

# A BEAM TRANSPORT SYSTEM FOR THE FRANKFURT FUNNELING EXPERIMENT\*

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## Abstract

The goal of the Frankfurt Funneling Experiment is to multiply beam currents by merging two low energy ion beams. In an ideal case this would be done without any emittance growth. Our setup consists of two ion sources, a Two-Beam-RFQ accelerator and a multi cell deflector which bends the beams to one common beam axis. Current work is the design of a new beam transport system between RFQ accelerator and deflector. With extended RFQ-electrodes the drift between the Two-Beam-RFQ and the rf-deflector will be minimized and therefore unwanted emittance growth prohibited. First rf-measurements with a scaled experiment will be presented.

## INTRODUCTION

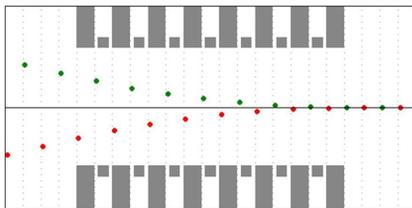


Figure 1: Scheme of funneling: two beams at  $f_0$  are injected into the deflector and one beam at  $f = 2f_0$  is extracted.

The capabilities for beam transportation in the low energy end of a linac is the limiting factor for the beam current of the linac. For a given ion current and emittance the limit is proportional to  $\beta = v/c$  for electric and to  $\beta^3$  for magnetic focusing and emittance conservation. Funneling uses a preaccelerated beam and therefore higher current limits because the higher  $\beta$ -factor. This higher limit will be used by doubling the beam current by bending two bunched beams at a frequency  $f_0$  with a rf-deflector to a common beam axis as shown in fig. 1. After this rf-deflector the beam will be injected into another rf-accelerator at frequency  $2f_0$  filling all rf-buckets. In an optimal case the beam emittance stays as low as for one single beam. Extracting twice the beam current from a single ion source would result in at least twice the emittance.

## EXPERIMENTAL SETUP

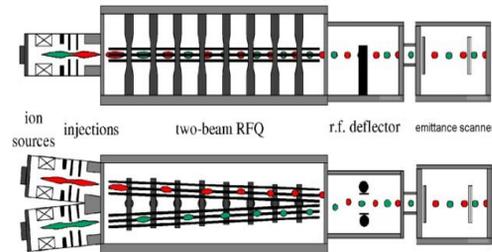


Figure 2: Top and side view of the experimental setup: the two ion sources, the two-beam radio-frequency-quadrupole, the deflector and an emittance scanner (from left to right).

The Frankfurt Funneling Experiment consists of two multicusp ion sources, a two-beam-RFQ accelerator, two different rf-deflectors and beam diagnostics as shown in fig. 2 schematically. The sources are directly attached to a LEBT consisting of two electrostatic lenses. Each ion source provides an He<sup>+</sup> beam of up to 1.4 mA [1] with an energy of 4 keV. The two-beam-RFQ accelerator combines two RFQ-beam lines in one common resonant structure [2]. Between the beam lines there is an angle of 75 mrad to create a crossing of the two beams after the RFQ. The phase shift of the beams is realized through a mechanical offset of the RFQ electrodes by  $\beta\lambda/2$ . The resonance frequency of the two-beam RFQ is 54.6 MHz. A matching section at the end of the RFQ should match the beams into the deflectors. At the end of the two-beam RFQ the particles have an energy of 179 keV. This experiment is downscaled to proof the principle of increasing the beam current without increasing the emittance.

The deflector is located at the beam crossing point and works with the same frequency as the two-beam RFQ [3]. The task of the deflector is to reduce the transversal angle of the beams from  $x' = 37.5$  mrad to  $x' = 0$  mrad in one, with a single cell deflector, or in several steps with a multi cell deflector.

The beam diagnostics instruments used are a Faraday cup, an emittance scanner and a bending magnet to measure the beam current, emittance and energy of the particles.

