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Design of an Electrostatic Octupole for Micro-Beam Deflection[2])

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In electrostatic deflection of focused ion and electron beams, a homogeneous field should be maintained within the deflector to reduce aberrations. The geometrical and voltage conditions are investigated to produce an electric field as homogeneous as possible within an octupole deflector. If the eight electrodes are equally shaped into a triangular cross section and are directed as one edge of each electrode with an angle of 360°/8 showing to the center of the device, then the adjacent electrode faces form parallel plate capacitors and the resulting field is the best fit to the ideal cosine potential distribution at the inner circle of the electrodes.

Bei der elektrostatischen Ablenkung von fokussierten Ionen- und Elektronenstrahlen sollte innerhalb des Deflektors ein homogenes Feld herrschen, um die Abbildungsfehler gering zu halten. Die geometrischen und Spannungsbedingungen werden untersucht, die ein möglichst homogenes Feld in einem Oktupol-Deflektor gewährleisten. Wenn die acht Elektroden gleiche Form haben, mit dreieckigem Querschnitt, und so ausgerichtet sind, daß die eine Kante jeder Elektrode mit dem Winkel 360°/8 zur Mitte der Anordnung zeigt, dann stellen die einander benachbarten Elektrodenflächen Parallelplattenkondensatoren dar, und das erzeugte Feld ist die beste Näherung an die ideale Kosinus-Potentialverteilung am inneren Elektrodenkreis.

1. Introduction

Electrostatic deflectors are in wide use to move focused ion and electron beams across a target [1 to 5]. The advantages over magnetic deflection are higher speed and lack of hysteresis. Heavy ion magnetic deflection is impractical because it would need extremely high fields. On the other hand, electrostatic deflection introduces additional aberrations by the energy difference of particles that move at different equipotential lines. The electric field can disturb a space charge compensation of positive ion beams.

Electrostatic multipole deflectors show high deflection sensitivity with respect to the applied voltage. They are used to simultaneously deflect into x and y directions from a common centre of deflection [1]. Contrary to parallel plate deflectors or Schlesinger deflectors [1] they can be used to vary the shape of the electric field by the applied voltages and to correct in this way the imperfections of mechanical manufacture, misalignment, etc.

The electric field within the deflector should be as homogeneous as possible to get low aberrations. This can be obtained by a high number of electrodes. But the larger the number of electrodes is, the larger the electric circuit generating the proper

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voltages [1] has to be. Another possibility is to reduce the number of the amplifier couples at the expense of a more complex electrode assembly [4, 5].

In this work attention has been drawn onto the shape of electrodes. The cross section of the electrodes of a multipole has been optimized on the basis of a simple model.

2. Model Assumptions

Within this work an octupole is taken as a special example of multipole deflector though the resulting optimized electrode shape can be applied to other multipoles, too. The basic geometry is shown in Fig. 1. The variables of the optimization are the angular electrode half-width ε and the voltages U_0 and U_1, these are indicated in Fig. 1. The aim of the optimization is to find the best fit of the potential distribution at the circle of the electrodes to the cosine potential function that gives an ideally homogeneous electric field. This means that the best fit would represent the case with the minimum deviation from the homogeneous field. Two different measures of the deviation are used during the fit procedure: At first, the absolute deviation

$$(\text{abs}) = \int_0^{2\pi} |U(\varphi; \varepsilon, U_0, U_1) - U_s \cos\varphi| \, d\varphi$$

is represented by the area spanned between the cosine and the real distribution, cf. Fig. 2. At second, a least square fit is generated by the square deviation

$$(\text{sqr}) = \int_0^{2\pi} \left(U(\varphi; \varepsilon, U_0, U_1) - U_s \cos\varphi\right)^2 d\varphi \, .$$

U_s is the amplitude of the ideal cosine potential needed for a certain deflection. The other symbols refer to Fig. 1. The integrals (abs) and (sqr), respectively, are equal to four times the integral taken from 0 to $\pi/2$. Hence the optimization is restricted to the first quadrant of φ.

Within the frame of this work it cannot be decided which measure of the deviation is more useful, because the "homogeneity" of the electric field (yet not defined) is not a trivial function of the boundary conditions ε, U_0, U_1. As it can be seen below, both optimization criteria give similar results. It is assumed that the potential between the electrodes varies linearly at the circle line. This simple assumption allows the optimization to be done without solving the Poission equation. In Section 4 an electrode shape is proposed that will better fulfill the linearity assumptions than the thin-walled electrode pieces of Fig. 1.

