THE FRANKFURT FUNNELING EXPERIMENT*

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Abstract

Funneling is a procedure to multiply beam currents of rf-accelerators at low energies. In the ideal case the beam current can be multiplied in several stages without emittance growth. The Frankfurt Funneling Experiment consists of two ion sources, a Two-Beam RFQ accelerator, two different funneling deflectors and a beam diagnostic equipment system. The whole set-up is scaled for He^+ instead of Bi^+ for the first funneling stage of a HIIF driver. The progress of our experiment and the results of the simulations will be presented.

INTRODUCTION

The maximum beam current of a linac is limited by the beam transport capability at the low energy end of the accelerator. For a given ion source current and emittance the linac current limit is proportional to $\beta = v/c$ for electric and to β^3 for magnetic focusing channels and ideal emittance conservation. The funneling scheme is making use of the higher current limits at higher beam energies by doubling the beam current combining two bunched beams preaccelerated at a frequency f_0 with an rf-deflector to a common axis and injecting into another rf-accelerator at frequency $2 \cdot f_0$ as shown in figure 1. Ideally the beam emittance could be staying as low as for one single beam. Extracting twice the beam from a single ion source would result in at least twice the emittance for the following accelerators.

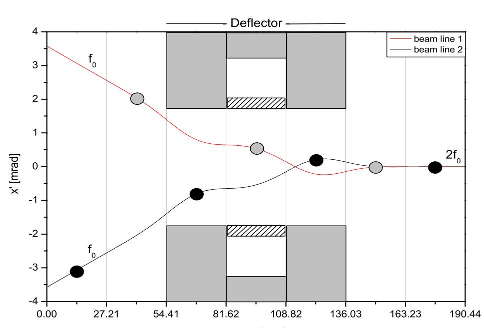

Figure 1: Principle of funneling demonstrated at a 3 cell deflector. To reduce the bending voltage drift tubes can be placed in the wider electrode apertures (shaded rectangle).

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A tree of ion linacs is planned to increase the heavy ion beam current from 25 mA Bi^+ at the first linac to 400 mA at 10 MeV/u for the main linac.

The first linac is an RFQ with two beam channels in one resonator. By the use of the Two-Beam RFQ the distance of the two beams are very small while they are still radially and longitudinally focused. Additional discrete elements like quadrupole-doublets and -triplets, debunchers and bending magnets, as they have been proposed in first funneling studies, might not be necessary [1, 2, 3]. A short rf-funneling deflector is placed at the beam crossing position behind the RFQ [4].

EXPERIMENTAL SETUP

The Two-Beam RFQ accelerator is designed for He^+-ions instead of Bi^+ to reduce experimental expenses, facilitate operation and beam diagnostics (fig. 2,3). Two small multicusp ion sources [5, 6] and electrostatic LEBT lenses are used. The LEBTs are directly mounted at the front of the RFQ. The angle of both beam axes is 75 mrad.

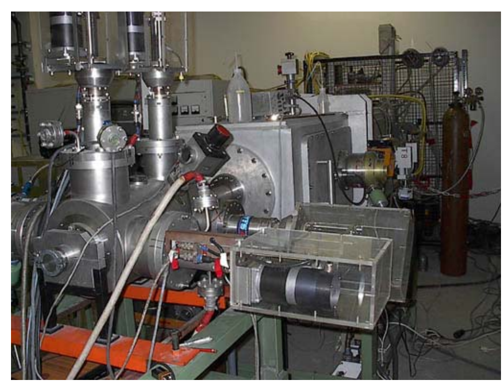

Figure 2: Picture of the experiment.

The Two-Beam RFQ consists of two sets of quadrupole electrodes, where the beams are bunched and accelerated driven by one resonant structure. The RFQ electrodes are divided in two sections. The first section, which is about two thirds of the total length of 2 meters, bunches and accelerates the beam to a final energy of 160 keV. At first the second part has been used as a transport section with unmodulated RFQ electrodes. For first beam tests only one RFQ-channel has been replaced by a section that matches the beam to the funneling deflector to optimize beam radius and phase width. This allowed us to compare both RFQ channels directly.

