DESIGN AND OPTIMIZATION OF ELECTROSTATIC DEFLECTORS FOR ELENA

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Abstract

The ELENA ring [1] will decelerate the antiprotons ejected from the Antiproton Decelerator (AD) at 5.3 MeV down to 100 keV kinetic energy. The slow antiprotons will be delivered to experiments using electrostatic beamlines, consisting of quadrupoles, correctors and deflectors. An extensive simulation study was carried out to find solutions to minimize the aberrations of the deflectors. These solutions will be presented together with the actual design of these devices.

INTRODUCTION

At low particle energies electrostatic devices have many advantages over magnetic ones, for example the absence of remanent magnetic fields, no need for cooling, cheap and simple production. Following a cost-performance analysis, electrostatic beamlines were chosen for ELENA.

1. Fast switch (FS) combinations: ELENA will deliver 4 antiproton bunches with a spacing of about 1 µs in a single extraction. These bunches will be distributed among 4 experiments running simultaneously using fast switches in the beamlines. This functionality is realized by a combination of a fast electrostatic deflector [2] (the same device which is used for ejection from the ring) and a static deflector. The fast deflector has a rise time <1 µs and gives an initial kick of 220 mrad. The static deflector gives the remaining deflection. The fast switches can be further classified into two groups:

   (a) Horizontal fast switches (HFS at positions 5, 6, 7, 8 and 11 in Fig. 1) - these devices deflect the beam in the horizontal plane by a total angle between 45.7° and 48.1°.

   (b) Vertical fast switches (VFS at positions 9 and 10 in Fig. 1) - these devices deflect the beam vertically to ATRAP1 and ATRAP2.

2. Standalone static deflectors will deflect the beam by an angle between 45.77° and 50.42° at positions 1, 2, 3 and 4 in Fig. 1.

Table 1: List of Electrostatic Deflectors

<table>
<thead>
<tr>
<th>Pos. in Fig. 1</th>
<th>Tot. defl [deg]</th>
<th>Type</th>
<th>Electrode angle [deg]</th>
<th>Range [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,2</td>
<td>48.1</td>
<td>Static</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>50.42</td>
<td>Static</td>
<td>48</td>
<td>±2.3</td>
</tr>
<tr>
<td>4</td>
<td>45.77</td>
<td>Static</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5,6,7</td>
<td>48.08</td>
<td>HFS</td>
<td>34.3</td>
<td>±1.2</td>
</tr>
<tr>
<td>8</td>
<td>45.76</td>
<td>HFS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9,10</td>
<td>90</td>
<td>VFS</td>
<td>77.4</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>t.b.d.</td>
<td>HFS</td>
<td>t.b.d.</td>
<td>0</td>
</tr>
</tbody>
</table>

OPTIMIZATION OF ELECTRODES

The mechanical aperture (A in Fig. 2a) was chosen to be 65 mm - slightly larger than the value adopted for the beamlines in general (60 mm) due to the following reasons: the fringe field of the device deflects the particles already outside of the electrodes, and the central particle trajectory deviates from the nominal arc towards the bending center. Also, the same device will be used for slightly different bending angles, which gives a further excursion of the central particle trajectory from the nominal arc. A larger aperture...
also relaxes the required mechanical tolerances of the electrodes.

The electric field needed to keep charged particles on a circular orbit scales inversely with the orbit radius \( \rho_0 \). Aberrations also decrease with larger bending radius. A value of \( \rho_0=600 \text{ mm} \) was chosen as a best compromise to keep the size of the device within the required limits. The required voltages of the electrodes are approximately \( \pm AE_{\text{kin}}/q \rho_0 = \pm 10.8 \text{ kV} \).

The radius of curvature of the electrodes in the non-bending plane (\( \rho_1 \) and \( \rho_2 \)) and their height \( H \) are free parameters (Fig. 2a). The height of the electrodes was chosen to be \( H = 180 \text{ mm} \) as it can be introduced into the vacuum chamber through a DN200CF flange.

The radii of curvature of the electrodes \( \rho_1 \) and \( \rho_2 \) affect the optical properties of the deflector: the focusing strengths in the two planes and the aberrations. The dominant aberrations of an electrostatic deflector of this type are \( \delta x_{\text{out}} \sim x^2 \), \( \delta x_{\text{out}} \sim y^2 \) and \( \delta y_{\text{out}} \sim xy \) where \( x_{\text{out}} \) and \( y_{\text{out}} \) are the transverse coordinates and \( x_{\text{out}}' \) and \( y_{\text{out}}' \) are the trajectory derivatives at the output. It can be shown that the minimization of the last two of these give the same constraints on the electrode radii.