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### MOTIVATION

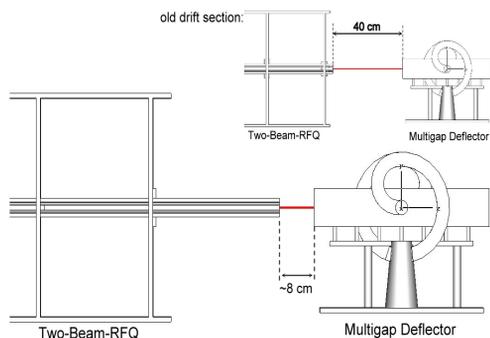


Figure 3: old and new drift section between RFQ and deflector.

Between the two-beam-RFQ accelerator and the multi cell deflector the ion beams are in a drift section for about 40 cm (fig. 3). In this drift section and at low energies like 179 keV the beam diameter increases caused by space charge effects. This results in beam losses at the entrance of the deflector and throughout the deflector. This is shown by particle dynamic simulations as seen in fig 4. A shorter drift could be realized with extended RFQ electrodes. With this the beams are in the focusing fields of the RFQ until approx. 8 cm before the multicell deflector. The impact of this extension of the electrodes on the rf parameters frequency, quality factor and field distribution are topic of this paper. These factors will be examined by simulation and experiment.

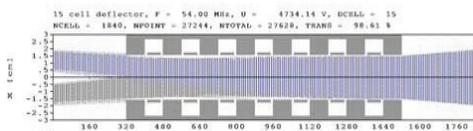


Figure 4: Particle dynamic simulations through the multicell deflector. Particles are lost at the entrance and throughout the deflector. [4]

### SIMULATIONS

First simulations with CST Microwave Studio showed an abnormal behavior for a 4-rod RFQ of the surface currents with the extended electrodes (see fig. 5 and [5]). The surface currents did not change directions at the low energy end of the left RFQ beam line. Also the frequency gets higher which is in contradiction to the added capacity through the extended electrodes. These effects are due to the low resolution these first simulations were done with. Further simulations with an increased resolution did not show this behavior as shown in fig. 6. In comparison with simulations of the existing two-beam-RFQ the resonance frequency is reduced by 1 MHz

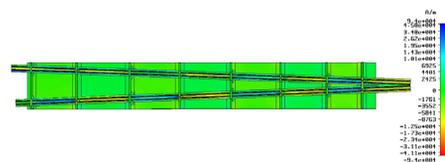


Figure 5: First CST MWS simulations of the extended two-beam RFQ.

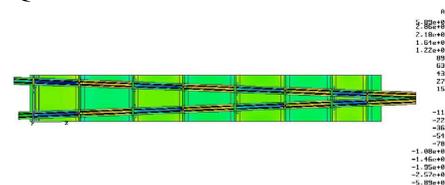


Figure 6: Surface currents from CST MWS with the extended electrodes.

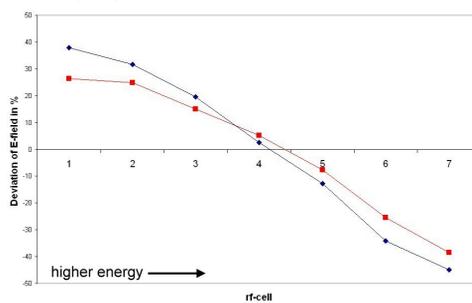


Figure 7: Measured deviation of the electric field for the existing two-beam RFQ. Blue = left, red = right beam axis.

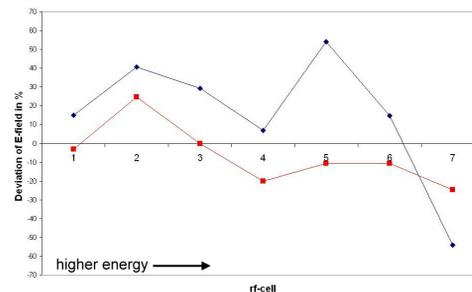


Figure 8: Simulated field deviation for the existing resonance structure. Blue = left, red = right beam axis.

