EXPERIMENTS WITH THE TWO-BEAM FUNNELING RFQ*

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Abstract

High intensity accelerator concepts for **H**eavy **I**on **I**nertial **F**usion (HIIF) injectors require small emittance, high current and high energy beams. The improvement of brightness in such a driver linac is done by several funneling stages at low energies, in which two identically bunched ion beams are combined into a single beam with twice the frequency, current and brightness. For the Heavy-Ion Driven Ignition Facility (HIDIF) we have proposed the use of a two-beam accelerator structure which provides two beams within one cavity and a single r.f. deflector structure which bends the two beams to one common axis. The progress of the experiment and first beam-test results will be presented.

1 INTRODUCTION

The beam currents of linacs are limited by space charge effects and the focusing and transport capability of the accelerator.

Funneling is doubling the beam current by the combination of two bunched beams preaccelerated at a frequency f_0 with an r.f. deflector to a common axis and injecting into another r.f. accelerator at frequency $2*f_0$.

By the use of the two-beam RFQ the two beams are brought very close together 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, are not necessary [1,2,3]. A short r.f. funneling deflector will be placed around the beam crossing position behind the RFQ. The layout of the proposed HIDIF-injector with two-beam RFQs in front of the first and second funneling sections is shown in figure 1 [4]. The HIDIF linac starts with 16 times 3 ion sources for three different ion species to allow so-called „telescoping“ at the final focus [5]. With four funneling stages the frequency has been increased from 12.5 MHz to 200 MHz accordingly [6].

For studies of the new two-beam RFQ structure and the r.f. deflector, the first two-beam funneling experiments will be carried out with He^+-ions at low energies to facilitate ion source operation and beam diagnostics.

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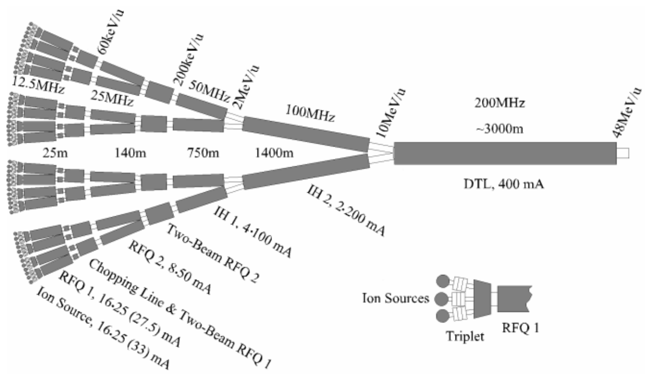

Figure 1: Layout of the 12.5...200MHz linac system for 400 mA of Bi^+.

Two small multicusp ion sources and electrostatic lenses, built by LBNL (Lawrence Berkeley National Laboratory) [7,8], are used. The ion sources and injection systems are attached directly on the front of the RFQ with an angle of 76 mrad, the angle of the beam axes of the two-beam RFQ.

Figure 2 shows a scheme of the experimental set-up of the two-beam funneling experiment.

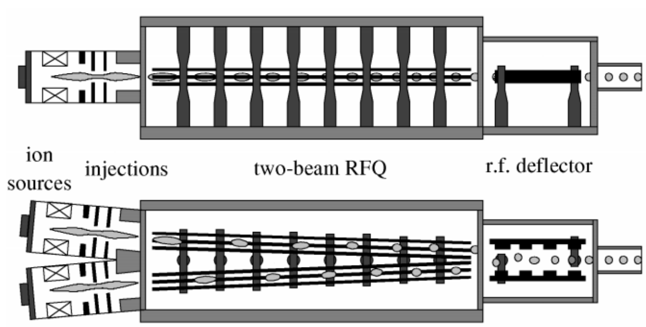

Figure 2: Experimental set-up of the two-beam funneling experiment.

Two-beam RFQ	**He^+**	**Bi^+**
f_0 [MHz]	54	12,5
Voltage [kV]	10.5	180
R_p-value [kOhm·m]	80	250
Q_0-Value	1800	5000
T_{in} [keV]	4	209
T_{out} [MeV]	0.16	12.54
Angle between beam axes [mrad]	76	76

Table 1: Main parameter of the experiment with the He^+ and the design parameters of a first HIDIF funneling stage for Bi^+.

2 ION SOURCES AND INJECTION SYSTEMS

To investigate the synchronous operation, the beam of both ion sources and injection systems have been tested on an emittance measurement device by different parameters of the ion sources and injection system. The measured normalized 90% RMS-emittance is shown in fig. 3.