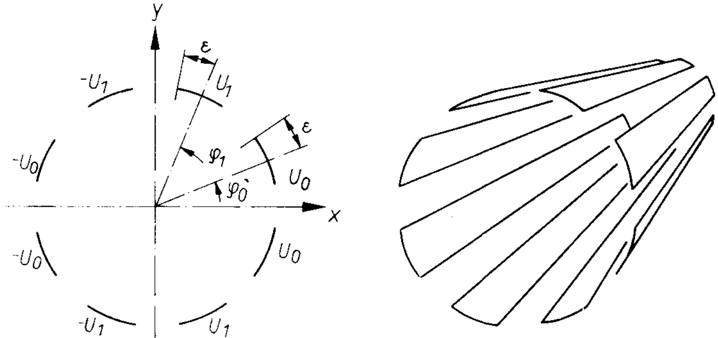

Fig. 1. Electrostatic octupole deflector — geometry and voltages for x deflection

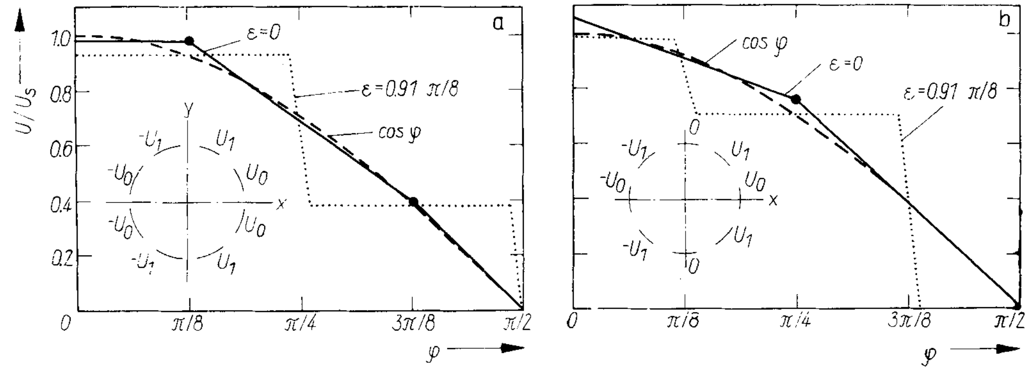

Fig. 2. Potential in the first quarter of the inner circle of the electrodes. Comparison of zero width and nearly full width (91%) electrodes with the ideal cosine deflector: a) voltages applied as in Fig. 1, b) octupole turned by $\pi/8$ with respect to the x-axis

3. Results of the Calculation

The optimization has been done in two consecutive steps. At first for a set of equidistant values of the electrode width ε in the range $[0, \pi/8]$ such voltages U_0, U_1 are found that give minimum (abs) and (sqr) deviations, respectively. Examples of the resulting potential distribution for high and zero ε are shown in Fig. 2a. In Fig. 3a

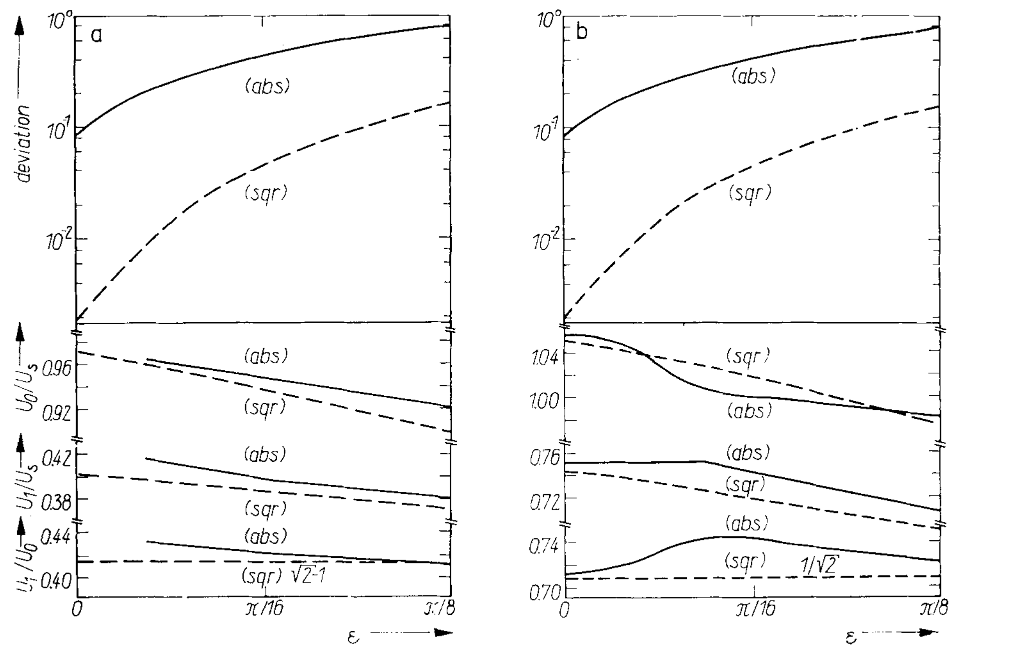

Fig. 3. U_0, U_1 and the voltage ratio U_1/U_0 corresponding to the minimum deviations (abs) and (sqr), respectively, are shown in dependence on the angular electrode halfwidth. It follows that small width electrodes should be preferred for cosine deflectors: a) geometry as in Fig. 2a, b) geometry as in Fig. 2b

