Performance of the GSI HLI-RFQ*

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Abstract

The new "High Charge State Injector (HLI)", a combination of an ECR ion source, a four-rod RFQ, and an IH structure, has been successfully put into operation at GSI. The HLI-RFQ is designed for the acceleration of U^{28+} from 2.5 to 300 keV/u with a high duty factor of up to 50%. Properties of the RFQ resonator and results of beam tests will be presented.

I. INTRODUCTION

The GSI accelerator facilities consist of the UNILAC, the heavy ion synchrotron SIS, and the storage ring ESR. The SIS synchrotron is capable of accelerating all elements including uranium up to energies of 1 Gev/u.

The new HLI- injector for the UNILAC, has been built to provide 2 to 20 MeV/u beams for the low energy program of GSI. The HLI injector consists of an ECR source, an RFQ accelerator, and an IH structure. Fig. 1 shows the arrangement of the HLI.

In recent years the ECR ion sources have been developed produce highly charged ions eq. U^{28+} at currents of up to 5 µA to inject whitout stripper directly into "poststripper" part of the UNILAC.

The 4 rod RFQ accelerator is designed to accelerate heavy ions with a charge to mass ratio of q/A 0.117 (U^{28+}) from an energy of 2,5 keV/u to 300 keV/u and to serve as injector for the following IH structure that further accelerates the beam to 1.4 MeV/u which is the proper energie for the injection into the first Alvarez of the UNILAC.

2. THE 4-ROD RFQ

The resonator consists of four rods arranged as a quadrupole. Diagonally opposite rods are connected by stems that are positioned on a common base plate. The quadrupole field between the electrodes is achieved by a λ/2-resonance which results from the electrodes acting as capacitance and the stems acting as inductivity. Such a structure is shown schematically in Fig. 2.

When the structure frequency and electrode voltage have been chosen to give good focusing properties, the lenght has to be optimized with respect e.g. to the beam emittance, the power consumption and the transmission, which is the ratio of d.c. input beam versus output beam.

The main advantage of this type of accelerator structure is its mechanical design that allows cooling of all components and hence an operation at high duty cycles which is required for the HLI-RFQ.

Fig. 3 shows the final design parameters a,m, and cell length Li along the RFQ structure. Table I summarizes characteristic parameters. The slow increase of the ion energie T as function of RFQ cell number N is demonstranting the fact that a significinant part of the structure is required for bunching.

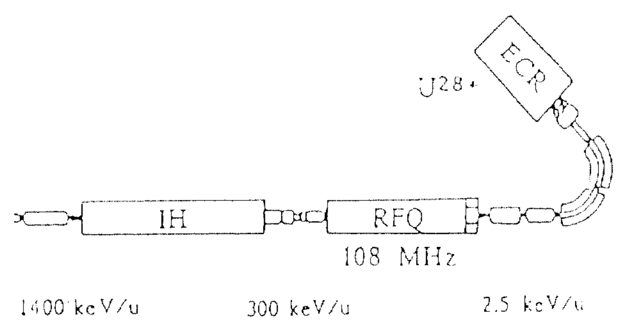

Fig. 1 Layout of the "high charge injector" HLI

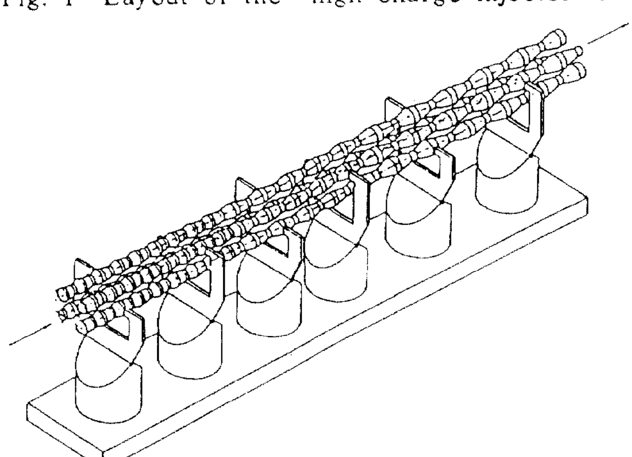

Fig. 2 Scheme of the 4-Rod RFQ structure

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3. RESULTS AND BEAM TESTS

The RFQ was assembled, aligned and tuned at GSI. Before the RFQ went into operation its The field flatness was examined and optimized under low power conditions. The field variation on the axis was +-5% as shown in the solid line in fig.4 (1). Parmteq calculations (fig.5) on the effects of this unflatness on the output emittance show that the beam shows nearly no difference compared to the structure with the ideal flatness (U(z)=const) [7]. Also for the maximum tilt one can achieve by asymerically positioning of tuners (fig.4 (2,3)) the effect is very small. Even for a larger unflatness which was measured at the beginning of the tuning (fig.4 (4)), the transmission and the emittance remain quite unchanged, while the output energy is below the design value and the buch structure is desolved.

