SIMULATIONS FOR THE FRANKFURT FUNNELING EXPERIMENT*

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Abstract

Beam simulations for the Frankfurt Funneling Experiment are done with *RFQSim* and *FUSIONS*. *RFQSim* is responsible for the beam transport through a RFQ accelerator. Behind the accelerator the program *FUSIONS* calculates the dynamics of macro bunches of both beam lines through a r.f. funneling deflector. A new space charge routine has now been included. The status of the development of *FUSIONS* and the results of the simulations will be presented.

INTRODUCTION

The Frankfurt Funneling Experiment consists of two multicusp ion sources, a Two-Beam RFQ accelerator and two different kind of funneling deflectors to bend both beam lines to a common beam axis (fig. 1). During the experiment only one deflector is in operation. First experiments with both kind of funneling deflectors have shown that funneling can be done [1]. After the upgrade of the last electrode section of the RFQ accelerator the beam size is reduced by approximately 65% [2, 3]. The new electrodes deliver a three dimensional matching of the bunch at the beam crossing point. First experiments will be done in the next time (see [4]).

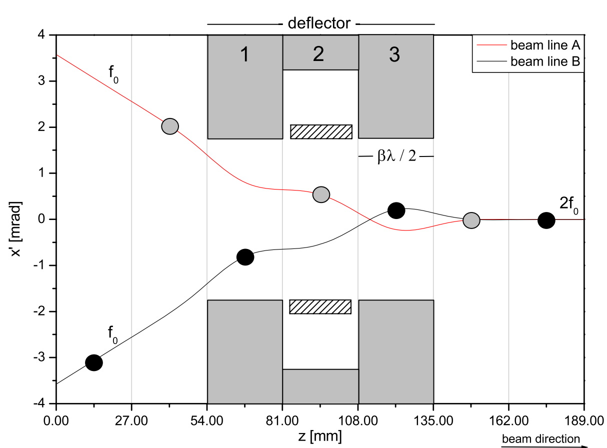

Figure 1: Schematic procedure of funneling.

The principle of funneling is displayed in fig. 1. The r.f. deflector bends alternately both beam lines to a common beam axis. Two beam lines with the repetition frequency f_0 are combined to $2f_0$. In cells with odd numbers the electric field bends the bunches of each beam lines in the correct direction, but not in the even cells. To reduce this unlovely effect the even cells are enlarged in aperture and drift tubes can be placed in the wider gaps to shield the fields (shaded rectangle).

THE SIM CODES

RFQSim

Beam dynamic transport through the RFQ accelerator is done by *RFQSim*. *RFQSim* is a particle simulation program for normal conducting RFQ accelerator structures at low energies. It transports macro particle bunches in the six dimensional phase space segmentally through the RFQ and more than 15 transport modules such as bunchers, quadrupoles, lenses and drift tubes. These modules can be placed before and behind the accelerator. Different space charge routines, e.g. method of charged rings, can be choosen.

FUSIONS

The beam through the funneling deflector is simulated with *FUSIONS* (**Fu**nneling **S**imulation for **Ion** Beam**s**). It is a newly developed particle dynamic simulation software for funneling deflectors.
A three dimensional potential distribution matrix $\Phi(x, y, z)$ and the relevant structure matrix of a deflector are used for beam transportation. They are generated and computed with *DefGen* [5].
Both beam lines, each containing a bunch with a six dimensional particle distribution from *RFQSim*, are transported segmentally through the funneling deflector.
The electric field components $\vec{E}(x), \vec{E}(y), \vec{E}(z)$ for each macro particle are calculated in every segment. Particle losses are determined with the help of the structure matrix.

Two different space charge routines are now integrated: a particle-particle and a particle-in-cell routine.
The particle-particle routine is based on the coulomb interaction

$$\vec{E}_j(\vec{r}) = \sum_{i=1, i\neq j}^{n} \frac{Q_i}{4\pi\epsilon_0} \frac{\vec{r} - \vec{r}_i'}{\left|\vec{r} - \vec{r}_i'\right|^3}. \quad (1)$$

The precision of the result is very high if the quantity of the simulated particles corresponds approximately with the real number of particles in the bunch. But the calculation time rises with the square of the particle number. If

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the number of particles doesn't represent the selected beam current, the particles are seen as macro particles. A macro particle covers a couple of real particles (typically 10^2 to 10^5). Then the charge of each particle is determined by the given current divided by the number of particles.
If the amount of simulated particles is too small the charge of each particle rises extremely and the coulomb forces are too powerful.

