UPGRADE OF THE HLI-RFQ ACCELERATOR*

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Abstract

The initial design of the four-rod RFQ accelerator became operational at the UNILAC high charge state injector (HLI) in 1991. Rf-tests and beam measurements indicated that not all design goals could be achieved. The mechanical stability and cooling for a high duty-cycle operation had to be improved. The new design will be described and the successful operation of the accelerator with uranium beams is reported.

Introduction

The GSI accelerator system [1] consists of the new 18 Tm heavy ion synchrotron SIS and the experimental storage ring ESR, both fed by the old UNILAC. With these new rings and the UNILAC injector it is possible to accelerate all elements up to uranium to energies above 1 GeV/u. The SIS and the ESR are now working since 1990.

Two new injectors HSI (Hochstrominjektor) and HLI (Hochladungsinjektor) have been planned to fill the SIS ring with short bursts of high current heavy ion beams and to continue providing low current, high duty factor beams for the nuclear physics research program at the UNILAC [2].

The high charge-state injector HLI consists of an ECR source and a four-rod RFQ, which accelerates from 2.5keV/u to 300keV/u for injection into the following IH-structure that further accelerates the beam to 1.4 MeV/u which is the proper energy for the injection into the first Alvarez tank without stripping. This injector is designed for a beam current of 5μA for the heaviest ions. The HLI injector, schematically shown in fig. 1, is succesfully working and delivering beams for experiments since June 92.

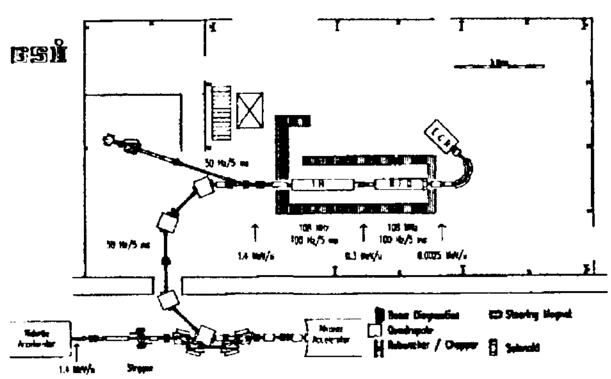

Fig. 1 Layout of the HLI injector

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The HLI-RFQ

The HLI-RFQ is a fixed frequency four-rod structure operating at 108.5 MHz. The resonator insert consists of four rods arranged as a quadrupole with diagonally opposite rods connected by cylindrical stems that are positioned in one plane on a common base plate, as shown schematically in fig. 2. The quadrupole field between the electrodes is achieved by a π-λ/2-resonance for which the electrodes mainly are the capacitance and the stems acting as inductivity. After the choice of frequency the electrode voltage and the geometrical parameters were optimized with respect e.g. to the beam emittance, the power consumption and the beam transmission.

The mechanical design of this type of accelerator structure allows cooling of all components. The stems, the electrodes, and the tuning blocks are mounted into the tank by screws to be able to change components in case of problems with high duty factor operation, which is required for the HLI-RFQ. Table 1 summarizes characteristic parameters. After the RFQ had been assembled, aligned and tuned, the field flatness was examined and optimized under low power conditions. The field variation along the axis was less than 5%.