A set of particles with input coordinates \( -20 \text{ mm} < x_{\text{in}} < 20 \text{ mm}, y_{\text{in}} = 0, y_{\text{in}}' = 0 \) and \( x_{\text{in}} = 0, x_{\text{in}}' = 0, -20 \text{ mm} < y_{\text{in}} < 20 \text{ mm}, y_{\text{in}}' = 0 \) was traced through the 3D fieldmap (Fig. 2b) of the standalone or combined devices with different radii of curvature of the electrodes \( \rho_1 \) and \( \rho_2 \). The output phase-space profiles of these beams were fitted with \( x_{\text{out}}' = c_x^{(1)} x_{\text{out}} + c_x^{(2)} x_{\text{out}}^2 + c_x^{(3)} x_{\text{out}}^3 \) and \( y_{\text{out}}' = c_y^{(2)} y_{\text{out}}^2 \) (due to the symmetry of the device only even powers of \( y_{\text{out}} \) appear).

Figure 2: a) Cross-section of the deflector in the non-bending plane. b) The COMSOL model with the simulated particles. Color indicates kinetic energy.

![Figure 2](image)

5: Beam Dynamics and EM Fields

D01 - Beam Optics - Lattices, Correction Schemes, Transport

Figure 3: The 2nd order aberration coefficients as a function of radius of curvature of the electrodes \( \rho_1 \) and \( \rho_2 \) for the standalone (S), horizontal and vertical fast switch (HFS, VFS) variants with bending radius \( \rho_0 = 600 \text{ mm} \). The solid lines indicate the minimum of the given plot; the dashed lines indicate the minimum in the other plane.

![Figure 3](image)

Figure 4: a) Visualization of the \( \delta x_{\text{out}} \sim x^2 \) and \( \delta x_{\text{out}} \sim y^2 \) aberrations of the standalone deflector for two geometries (black circles: optimized geometry; red squares: spherical deflector) The solid lines are the fitted polynomials (see text), the dashed lines are the linear terms. c) Focusing powers (slope of the \( x_{\text{out}}' - x_{\text{in}} \) and \( y_{\text{out}}' - y_{\text{in}} \) curves).

![Figure 4](image)

The 2nd order coefficients \( c_x^{(2)} \) and \( c_y^{(2)} \) are shown in Fig. 3 as a function of \( \rho_1 \) and \( \rho_2 \) for the three different types of deflectors with the minimum-aberration lines overlaid.

For the standalone deflector \( \rho_1 \sim \rho_2 \sim 400 \text{ mm} \) have been chosen to minimize \( \Delta x_{\text{out}} \sim x^2 \) and \( \Delta x_{\text{out}} \sim y^2 \) aberrations simultaneously. Figs. 4 a) b) demonstrate the improved linearity of this device with the optimal geometry \( \rho_1 \sim
MECHANICAL DESIGN

The two electrodes will be mounted in a grounded frame as a separate unit, as shown in Fig. 5a. Each electrode is supported by two ceramic rods and tubes. One of the rods is fitted into a tight hole of the electrode; the other rod is going through a slotted hole. This solution allows an eventual different thermal expansion of the electrodes and the frame during bake-out at 250 °C in both horizontal and vertical directions, without compromising the alignment precision of the electrodes. In case of the quick switch combinations an electrical shielding plate will be mounted to the electrode assembly in order to shield the non-deflected beam from the electrical field of the electrodes.

This electrode frame will be placed in a vacuum chamber as shown in Fig. 5b for the horizontal quick switch combination, relying on gravity for mounting. The three feet of the frame (two of which are visible in Fig. 5a) will be positioned in three alignment holes machined into the bottom plate of the vacuum chamber as shown schematically in Fig. 5c. One of these holes is fitting the frame foot tightly; the slotted hole allows movement in one direction thereby allowing a different thermal expansion of the frame compared to the vacuum chamber. The third hole allows movement in the horizontal plane.

The electrical connections use spring-loaded contacts and commercial SHV-20 kV feedthroughs on the bottom of the vacuum chamber.

REFERENCES