The particle-in-cell routine avoids the dependence of the particle number. A three-dimensional mesh is placed around the bunch. On each mesh point the potential of all particles of the bunch is stored:

$$\varphi_j(\vec{r}) = \sum_{i=1, i\neq j}^{n} \frac{Q_i}{4\pi\epsilon_0 \left|\vec{r} - \vec{r}_i'\right|}. \quad (2)$$

This gives a three-dimensional potential distribution of the bunch. For each particle the electric field components of the eight surrounding mesh points are computed. The momenta are transferred to the particle.
The routine is faster than the particle-particle routine. The calculation time depends on the number of meshes and the quantity of particles, but in linear relation.

INVESTIGATIONS WITH THE 15 CELL DEFLECTOR

The RFQ accelerator and the funneling deflector are driven with a frequency of $f = 54.5$ MHz. The experimental set-up is scaled in He^+ instead of Bi^+ of a first funneling stage of a HIF driver. The deflector is placed 53 cm behind the RFQ in the beam crossing point. The beam lines have an angle of $x' = 76$ mrad. For a single cell deflector with an electrode aperture of $d = 13$ mm the bending voltage is about $U_D = 21$ kV for He^+ and approximately 1 MV for Bi^+. To bend a He^+ (Bi^+) beam with the 15 cell deflector a voltage of $U_D = 4.2$ kV ($U_D = 246$ kV) for an aperture of $d = 30$ mm is required.

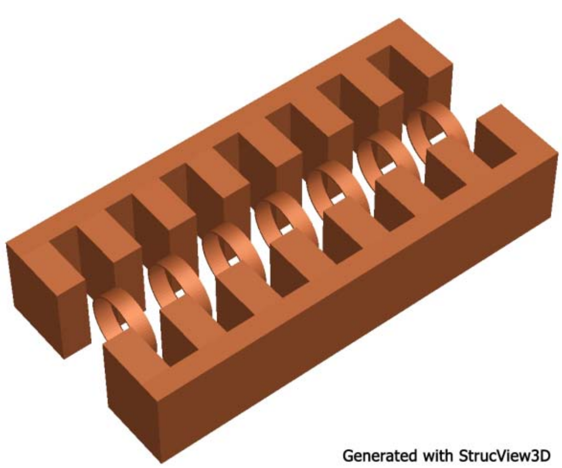

Figure 2: 3D model of the generated structure.

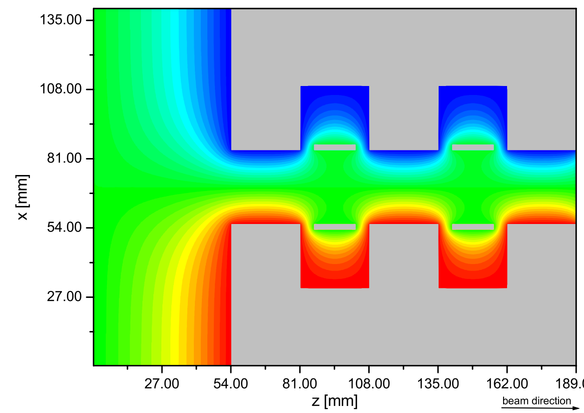

Figure 3: Potential distribution in the first cells of a 15 cell deflector.

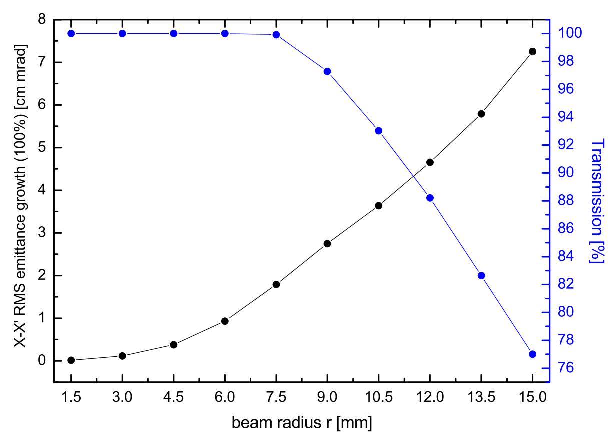

Figure 4: X-X' RMS emittance growth and transmission as a function of the beam radius.

The generated structure is shown in figure 2. In odd cells the aperture is $d = 30$ mm. Even cells have an aperture of $d = 80$ mm. The drift tubes with a radius of $r = 15$ mm have a length of $l = 16$ mm.
Figure 3 displays the potential distribution in the first five cells of the funneling deflector.
The following simulations were done with a special particle distribution to show the effect of emittance growth during funneling. The bunch has no divergences and no energy deviation. Additionally the calculations were done without current, $I = 0$ mA, to avoid space charge effects. The 20000 particles are randomly distributed in the x, y and φ coordinates.
At first the influence of the beam radius has been investigated. The radius varied between 1.5 mm and 15 mm. This correlates with the ratio of the beam diameter and the electrode distance between 10% and 100%.
Figure 4 shows the emittance growth and the limitation of the beam radius. If the beam is very small the emittance growth is approximately zero. If the bunch gets too large ($r > 7.5$ mm) particle losses appear at the deflector

electrodes and in spite of particle losses emittance growth is going on.

