went into operation with only four weeks delay.

The operation for this year schedules predominantly

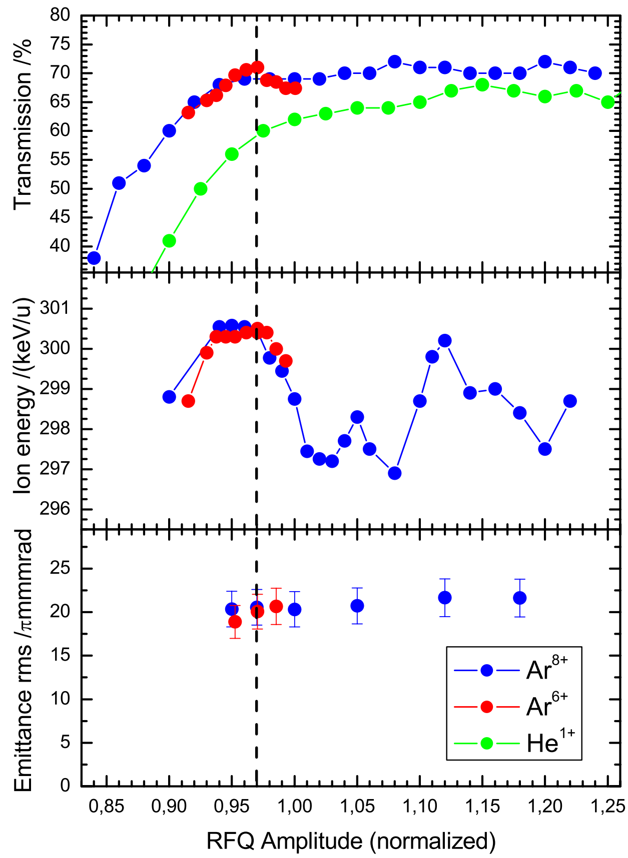

Figure 6: Results of the beam commissioning for $^{40}Ar^{6+}$, $^{40}Ar^{8+}$ and $^{40}He^{1+}$. Measured beam emittances (top), ion energies (middle) and transmissions (bottom) as a function of the RFQ amplitude, normalized to the mass-to-charge ratio are shown. The dashed line shows the working point derived from these measurements.

^{48}Ca, which is not demanding high rf powers in the RFQ due to its low $A/q = 4.8$. In the second half there will be a long run with ^{64}Ni and shorter beam times with Xenon and Nitrogen. These ions require avg. powers around 30 kW.

In order to get further, an upgrade of the tuning plates is foreseen for the end of this year. Advanced high power contacts are currently under design, mechanical tests will be performed in the next months.

In the near future, 50% duty cycle will be the maximum useable. The long term perspective, though, is to use the HLI as an injector for an independent cw linac.

REFERENCES

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