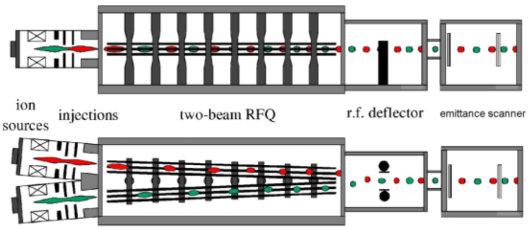

Figure 3: Scheme of the experimental set-up.

THE NEW RFQ ELECTRODES

The old transport section had unmodulated electrodes with constant aperture. In the new design the aperture increases and the last 8 of the total 12 cells have a modulation up to $m = 1.4$ to bunch the beam with the time focus at the funneling deflector. At the same time the focusing is made stronger to avoid a diverging beam and get more beam into the aperture of the deflector. Thus the RFQ provides a longitudinal and radial focus at the deflector.

Figure 4 shows the comparison of beam dynamics simulations for the old and the new RFQ electrode end matching section. The new electrode design reduces the beam radius from $r = 1.7$ cm to $r = 0.9$ cm and phase spread from $\Delta\varphi = 100°$ to $\Delta\varphi = 25°$ at the position of the funneling deflector, which is 54 cm behind the RFQ.

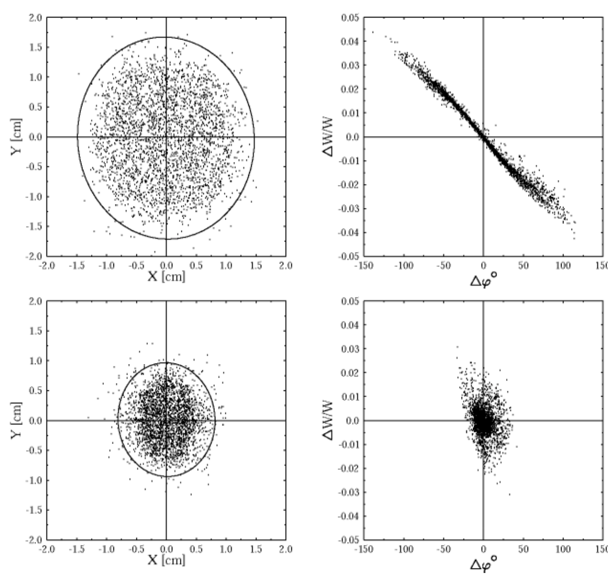

Figure 4: RFQSIM results with old (top) and new (bottom) RFQ electrode matching section.

BEAM TESTS

We have done a number of beam experiments to test the new matching out section. Figure 5 shows the beam pulses of the RFQ at the point of the beam crossing. The matching section in the new beam line reduces the pulse length. The Faraday cup used has only a restricted bandwidth and cannot resolve the pulses with high resolution. But the results clearly show the improvement of the pulse width for the new matching.

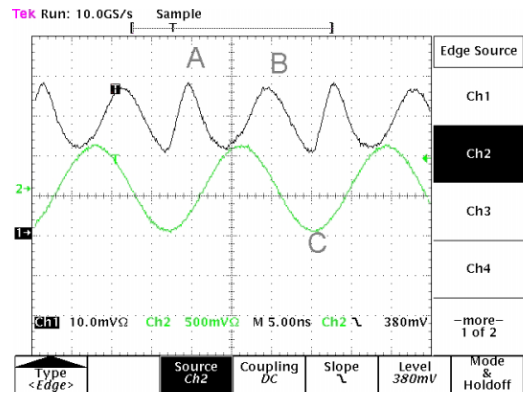

Figure 5: Bunch measurements with both beams.
A: New matching electrode end section
B: Unmodulated electrode end section
C: 54 MHz RF-trigger-signal

Figure 6 illustrates an emittance measurement with both beams at the point of beam crossing. The emittance from the beamline with the matching section reduces the beam radius. The measurements are in good agreement with our simulations shown in figure 7.

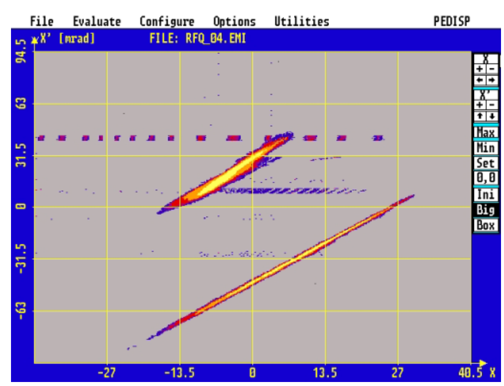

Figure 6: Measured emittances of old (bottom) and new (top) RFQ channels.

