VERTICAL FOCUSSING WITH A FIELD GRADIENT SPIRAL INFLECTOR

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Abstract

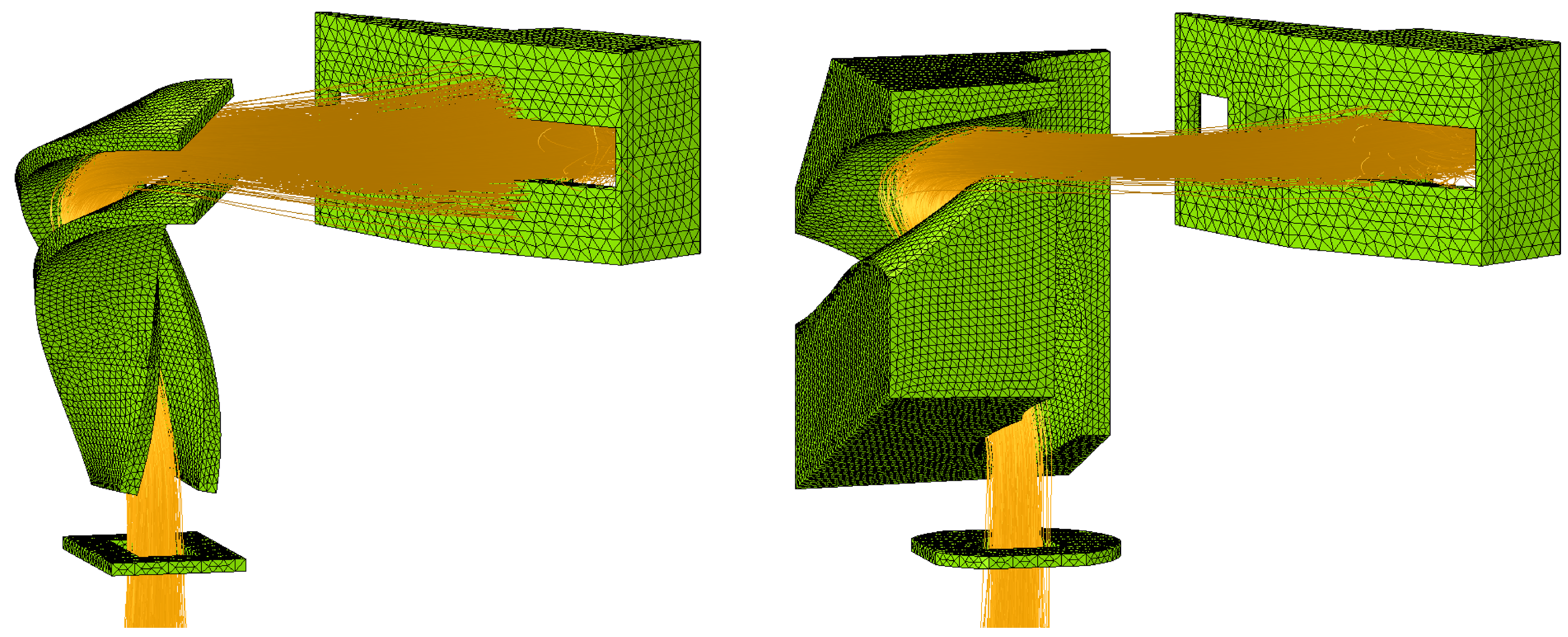
Traditional spiral inflectors suffer from vertical defocussing, leading to beam loss. In this study the electrode shape of an inflector is modified to intentionally produce transverse electric field gradients along the beam path, which have a significant influence on the optics. This is done by placing the traditionally parallel electrodes at an angle relative to each other in the transverse plane, creating a quadrupole field on the central path. Varying the electrode angle along the path length creates an alternating gradient effect. The electrode entrance and exit faces are also shaped to create quadrupoles inside the fringe field. By numerical optimisation a design with good vertical focussing is obtained. Experiments show a roughly 100% improvement in transmission with the buncher turned off. However, high losses at extraction are observed with the buncher turned on, due to RF-phase spread introduced by longitudinal defocussing in the inflector. This limits the improvement to 20% during normal cyclotron operation, and shows that the longitudinal spread introduced by an inflector has a significant influence on transmission.

