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PARTICLE DYNAMICS IN A LOW FREQUENCY HIGH CURRENT RFQ PROTOTYPE†

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A new high-current injector for all ions up to uranium is planned at GSI, the first part being a large RFQ operating at 27 MHz. A prototype corresponding to the low-energy part of this RFQ (~4 m, 190 cells) is being built at the Institut für Angewandte Physik for rf and beam tests. Results of particle dynamics calculations and the status of the project will be discussed.

1 INTRODUCTION

At the Gesellschaft für Schwerionenforschung (GSI), Darmstadt, major parts of the experimental work for the German heavy ion inertial fusion program can be done because of the unique heavy ion accelerator facilities[1]. While the synchrotron SIS and the storage ring ESR have already been installed,[2] the upgrade program for the UNILAC is still underway[3]. A high charge state injector is being built for nuclear physics research at the UNILAC; when it is operational, the first part of the UNILAC will be rebuilt into a high-current injector linac for SIS. This injector should be capable to accept and accelerate heavy ion beams with currents as high as 25 mA of U^{++} at low initial particle energies: for example, 2.4 keV/u. This requires low frequencies (10–30 MHz) to which RFQs are well suited[4,5]. Therefore the injector will be a combination of a high-current ion source, a dc injector, and a large low-frequency RFQ added to the UNILAC. This can be considered to be one injection branch of an HIIF driver as described in the HIBALL conceptual study[6].

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2 RFQ PARAMETERS

The design of the RFQ is based on the requirements for SIS injection. The maximum current at injection, filling the synchrotron up to the space-charge limit, is 0.2 mA times the ratio of mass over charge state for singly charged ions up to Xe or doubly charged heavier ions up to U. The input energy of the RFQ is 2.4 keV/u. At about 200 keV/u the Wideroe part of the old UNILAC is capable of accepting ion beams of such high intensity. The beam dynamic design for the RFQ uses a novel approach developed for heavy-ion RFQs[7,8,9]. Here the current limits along the RFQ are taken as the main criteria for the choice of the parameters of the accelerator cells. The radial and axial phase advances as well as stable phase, focusing forces, and bunch lengths are changed adiabatically, resulting in a short and compact RFQ with good beam emittance. This allows the RFQ to be operated at the frequency of the Wideroe, 27 MHz. At an electrode voltage of 180 kV, a current limit of 60 mA for U^{++} should be feasible. The overall length is about 35 m. Until now, no operational RFQ has fulfilled these requirements. Therefore a prototype covering a relevant part of the full scale RFQ is being built in the Institut für Angewandte Physik for rf and beam test measurements to validate the design criteria.

3 BEAM DYNAMICS CALCULATIONS

Beam dynamics calculations have been carried out with the PARMTEQ code developed at LANL[10]. Figure 1 shows results for an RFQ consisting of 550 cells, corresponding to a length of 20.5 m and a final energy of 130 keV/u. In the upper plots no space-charge forces are included; in the lower part calculations were done for the design current. In both cases the longitudinal and transverse beam formation takes place in the first part of the RFQ; later on, only slow changes occur. This is also illustrated in Figure 2, where transmission and relative transverse emittance growth are plotted versus cell number. The prototype should consist of about 200–280 cells for obtaining relevant information from beam measurements. For reasons of available space, rf power and handling, the prototype will be 4 m long, i.e., 220 cells. The main parameters of the prototype are listed in Table 1.

For a normalized transverse input emittance of 0.3 π mm mrad (130 π mm mrad unnormalized) and a transverse waterbag distribution, the transmission is 94% in the case of no space-charge forces, and the transverse emittance growth is less than 10% for 100% of the output beam. At design current the transmission is reduced to 92% in the prototype, the transverse focusing still has to be increased slightly to improve transmission. The transverse emittance growth is about 40% for the full beam and 20% for 95% of the output beam. The longitudinal output emittance at the end of the prototype is smaller than 8° keV/u and is decreased to about 2° keV/u at an energy of 130 keV/u, which is clearly better than the required value for injection into the Wideroe. The results also show that, up to now, no disadvantages concerning beam quality could be found compared to the standard design; see Ref. 11. The space-charge calculations were done with an $r - z$ Poisson solver, including the effect of neighbor bunches and image charges (assumption: metallic tube at aperture a).