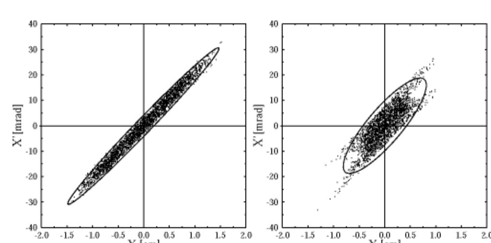

Figure 7: Simulated emittances of old (left) and new (right) RFQ channels.

THE SIM CODES

All simulations were done with *RFQSIM* and *DEFTRA*. *RFQSIM* is a beam dynamic transport program for RFQ accelerators. It transports macro particle bunches in the 6-dimensional phase space segmentally through the RFQ and more than 15 transport modules such as bunchers, quadrupole, lenses and drift tubes. These modules can be placed before and behind the accelerator.

DEFTRA is used to simulate two beam lines through a funneling deflector. It needs a particle distribution file from *RFQSIM*. Furthermore the 3D structure and the potential matrices $\Theta(x, y, z)$ and $\Phi(x, y, z)$ of the funneling deflector with fringe ranges computed by *DEFGEN* are required [8]. The bunch of each beam line is transported segmentally through the structure and the fringe ranges.

DEFLECTOR SIMULATION

To reduce beam losses, beam divergency and phase spreading of our 17 cell funneling deflector several shorter versions are investigated. The existing single deflector has the disadvantage that the large bending voltage of about 21 kV for He^+ corresponds to MV for Bi^+ (HIDIF). Figure 8 illustrates the potential distribution of a funneling deflector with 9 cells at a bending voltage of approximately 6.4 kV. The electrode aperture in the short gaps start from 30 mm to 20 mm, the drift tubes in the large gaps vary from 15 mm to 12 mm.

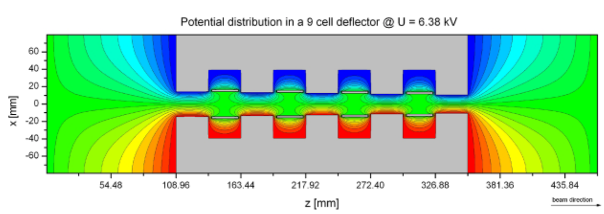

Figure 8: Intersection at the beam axis of the 9 cell deflector in top view of the potential distribution matrix.

The (x, x') and $(\Delta W/W, \Delta\phi)$ emittances behind the 17 and the 9 cell deflector for one beam line are shown in figure 9. Due to different deflector lengths a drift of 11 cm has been placed behind the 9 cell deflector for true comparison. The phase width is reduced from $\Delta\varphi = 150°$ to $\Delta\varphi = 55°$.

Further investigations have to be done.

CONCLUSIONS

Our first experiments with the two beam RFQ accelerator have shown that funneling can be done, but the beams were not matched to the funneling deflector [9].

By adding the new 3D matching section to one RFQ channel we were able to improve the matching.

The second RFQ channel is now modified with the new matching electrodes too [10]. Next step will be new funneling experiments with the two matched beams.

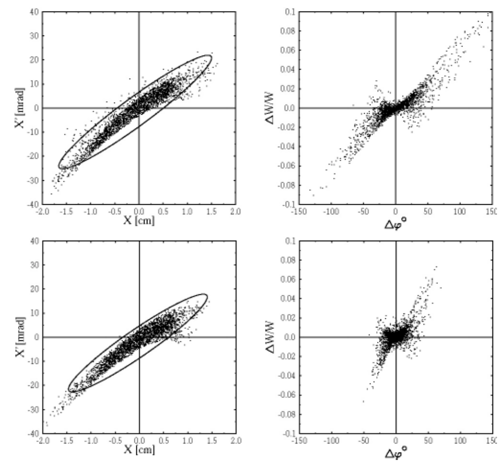

Figure 9: Emittances of the existing 17 cell deflector (top) and a newer 9 cell deflector (bottom). For better comparison only one beam line is shown.

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