the results for U_0, U_1, U_1/U_0, (abs), and (sqr) are given in dependence on ε. The (abs) and (sqr) fall monotonously down as ε is reduced from $\pi/8$ to zero.

Fig. 2b and 3b show the results for the alternative approach of applying 2×2 voltages to the eight electrodes as indicated by the insert. Compared to the geometry of Fig. 1, 2a, and 3a, the set of electrodes is rotated by $\pi/8$ with respect to the x–y system that defines the zero phase angle of the (fixed) cosine distribution.

The minimum of (sqr) has been calculated analytically. Therefore the dotted lines in Fig. 2 and 3 represent exact values. But the minimum of (abs) has been found by digital approximation. From the evaluation of different variants of the approximation it is judged that the calculated minimum (abs) is at the true minimum at least by 1% and the optimum voltages U_0 and U_1, respectively, are exact within $\pm 0.5\%$.

4. Discussion and Final Electrode Shape

Within the given model (Section 2) the octupole made of zero width electrodes is ten times better than that of full width or nearly full width. This conclusion can be drawn if the deviations (abs) and $\sqrt{(\text{sqr})}$ are taken as measures of performance. Both give nearly the same results. With small width electrodes and tall spaces betweeen them the fit to the ideal cosine distribution is very much better than with broad electrodes and small spaces. In Fig. 2 this can clearly be seen. Obviously, two or three straight lines fit the cosine function very tightly compared to the step function.

On the other hand, the assumption of the calculation, that the potential around the circle varies linearly with φ will hardly be fulfilled by electrodes made of a line. The potential of the electrodes with $-U_0$ and $-U_1$, respectively, will influence the distribution between the electrodes with $+U_0$ and $+U_1$. Therefore the potential indicated by full lines really will be lowered between the wire-like electrodes and the linearity supposition (which might be correct for small gaps) is not fulfilled. Restoring the linearity will restore the good fit. This has been done approximately by extending the electrodes to the outer side into a triangular shape, see Fig. 4. The edges directed to the centre have an angle $2\pi : n$, with $n = 8$, the number of electrodes. This results in parallel gaps between the electrodes. They determine the electric potential at the mantle of a cylinder that is defined by the inner edges of the electrodes. At this mantle the variation of the potential between adjacent electrodes is only approximately linear due to (i) the fringing fields, (ii) the influence of the remaining electrodes, and (iii) the curvature of the considered cylinder mantle. The radial extension of the electrodes should be larger than the gap between them, i.e. adjacent electrodes should form capacitors with large parallel plates. Despite of the imperfections of this approximation it is concluded that the propos-

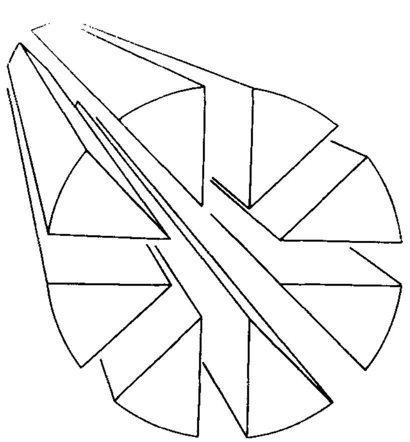

Fig. 4. Preferred octupole geometry

ed geometry (Fig. 4) creates a field that fits the cosine potential distribution on the mantle of the cylinder much better than the octupole of Fig. 1, which has broad and flat electrodes. Hence our configuration gives a more homogeneous electrostatic field within the deflector, i.e. in the interior of the cylinder.

References

[1] J. Kelly, Adv. Electronics Electron Phys. **43**, 43 (1977).
[2] E. F. Ritz, Adv. Electronics Electron Phys. **49**, 299 (1979).
[3] H. Paik, G. N. Lewis, E. J. Kirkland, and B. M. Siegel, J. Vac. Sci. Technol. **B 3**, 75 (1985).
[4] S. Moriya, K. Komatsu, K. Harada, and T. Kitayama, J. Vac. Sci. Technol. **B1**, 990 (1983).
[5] T. Soma, M. Idesawa, E. Goto, and T. Sasaki, J. Vac. Sci. Technol. **B3**, 177 (1985).

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