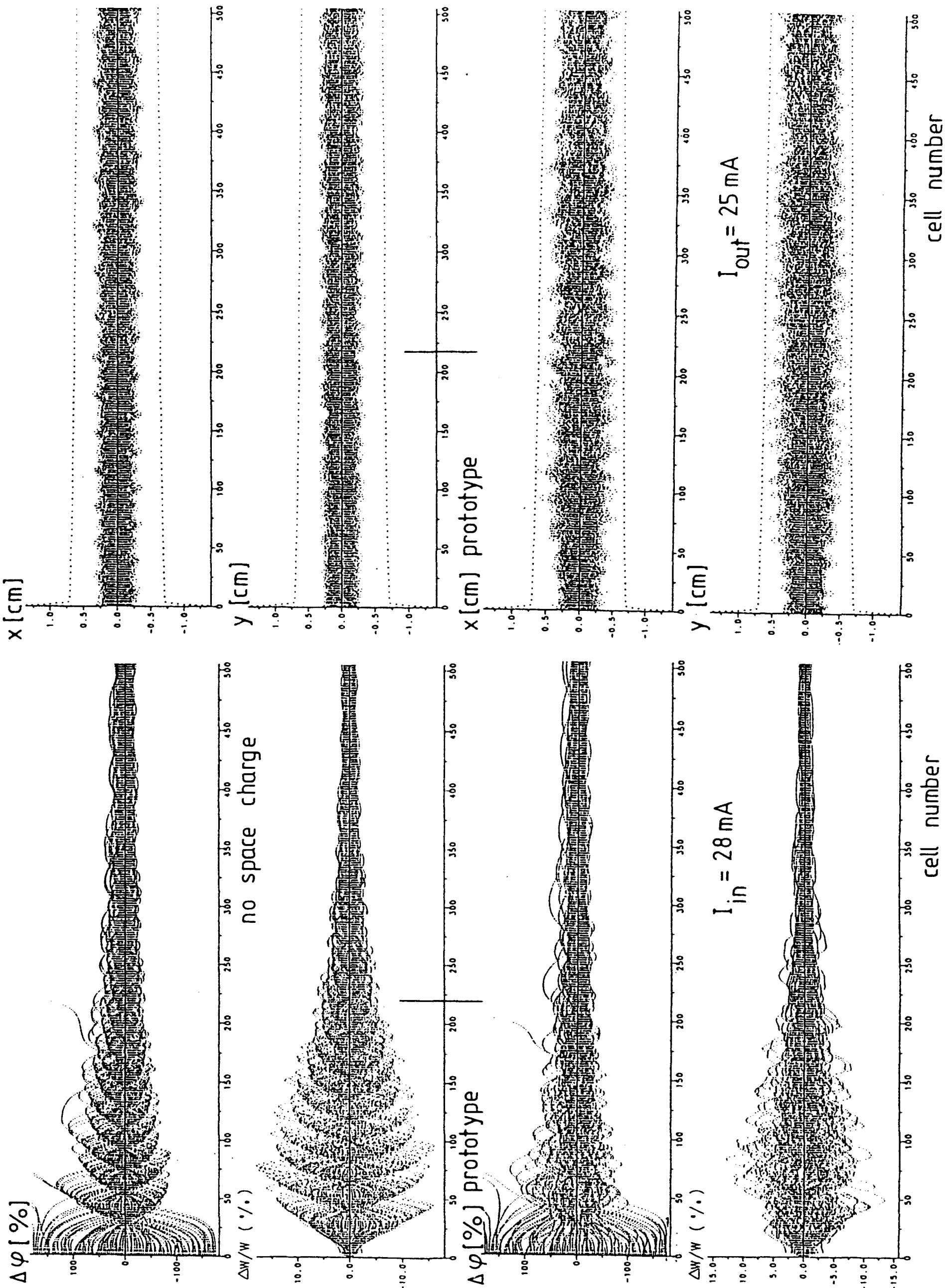
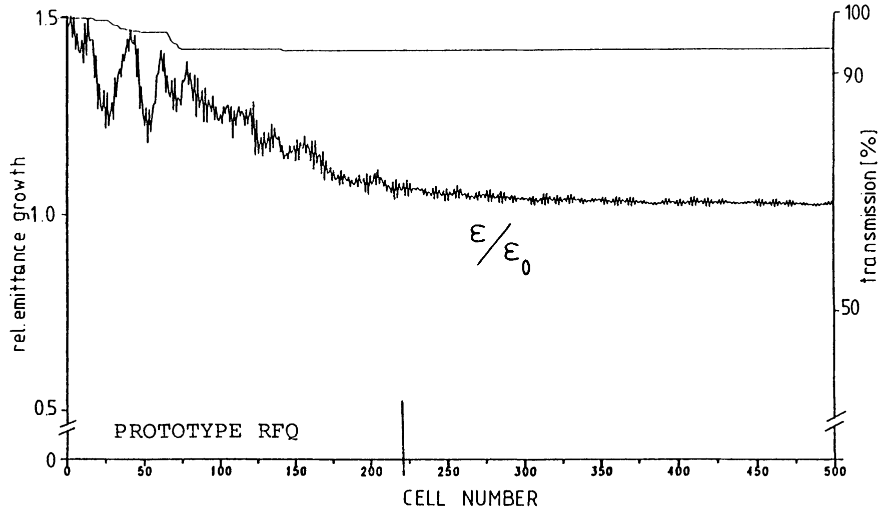
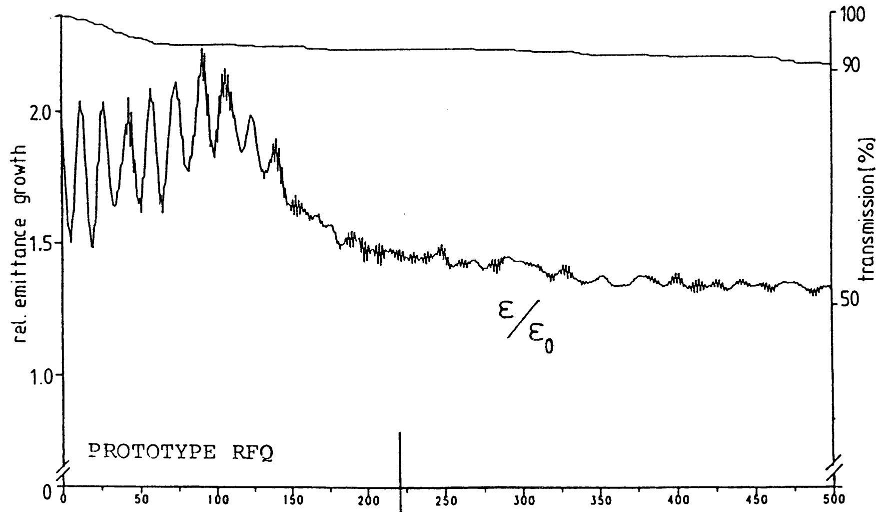