INTRODUCTION

Traditional spiral inflectors suffer from vertical defocussing, leading to beam loss. Solutions:

- **Adding quadrupoles behind the inflector. Not enough space.**
- **Using V-shaped electrodes to create focussing fields, similar to the vertical direction of a spherical electrostatic bend [1].**

A new design is proposed: The electrodes are shaped to produce quadrupole electric fields in the transverse plane, and the quadrupole strength is varied along the beam path, creating an alternating gradient effect.



TOSCA [2] model of a traditional spiral inflector (left) and a vertically focussing field gradient inflector (right)

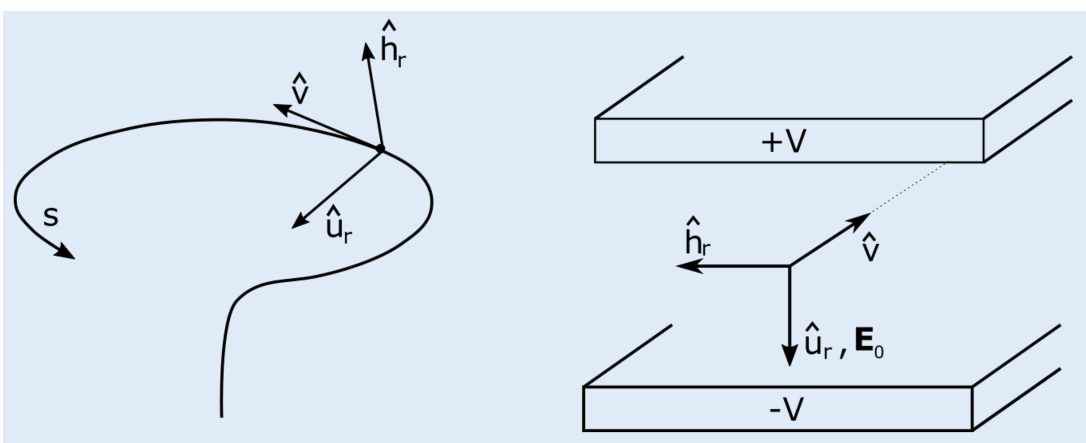
ELECTRIC FIELD GRADIENTS

Traditional spiral inflectors specify the electric field on the central trajectory but place no constraints on the transverse field gradients [3]. Here we attempt to influence the optics by creating appropriate electric field gradients.

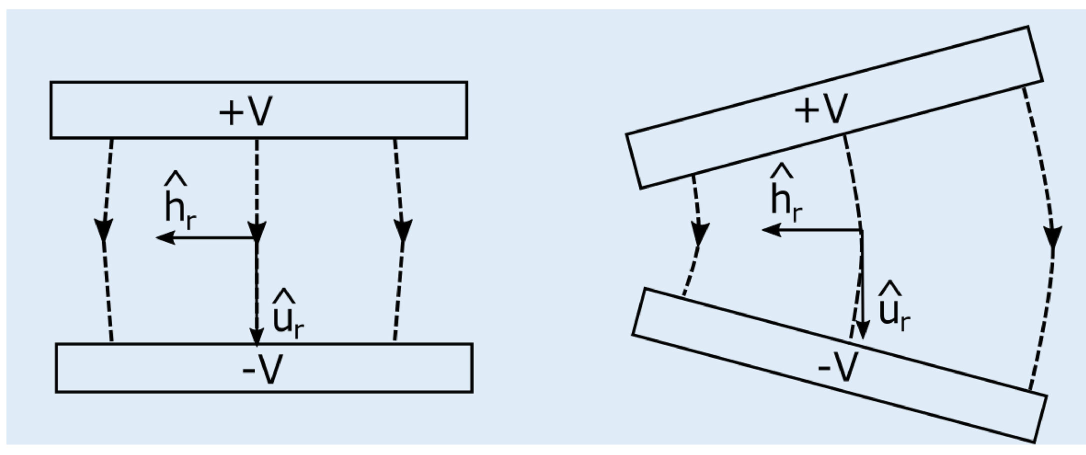
- **Create gradients by tilting the electrodes. Approximate as a 2D field in the transverse plane:**

$$\frac{\partial E_{h_r}}{\partial u_r} = \frac{\partial E_{u_r}}{\partial h_r} = -QE_0 \qquad \text{Where the electrode tilt is expressed by:} \qquad Q(s) = \frac{1}{u_r}\frac{du_r}{dh_r}$$