The first beam tests were performed in June 1991 and showed encouraging results. The output beam showed the proper bunch structure and ion energy. The signal of the phase probe (fig.6) shows a bunch width of less than 1nsec. The energy of the ion beam is plotted as function of the electrode voltage in fig.7. The radial emittance was in good agreement with the theory, as demonstrated in fig.8

A closer inspection of the output beam showed an angular offset of appr. 1^{o} and more important a smaller transmission than predicted. Only 40-50% of the beam current behind the spectrometer were measured at the RFQ exit [2].

This problem has not been solved yet. We have checked the electrode alignment and the field flatness and operated with a field tilt by intentionally mispositioning of the tuners but the output beam remained unchanged. Also possible dipole components in the RFQ were checked but their value was determined to be smaller than 2% only.

The input matching was modified by shifting the matching solenoid closer to the RFQ and by increasing the gap between the electrode and the beam entrance flange but this had also no effect on the transmission.

So far the transmission of the first part of the HLI differs from the expected value by a factor of 2. Investigations on improving the transmission are still going on. Experiments with helium at increased electrode voltage resulted in the required transmission value of 90%, hence this value can be achieved and is expected to be realized under regular conditions soon.

Rf operation was very stable, very little multipacting at low levels and a quick thermal equilibrium at power levels up to 100 kW 25% d.c. with small frequency shifts.

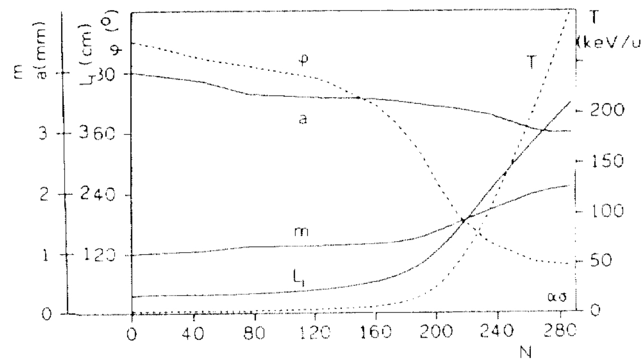

Fig. 3 RFQ parameters vs. cell number

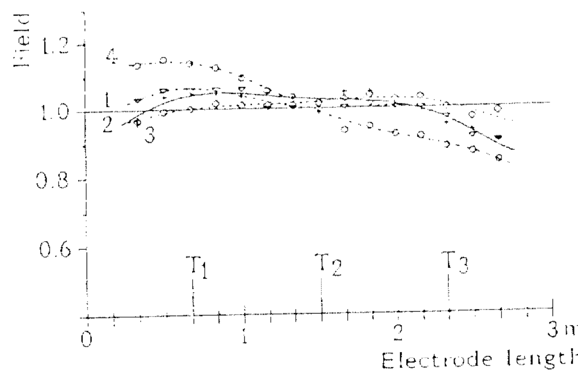

Fig. 4 Measured voltage distribution along the RFQ electrodes for during tuning

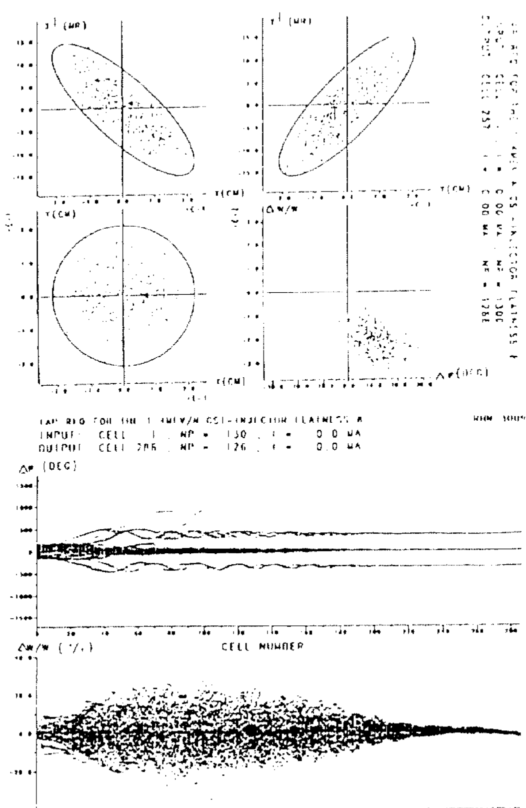

Fig. 5 Calculated output emittances including measured voltage distribution (a) and longitudinal beam behavior vs. cell number (b)

Unexpected difficulties were encountered at high power levels due to a rf modulation caused by ponderomotoric forces, qualitatively similar to the effects studied at spiral loaded cavities [8]. This effect has been characterized as a mechanical oscillation of the electrode ends which was excited at the pulse repetion frequency. Its resonance is at 178Hz at which it shows strong strong amplitude modulation resp. foreward power modulation (fig7) if the tank amplitude is kept constant during the pulse by the control system. Even the pertubation is small at 50 Hz rep. rate and design value of duty cycle of 25% this effect will make it difficult to achieve 50% which at 50Hz without additionally mechanical stabilisation of the electrodes. Fig.10 shows a view of the HLI RFQ.