FIGURE 1 Longitudinal and transverse beam behavior along the RFQ up to 130 keV/u. The prototype covers the part where longitudinal and transverse beam formation primarily takes place. Input emittance: 0.3 π mm mrad normalized, matched beam.



(a)



(b)

FIGURE 2 Transmission and relative emittance growth corresponding to FIGURE 1 for (a) no space charge, and (b) design current.

4 STATUS OF THE PROJECT

Sparking tests were performed with a 1-m-long, four-rod spiral RFQ with unmodulated electrodes. An electrode voltage of up to 205 kV (minimum gap 7 mm) could be achieved at duty cycles of up to 5%—higher than necessary for SIS operation. The measurements were limited by the available output power of the rf amplifier. No sparks were observed[12] after conditioning.

TABLE 1
RFQ Parameters

Frequency f [MHz]	27
Length l	3.97 [m]
Number of cells	220
Input energy T_{in}	2.4 [keV/u]
Output energy T_{out}	20 [kev/u]
Synchronous phase φ_s	90–39[°]
Minimum aperture radius a	7.0–6.4 [mm]
Modulation parameter m	1–1.3
Transverse synchronous acceptance α^{tr}_{synchr} (norm)	1 π [mm mrad]
Input emittance ε_{in}(norm.)	0.3 π [mm mrad]
Design current I	$0.2 \cdot A/\xi$ [mA]
Electrode voltage U_{el}	$1.51 \cdot A/\xi$ [kV]
Maximum ratio of mass to charge state A/ξ_{max}	130
(A = atomic mass number, ξ = charge state)	