- **Create similar gradients in the fringe field by cutting the entrance and exit edge at an angle**

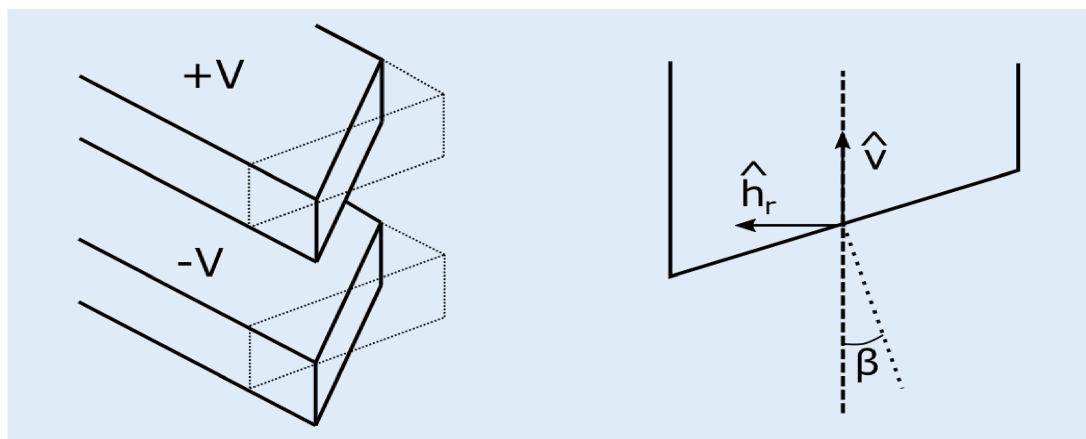


The spiral inflector coordinate system



Traditional parallel electrodes and proposed tilted electrodes

The amount of tilting varies along the path length

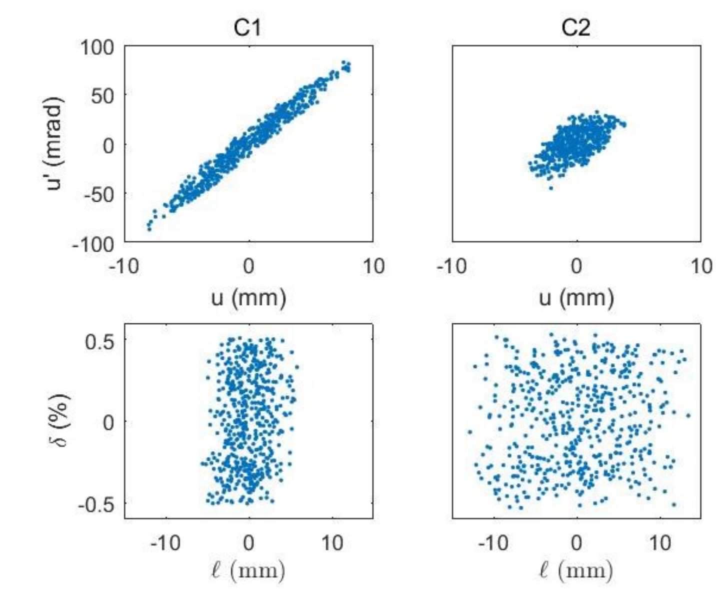


Cutting the entrance or exit edge at an angle

DESIGN PROCEDURE

- **The inflector transfer matrix is obtained numerically using ray tracing with Matlab. A number of precalculated 3D TOSCA fields are scaled linearly during run time to estimate the electric field for an arbitrary electrode design.**
- **The magnetic field plays an important role due to the solenoid effects, so a realistic TOSCA-based field is used [4].**
- **The transfer matrix is numerically optimised with random sampling to obtain promising starting positions, followed by steepest descent to reach optimal values.**

