A SINGLE BUNCH RFQ SYSTEM FOR HEAVY IONS*

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Abstract

A novel scheme for the generation of single, isolated bunches has been developed. The design of the multi-gap deflector geometry and the results of particle simulations will be discussed. A planned experimental setup for a single bunch RFQ system and a combination of a two-beam RFQ with such a deflector for beam funneling is presented.

I. INTRODUCTION

The deflection of single beam bunches is needed in several accelerator applications, e. g. for time-of-flight experiments in atomic and nuclear physics where bunched ion beams with pulse pauses of up to several µsec are necessary. Another field of interest for a defined microstructure is the injection into booster synchrotrons for e. g. spallation sources. Also the funneling of ion beams needs a deflection system, which bends the two beams to one common axis [1].

To deflect single beam bunches one has to apply transversal electric fields e. g. with a plate capacitor. The electric fields can be produced by pulsed static deflectors with short rise time ($\tau < 1/2$ f, f = accelerator frequency) [2], where the deflection angle is proportional to the applied electric field and the deflector length l or by an rf-deflector which can be driven by resonant structures. So it is possible to reach higher voltages then in static deflectors, because the voltages of amplifiers with short rise times are limited to approximately 1 kV. In the rf-case the deflector length must be proportional to the particle velocity and the deflection angle depends on the rf-phase φ at the entry of the deflector. For the optimal lengths and phase the rf-amplitude is the static voltage times $\pi/2$ for the same deflection angle. The electric field is not homogenous, so that boundary effects have to be taken into account. In this paper a new concept, based on a resonator driven multi-gap deflector, will be discussed.

II. THE DEFLECTOR GEOMETRY

The electrode geometry of the multi-gap deflector consists of some capacitors with equal length but different distances. In this geometry the particles will see the deflecting field in one direction several times but the deflection in the opposite direction is always less. The length of the capacitors have to be proportional to the particle velocity and to the inverse of
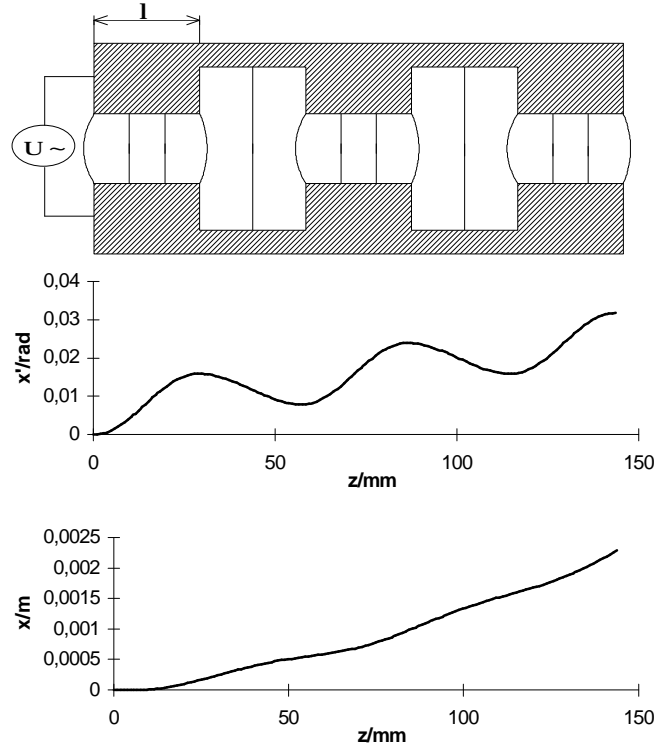
Fig. 1: Scheme of the multi-gap deflector electrode geometry and the behavior of the deflection angel x' and the deflection x.

the frequency of the deflection system. In Figure 1 the scheme of the multi-gap deflector electrode geometry and the behaviour of the particles along the deflector are shown.

The single cells can be treated like isolated rf-deflectors. If the electric field is taken as a constant field with the cell length l, the deflection angle x'(z) and the deflection x(z) in one cell can be written as:

$$x'(z) = \frac{a}{k} (\cos(\varphi) - \cos(k \cdot z - \varphi)) + x'(0)$$

$$x(z) = \frac{a}{k} (\cos(\varphi) \cdot z - \frac{1}{k} \sin(k \cdot z - \varphi) + \frac{1}{k} \sin(-\varphi)) + x'(0) \cdot z + x(0)$$

where $a = \dfrac{\xi \cdot e \cdot U}{A \cdot m_0 \cdot d \cdot v^2}$ and $k = \dfrac{\omega}{v}$

with ξ/A = relative charge to mass ratio; e = electron charge, m_0 = mass unit; U = gap voltage; d = gap width; v = particle velocity, $\omega = 2 \pi$ f with f = frequency; x'(0), x(0) = angle and displacement at cell entry.