4. ACKNOWLEDGEMENTS

We thank those who helped and hope that those who are waiting for the completion will still have some patience left until everything works as expected.

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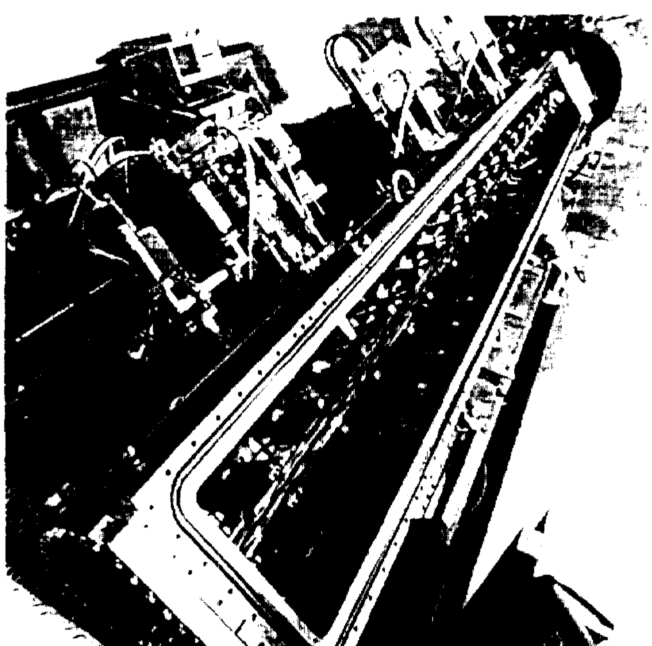

Fig. 10 View of the HLI RFQ

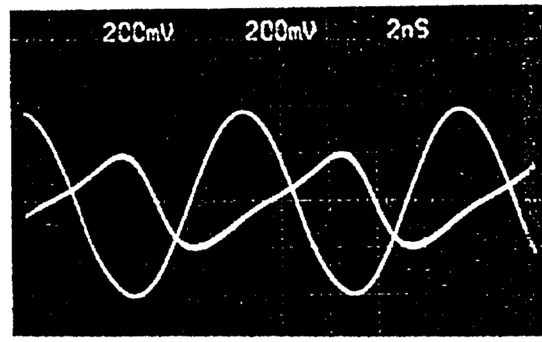

Fig. 6 Phase probe signal of the bunched beam

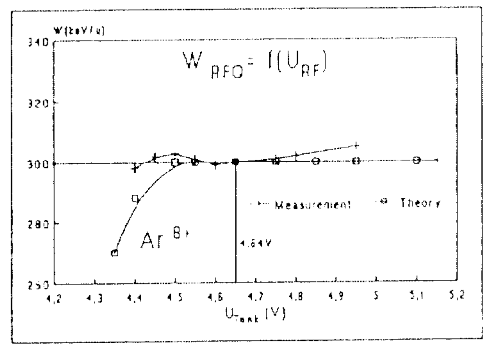

Fig. 7 Output beam energy as function of the electrode voltage

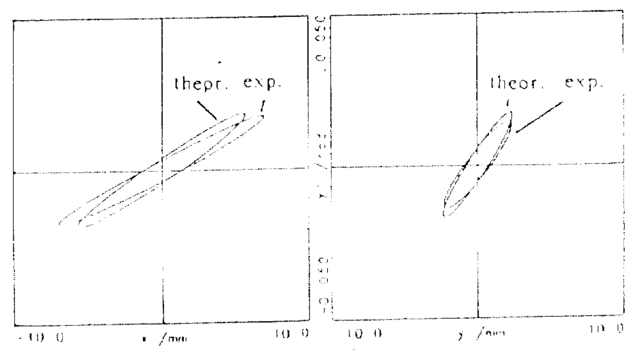

Fig.8 Measured and calculated beam emittances

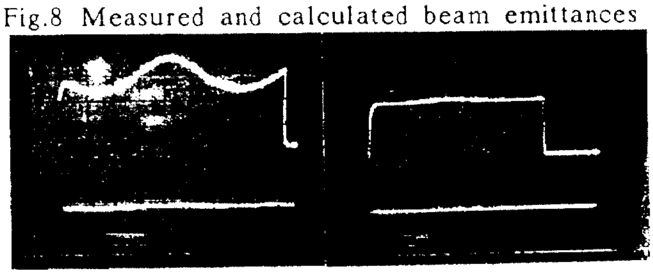

Fig.9 Input power modulation for 178Hz, 4.4msec and 50Hz, 3.5msec rf pulses

Table I. Design parameters of the HLI-RFQ

Injection/final energy	2.5 / 300 keV/u
Frequency , electrode voltage	108.5 MHz /80kV
Duty cycle - rep. rate	25-50%, 50-100 Hz
Aperture/modulation	3.0 mm / 1 - 2.1
Tank diameter , length	35 cm / 3.0m
Radial acceptance (norm.)	1.0 π mm mrad
Input/output emittance	0.5/0.55 π mm mrad
Longitudinal emittance r.m.s. (100%)	10° keV/u