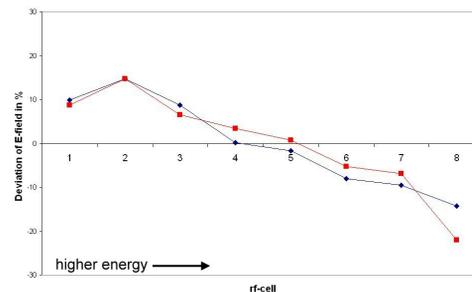


Figure 9: Simulated field distribution along the two-beam RFQ with extended electrodes. It shows a difference of  $\pm 20\%$ . Blue = left, red = right beam axis.

(from 59.17 MHz to 58.16 MHz) and the quality factor was lowered by 5% (from 4150 to 3940). The results of field distribution simulations for the existing two-beam-RFQ did not match the experimental results (see fig. 7 and 8). This is presumably again due to the resolution of the simulation. But with the extension those simulations show reasonable field distribution of  $\pm 20\%$  as shown in fig. 9.

## EXPERIMENTS

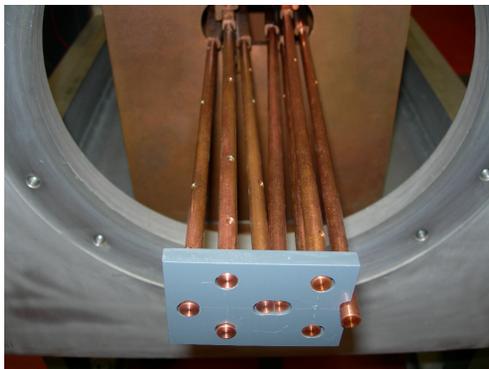


Figure 10: Photo of the experimental electrode extension.

The simulations were tested with a experiment. The extension of the electrodes were modeled with 30cm long copper rods which could be inserted into the existing hollow electrodes as shown in fig. 10. The measurements match the predictions of the simulations quite well: while the absolute values do not match the measured values of the frequency and quality factor  $Q$  perfectly, the differences through the electrode extension are in good comparison with the simulation. The frequency drops 1 MHz from 56.16 MHz to 55.09 MHz and the  $Q$  value decreases 7%.

The deviation of the electric field along the two beam lines was measured with an added capacity between the electrodes. A more homogeneous distribution is achieved as shown in fig. 11.

All those impacts of the electrode extension on those rf parameters is explainable through the added capacity of the longer electrodes. A tuning system consisting of 2 capacitors between stem 7 and 8 result in a similar field distribution as with the electrode extension [6].

## CONCLUSIONS

Simulations with a high resolution showed the expected changes that come with added capacity of the extended electrodes at the high energy section: lower frequency, lower  $Q$ -Value and a more homogeneous field distribution. All those simulated values are validated through experimental results with a simple realisation of the electrode extension.

The next step will be to recalculate the particle dynamics with the longer electrodes to match the energy of 179keV

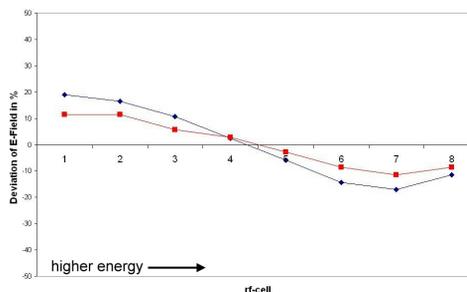


Figure 11: Measured field distribution along the two-beam RFQ. It shows a difference of  $\pm 20\%$ . Blue = left, red = right beam axis.

and still have the 3D-matching for the deflector. After this is done a solution has to be found to create a stable adjustment of the extended electrodes.

## REFERENCES

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