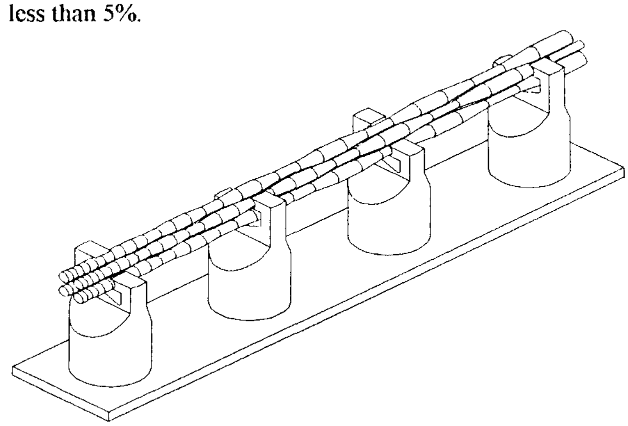

Fig 2 Scheme of the Four-Rod-RFQ

Table 1
Main Parameters of the HLI-RFQ

f	108.5 [MHz]	length	2.95 [m]
cells	287	Rp	175 [kΩm]
T_{in}	2.5 [keV/u]	T_{out}	300 [keV/u]
φ_s	90-18 [°]	a	4.0 - 3.0 [mm]
m	1.0 - 2.1	α_N	0.5 [π mm*mrad]
U_{el}	9.4 A/q [kV]	transmission	> 90%

The first beam tests showed good results. The output beam had the proper bunch structure and ion energy. The width of the bunch, measured by time of flight with two probes, was less than 1 nsec. The energy of the ion beam and the radial emittance was in good agreement with the theory. In the beginning of the commissioning the beam transmission was 50%. It decreased continuously to 20% even at small input emittances (see curve a in fig.3), while close to 100% were calculated by the PARMTEQ code. Only by increasing the electrode voltage above the design value (for light ions like He^+) the transmission increased to 90%. Extensive beam measurement, field calculations and beam dynamics studies indicated that the misalignment of the four electrodes can lead to the observed beam losses [3,4,5].

An inspection of the RFQ tank confirmed the suspicion: the initial alignment of the four field generating electrodes was changed, radial displacements up to 0.8 mm were measured. Beam dynamics computations showed that already deformations of only 0.2 mm result in field distortions and transmission losses. A realignment of the electrodes - before the RFQ upgrade - improved the beam transmission considerably (curve b in fig. 3).

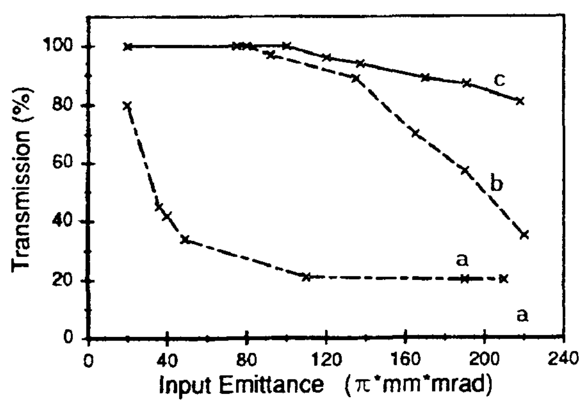

Fig. 3 Beam transmission for different input emittances before and after the upgrade

For the cooling of the electrodes, 4 mm diameter cooling lines were brazed to the back of the electrodes. Therefore the waterflow was limited. At high fields and 25% duty cycle the temperature of the cooling water for the electrodes was increased by 40 °C. It became evident, that the resulting thermal stress is a source for misalignment.

Also rf-operation revealed some problems: rf-operation was stable, with very little multipactoring at low levels and a quick thermal equilibrium at power levels up to 130 kW (25% duty cycle) with small frequency shifts. At high power levels an rf modulation caused by ponderomotive forces was observed, which was qualitatively similar to the effects studied at helical and spiral loaded cavities. This effect was characterized as mechanical oscillations of the electrode ends, which were excited at the pulse repetition frequency. Its resonance is at 178 Hz at which it shows strong amplitude resp. forward power modulation, if the tank amplitude is kept constant during the pulse by the control system. Even the pertubation could be controlled at 50 Hz repetition rate and design field value, this effect makes it difficult to achieve 50% duty factor without additional mechanical stabilization of the electrodes. An improved feedback system would have solved this problem as well, but it would not be practical for routine operation.

An improved design has to have a better cooling of the field producing electrodes and an increased mechanical rigidity. The 4 mm diameter cooling lines were replaced with 12 mm tubes increasing the cooling roughly fourfold. Figure 4 shows the new arrangement of the electrodes and the attached cooling tubes.