The aluminium vacuum tank of the prototype RFQ and the spiral stems have been ordered; assembly will be finished in spring 1991. First beam tests with a He^+-beam are scheduled for June in the institute. The ion source and the extraction system are operational. Two einzel lenses, under construction, will provide a converging beam with an angle of about 2.5° for radial matching into the RFQ. The design current for He^+ is 0.8 mA and the corresponding electrode voltage is 6 kV, which facilitates first operation and beam measurements in our laboratory. Higher currents can be accepted at increased electrode voltages as shown in Figure 3. The dependence of transmission and emittances on voltage and beam current will be compared to results of beam simulation for determining the properties of the RFQ as precisely as possible. Adequate devices for energy and emittance measurements are at hand[13]. After this short test phase, the RFQ, which is shown in the computer drawing of Figure 4, will be installed at the high current injector test stand and operated at high rf power levels with heavy ion beams, e.g., Ar^+ or Kr^+, at GSI.

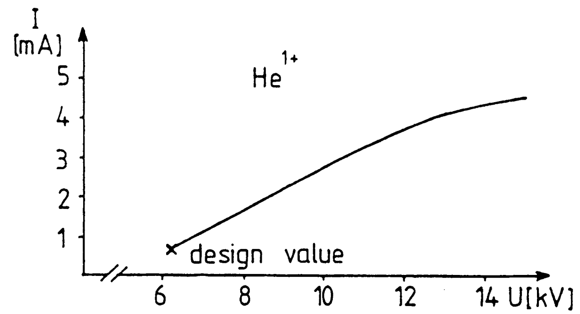


FIGURE 3 Beam current versus electrode voltage for He^+ for a transmission of 90% in the prototype; $\varepsilon_{in} = 0.3\ \pi$ mm mrad normalized.

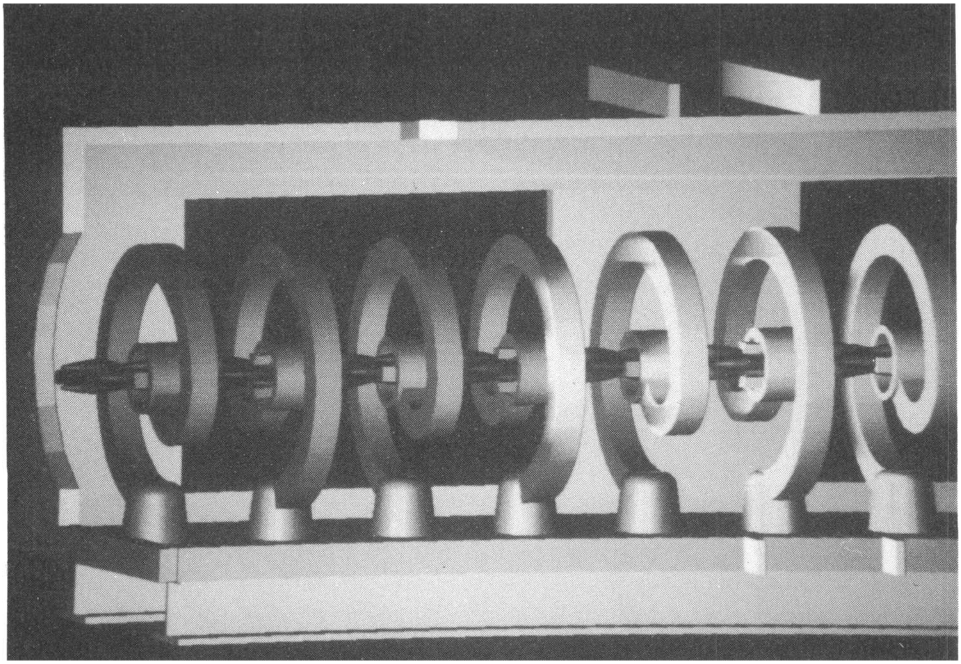


FIGURE 4 Computer drawing of the prototype RFQ.

5 CONCLUSION

The design of a heavy-ion, high-current RFQ operating at 27 MHz will be tested by a short prototype accelerator, which covers one third of the total cell number at a length of 4 m. The relevant part of beam formation takes place in this portion. Measurements of beam quality, transmission, mechanical and rf properties can provide the necessary information needed for the construction of the full-scale high-current UNILAC injector for SIS.

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