The next investigation shows the emittance growth as a function of the phase width (fig. 5). The input bunch has a cylinder geometry. The first four beam radii of the last calculation from figure 4 were chosen, because no particle losses occured. The length of the cylinder varied between $\Delta\varphi = 10°$ and $\Delta\varphi = 180°$. The graph shows that the emittance increases exponentially. All simulations results have a transmission of 100%.

With the last simulation the variation of the energy in the region $\Delta W = \pm 10\%$ of the stable energy has been investigated. This time not a bunch but one stable particle whose energy varied by ΔW was taken. The particle entered the deflector with an offset of $x = 0.963$ cm at an angle of $x' = 37.5$ mrad. Figure 6 displays the output position of the x coordinate behind the funneling deflector. The phase divergence as a function of the energy deviation is shown in figure 7. It's a linear proportion.

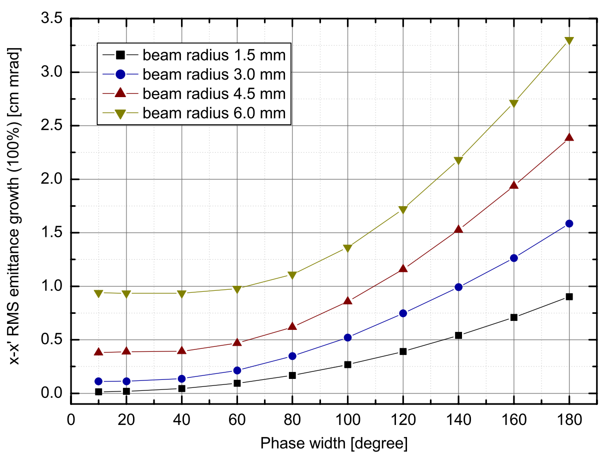

Figure 5: X-X' RMS emittance growth as a function of the phase width.

CONCLUSIONS

The simulations have shown that the beam radius should be less than 7 mm at the entry of the 15 cell funneling deflector. In addition the phase width should be the smaller than $\Delta\varphi = \pm 30°$. This avoids particle losses and strong emittance growth during funneling.
Both space charge routines, a particle-particle and a particle-in-cell routine, are now integrated. Further investigations of particle dynamics in funneling deflectors have to be done.

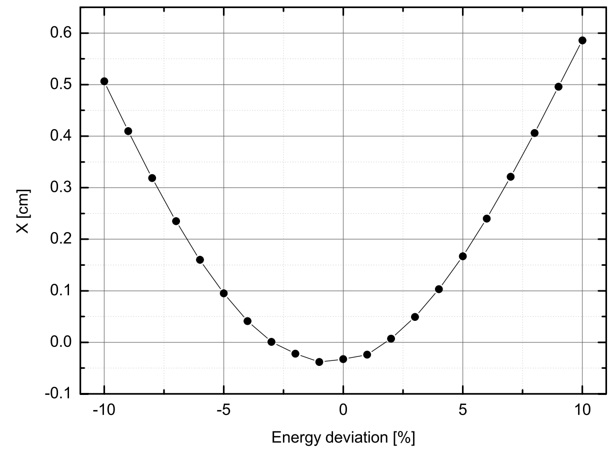

Figure 6: Divergence of the x coordinate of a stable particle as a function of the energy deviation.

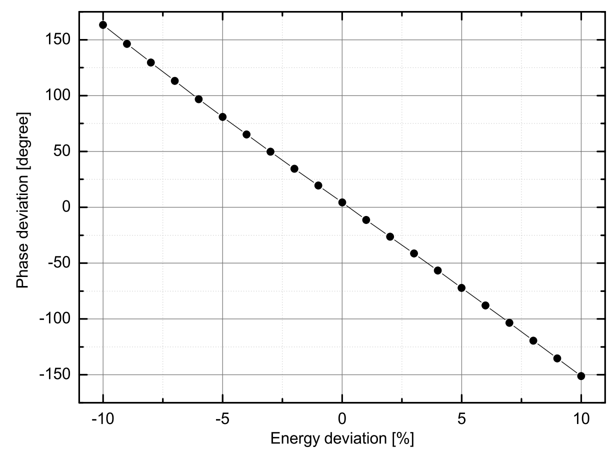

Figure 7: Phase divergence of a stable particle as a function of the energy deviation.

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