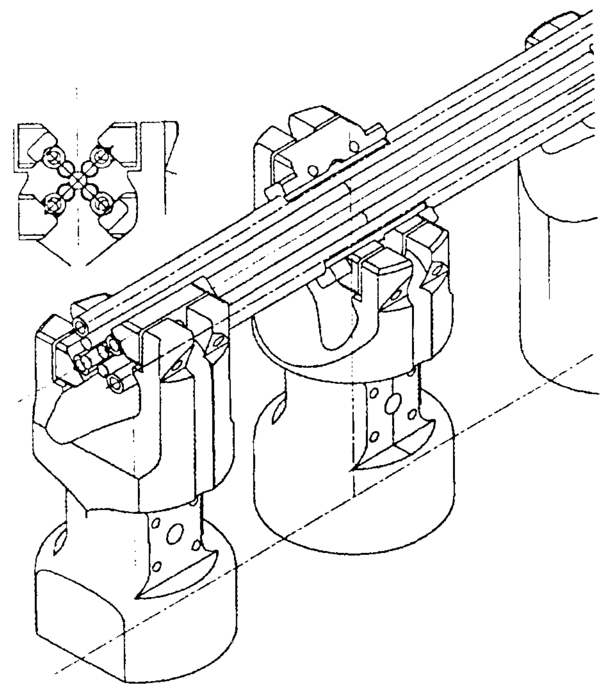

Fig. 4 Arrangement of four-rod electrodes with direct cooling

The design changes should not alter the rf-properties of the structure such as the quality factor Q or the shunt impedance. This goal was realized in part by proper selection of the tube diameter, by changing of the mounts between the stems and the electrodes in order to reduce the capacitive loading. A modified stem design allowed the cooling lines and electrodes to be mounted directly onto the stems. The cooling tubes were soldered due to the tight time schedule. At present the brazing technique in a vacuum oven is tested and the electrodes will be replaced for safer operation. The electrodes were aligned with a high precision, an accuracy of position within ± 0.08 mm could be achieved.

The larger cooling tube for the electrodes gives a stiffer system at the same time. Together with the better alignment the operational properties have been improved. Curve c in fig. 3 shows the improved transmission even for larger beam emittances. The temperature of the rods is now raised by 6 degrees only at full field level and the mechanical oscillations are suppressed. The maximum power load of the RFQ has been raised to 175 kW / 25% duty cycle.

The operation of the upgraded RFQ accelerator has confirmed the expected performance. At a 25% duty cycle uranium acceleration has been demonstrated in a long-term run. Afterwards no misalignments of the electrodes have been detected. At present the cooling of the internal base plate is installed for further improvement of the operation and to achieve the 50% duty cycle.

Conclusions

The upgrading of the HLI-RFQ has been successful. The HLI is now in routine operation for the physics program. The new injector enables the independent two beam operation for UNILAC and SIS experiments [6]. After installation of the cooled base plate and the brazed electrodes the 50% duty factor operation is expected soon.

Acknowledgements

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References

[1] K. Blasche, D. Böhne "Status Report on the GSI Synchrotron and first Beam Results", PAC 89, IEEE-89CH2669-0 (1989) 27
[2] J. Klabunde, "The UNILAC Upgrade Project" Linac 88, CEBAF Rep. 89-001 (1989) 242
[3] J. Klabunde, "The High Charge State Injector for GSI", Linac 92, AECL-10728 (1992) 570
[4] J. Friedrich, A. Schempp, H. Deitinghoff, U. Bessler, H. Klein, R. Veith, "Performance of the GSI HLI-RFQ", Linac 92, AECL-10728 (1992) 609
[5] J. Klabunde et al., "Beam Dynamics Simulation in a Four-Rod RFQ", these proceedings
[6] N. Angert et al., "Two Beam Time Share Operation of the UNILAC", these proceedings