Parameter	C1	C2
Vertical emittance growth (%)	+45	+5
Vertical half-width (mm)	8.9	2.9
Horizontal emittance growth (%)	+45	+30
Horizontal half-width (mm)	3.0	1.5
Longitudinal half-width (mm)	5.5	12.9
RF phase spread (degrees)	±39	±90



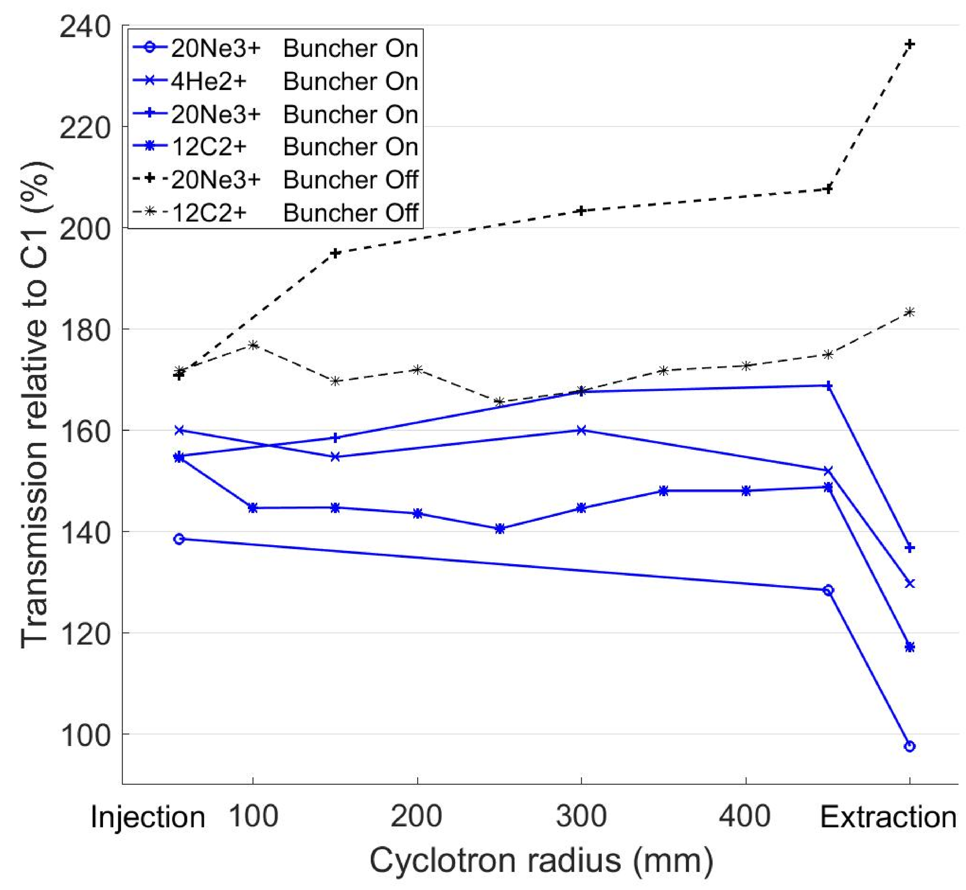
Beam parameters at the first acceleration gap for inflector C1 (standard) and C2 (new)

EXPERIMENTAL TESTING

A traditional inflector (called C1) and the new field gradient design (called C2) were tested in the Solid Pole Cyclotron 2 at iThemba LABS.

- **Without the buncher, the C2 inflector improved total transmission by 80% - 120%.**
- **With the buncher activated, C2 improves the injection efficiency by 50% but suffers from bad extraction. The total improvement is about 20%.**

C2 has very good vertical focussing resulting in the good performance when the buncher is turned off. But C2 also has a large longitudinal spread, resulting in a large RF phase spread and poor performance when the buncher is turned on. The inflector is effectively debunching the beam.



CONCLUSION

- **An inflector with very good vertical focussing has been developed and tested.**
- **However, it suffers from longitudinal defocussing.**
- **At the moment, a more general method to control the electric field gradients is being tested. It is based on an analytic second order solution to the electric potential around the central path, and results in a quadratic electrode profile in the transverse plane. This doubles the degrees of freedom available to control the electric field gradients.**

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