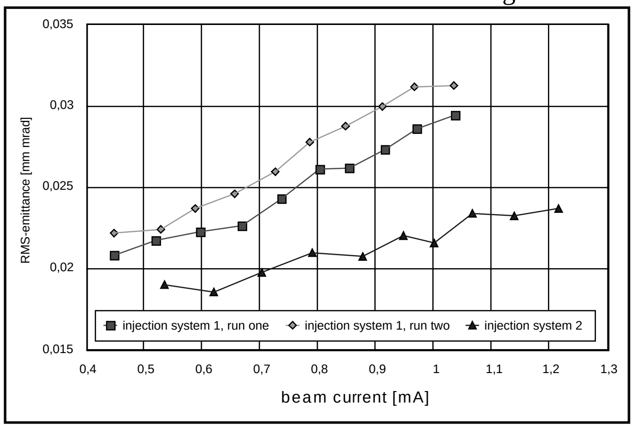

Figure 3: Normalized 90% RMS-emittance of the two injection systems at different beam currents.

3 THE TWO-BEAM RFQ

The two-beam RFQ consists of two sets of quadrupole electrodes, where the beams are bunched and accelerated with a phase shift of 180° between each bunch, driven by one resonant structure. With the use of identical RFQ electrode designs for both beam lines, the electrodes of one beam line are installed with a longitudinal shift of 2.55 cm (i.e. $\beta\lambda/2$ at final energy) to achieve the 180° phase shift between the beam bunches of each beam line. Figure 4 shows the with a fast faraday cup measured micro-bunch current of the two RFQs, which demonstrates the 180° phase shift between the beam bunches.

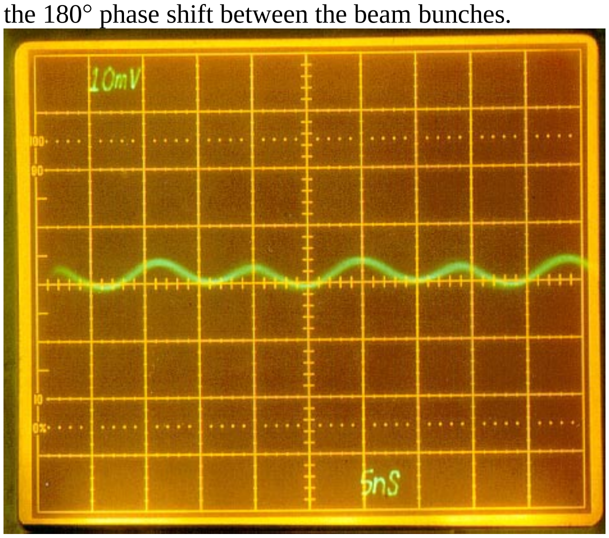

Figure 4: The measured micro-bunch current of the two RFQs demonstrate the 180° phase shift between the beam bunches. The scale is 5 ns/div. horizontally.

In Figure 5 the measured energy spectra behind the RFQ are shown. The final beam-energy of 166 keV is reached at an electrode voltage of 10 kV, which is the design voltage. Below 4 kV electrode voltage the He^+ beam is only transported and not accelerated. The energy is now the energy of the injection system of 4.15 keV.

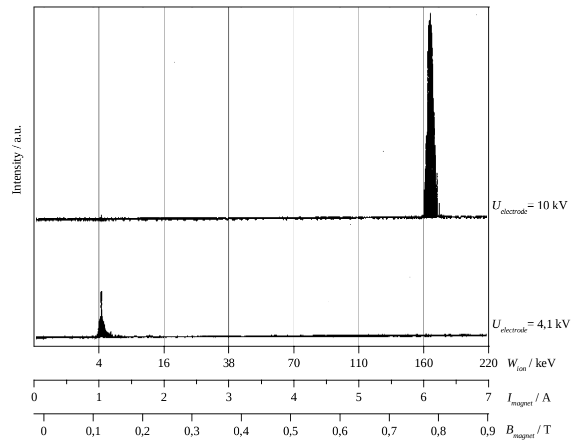

Figure 5: Energy spectra behind the RFQs. With the design voltage of 10 kV the final beam-energy of 166 keV is reached.

At the beam crossing position behind the two-beam RFQ emittance measurements have been done. Figure 6 shows the two measured RMS-emittances. The normalized 90% RMS-emittance of the two beams are 0.107 and 0.114 mm mrad, the deviation is about 6 %.