The advantages of the multi-gap deflector are lower electric fields than in single gaps and so a smaller influence of boundary effects. Another possibility is to add focusing elements in the cells with greater aperture [3].

III. APPLICATIONS

A. Single Bunch Deflection System

For the chopping of bunched ion beams a combination of one single gap deflector and a multi-gap deflector, running on an asynchronous frequency compared to the bunch repetition rate, could be used. The multi-gap deflector has to prepare the different angels between the succeeding bunches and the single gap deflector has to form the longer time structure. Here the length of one deflection cell should be $\beta\lambda/2$ ($\beta = v/c$; c = speed of light) to get a maximal deflection angle $x(l)$ which for $\varphi = 0$ then can be written as

$$x'(l) = 2\frac{a}{k}$$

Figure 2 shows a scheme of a single bunch deflection system for He$^+$, an ion energy of 50 keV/u and a repetition rate less then 5.4 MHz. The static deflector is designed to inject 10 bunches of the RFQ beam into the rf deflector with a variable distance between the packages. Only one bunch passes the multi gap deflector. The time structure is shown in figure 3.
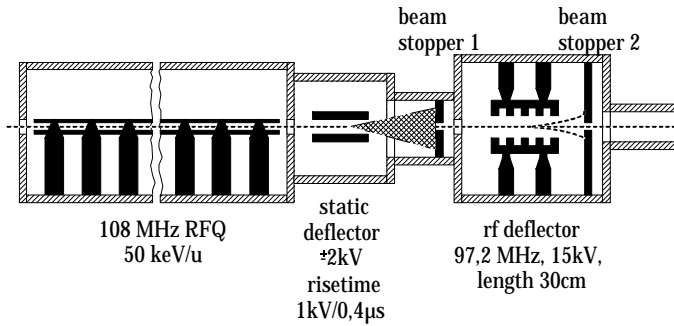
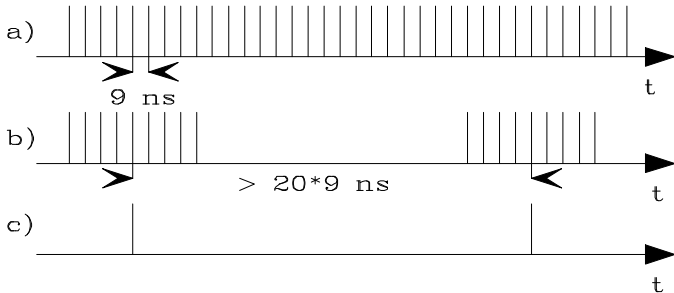Fig. 2: Scheme of the single bunch deflection system for He$^+$ at 50 keV/u and a repetition rate < 5.4 MHz.

Fig. 3: Time structure of the single bunch system.
a) RFQ output, b) behind beam stopper 1,
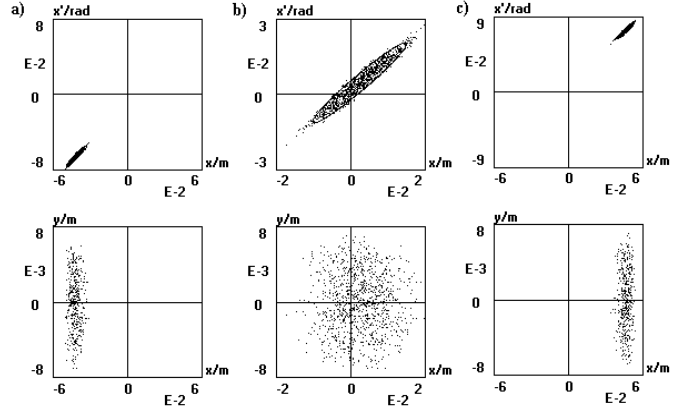c) multi-gap deflector output.

Fig. 4: Output of the multiparticle calculations for the single bunch deflection system for three succeeding bunches
a) and c) go to the beam stopper, b) to experiment.

In Figure 4 the output of multiparticle simulations for three succeeding bunches is shown. Behind the multi-gap deflector the bunches are separated more than 1 mm, so only one bunch can pass the aperture of the second beam stopper.