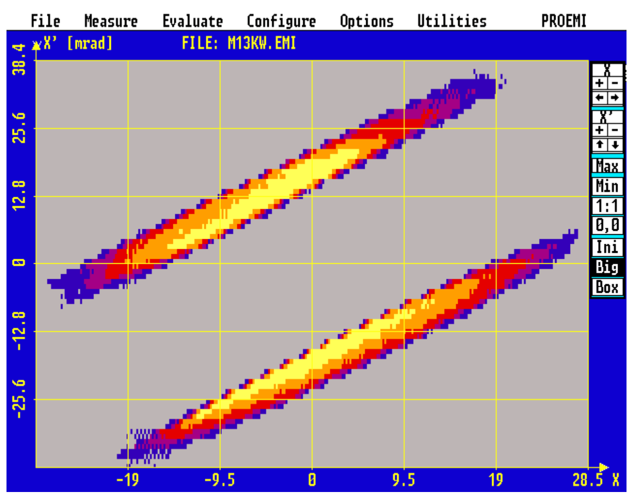

Figure 6: Measured emittances 1m behind the RFQ at the place of beam crossing. The ellipses correspond to the 90% normalized RMS-emittances which are ε_{RMS}=0.107 and 0.114 mm mrad for each beam.

5 FUNNELING-DEFLECTOR

For bending the two beams to a common axis, a funneling-deflector is mounted directly behind RFQ. This device is like a plate capacitor with an electric field only in the bending plane. The crosspoint of the two beams is situated right in the middle of the deflector. As the bunches leave the RFQ with a phase shift of 180° and with alternating angle (± 37.5 mrad), they are step by step deflected to angle zero, when the field is smaller in the case of wrong polarity. Figure 7 shows a simulation of the change in angle of the stable particle during the motion through the funneling-deflector. As the calculation shows, the optimum voltage for operation is about 3 kV. Figure 8 shows the scheme of the funneling-deflector.

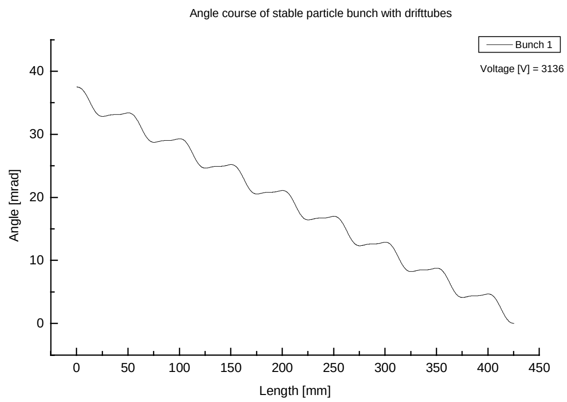

Figure 7: Motion of the stable-particle during bending in the funneling-deflector.

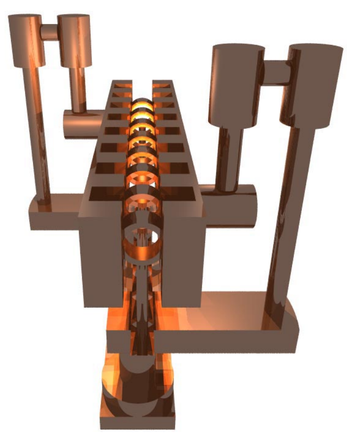

Figure 8: Picture of the funneling deflector. To reduce the E-field a drift tube is mounted between the plates each second cell.

To minimize the field in case of wrong polarity we decided to use drift tubes each second cell. The amplitude of the simulated E-field on the symmetrical axis of the deflector over the length of two cells is shown in Fig. 9.

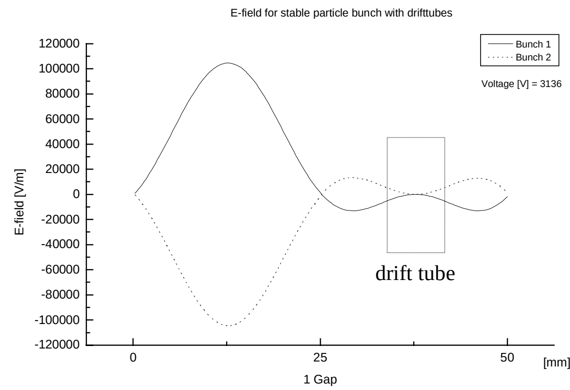

Figure 9: E-field in the funneling-deflector over the length of two cells.

6 CONCLUSIONS

The beam test results of the two-beam RFQ and the theoretical investigations on the funneling section have shown that the chosen set-up should be able to bend the two beams to a common axis. Next step will be the experimental test of the funneling-deflector.

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