B. Funneling

The multi-gap deflection structure could also be used for beam funneling. Here the frequency of the deflector has to be the same like the accelerator frequency so that the bunches from different beam axes will see opposite field directions, caused by the phase shift of 180° between each bunch. If the two incoming beams are parallel the cell length of the deflector has to be $\beta\lambda$ to get only a displacement, because then for $\varphi = 0$ the deflection angle $x' = 0$ and the deflection x is maximal. Our favoured scenario for beam funneling is a two-beam RFQ with convergent beam axes and a multi-gap funneling element with a cell length of $\beta\lambda/2$, placed before the beam crossing. Figure 5 shows a layout of a planned funneling experiment for He$^+$ with two ion sources, a two-beam RFQ and a multi-gap deflector [4,5].
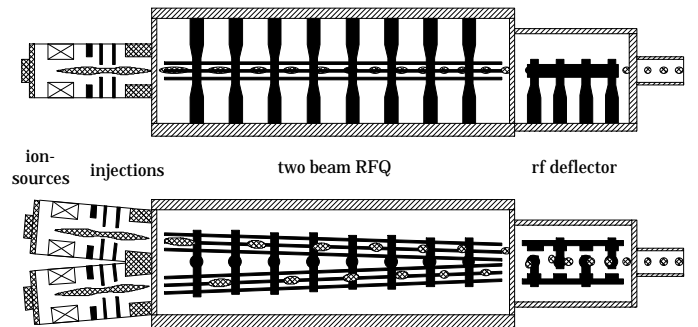
Fig. 5: Scheme of the planned experimental setup for funneling.

The two-beam RFQ structure is under development and a prototype with parallel beam axes passed the high power test.

First multiparticle calculations for the deflector design have been done. In table 1 the main parameters of the planned experiment with He$^+$ which is a scaled version for Bi$^+$ as it would be required in a first funneling stage of a heavy ion fusion driver are shown. In figure 6a the input distribution for the particle simulation and in figure 6b the output is plotted.

two-beam RFQ	He$^+$	Bi$^+$
f$_0$ [MHz]	54	27
Voltage [kV]	3.5	180
Rp-value [kΩm]	100	250
Q$_0$-value	2000	3000
T$_{in}$ [keV]	4	230
T$_{out}$ [MeV]	0.2	12.54
Length [m]	2	16
angle between beam axes [mrad]	75	75
rf deflector		
f$_0$ [MHz]	54	27
Voltage [kV]	5.2	200
Length [cm]	43	100

Table 1: Main parameters of the planned experiment with He$^+$ and design parameters of Bi$^+$.
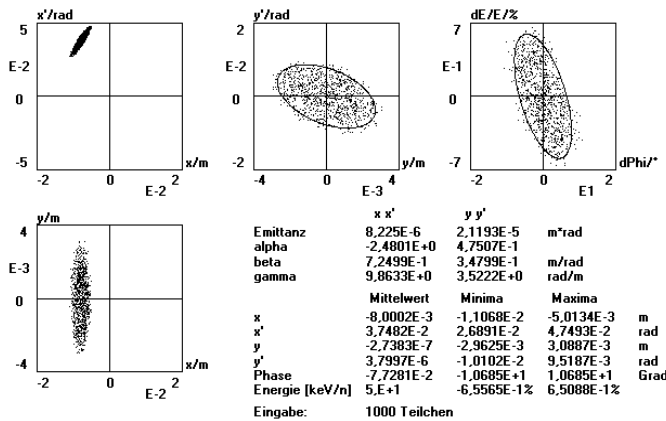

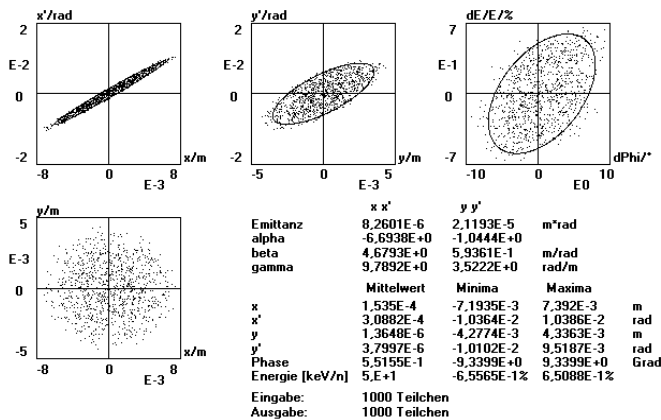Fig. 6a: Input distribution for the funneling simulation.

Fig. 6b: Output distribution of the simulation of the funneling section.

For an input distribution with displacement and angle in the opposite direction and a phase shift of 180° the results are the same. The bunch is bend 37.5 mrad to the common axis. These results show, that such a system can be used for funneling.

IV. OUTLOOK

The presented designs show, that the novel approach with the multi-gap deflector can be applied for the generation of single, isolated bunches and beam funneling. Further work and detailed multiparticle calculations for optimization have to be done. To take real field geometries in account, MAFIA and OPERA simulations have been done. Also the boundary effects, space charge forces and resonator structures have to be studied. A two-beam RFQ with convergent beam axis is under development, the RFQ electrode design is in progress.

V. REFERENCES

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