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Original research article

Differential algebraic description for aberrations analysis of typical electrostatic einzel lens

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ABSTRACT

In the present paper the modern map method has been used to calculate the third-fifth order geometric aberration, the first-third order chromatic aberration and the Gaussian optical properties for Schiske's and inverse Schiske's electrostatic lenses. COSY INFINITY 10 program is used for the aberration analysis and calculation of properties of electrostatic electron lenses. The Numerical results show that the differential algebraic method is an excellent method with high accuracy for calculating the high order electron optical aberration analysis.

1. Introduction

With the increasing sophistication of electron beam techniques (lithography, electron microscopy, ion implantation), it must be important to improve the aberration performance of high-resolution electron optical systems. So it is necessary to achieve higher order aberrations of the systems. Many theoretical tools have evolved to deal with correction aberration and the high order aberration analysis, such as approximately analytical method [1], canonical theory [2], and Lie algebra method [3]. These theoretical tools explain the derivation of high order aberrations, but these methods in the high order aberration analysis become complex in the expressions of the aberration. In contrast, the differential algebra method provides a powerful method for high order aberration analysis and numerical calculation of electron optical systems. In the present work, by tracking the general electron trajectory equation in rotating coordinates the transfer map can obtained in the same coordinates. The third order chromatic and fifth order geometric aberration for Schiske's and invers Schiske's models electron lenses are calculated using the computer code COSYINFINITY 10 [4,5].

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2. General electron trajectory equation in rotating coordinates

The general electron trajectory equation is usually expressed in a fixed coordinate frame [6,7],

$$
\begin{aligned}
X'' &= \frac{\rho^2}{2\Phi}\left(\frac{\partial\Phi}{\partial X} - X'\frac{\partial\Phi}{\partial Z}\right) + \frac{\eta\rho^2}{\sqrt{\Phi}}(\rho B_Y - Y'B_t),\\
Y'' &= \frac{\rho^2}{2\Phi}\left(\frac{\partial\Phi}{\partial Y} - Y'\frac{\partial\Phi}{\partial Z}\right) + \frac{\eta\rho^2}{\sqrt{\Phi}}(-\rho B_X + X'B_t),\\
\eta &= \sqrt{\frac{e}{2m}},\ \rho = \sqrt{1+X'^2+Y'^2},\ B_t = \frac{1}{\rho}(B_Z + X'B_X + Y'B_Y),
\end{aligned}
\tag{1}
$$

where the uppercase letters, X, Y, and Z, imply the fixed coordinates in. To transform Eq. (1) to rotating coordinates, the expression of rotating transform coordinates [6,7] in electron optics are used.

$$
\begin{aligned}
x'' &= 2\theta' y' + \theta'^2 x + \theta'' y + \frac{\rho^2}{2\phi}\left[\frac{\partial\phi}{\partial x} - (x' - \theta' y)\frac{\partial\phi}{\partial z}\right] + \frac{\rho^2}{\sqrt{\phi}}[\rho B_y - (y' + \theta' x)B_t],\\
y'' &= -2\theta' x' + \theta'^2 y - \theta'' x + \frac{\rho^2}{2\phi}\left[\frac{\partial\phi}{\partial y} - (y' + \theta' x)\frac{\partial\phi}{\partial z}\right] + \frac{\rho^2}{\sqrt{\phi}}[-\rho B_x + (x' - \theta' y)B_t],\\
\rho &= \sqrt{1 + (x' - \theta' y)^2 + (y' + \theta' x)^2},\ \mathrm{B}_t = \frac{1}{\rho}[B_z + (x' - \theta' y)B_x + (y' + \theta' x)B_y]
\end{aligned}
\tag{2}
$$

where the lowercase letters, x, y, and z indicate the corresponding rotating coordinates, φ is the potential function and B is magnetic induction andθ is the rotating angle. Although Eq. (2) becomes more complicated than Eq. (1), it does take an important role in explaining the DA method in rotating coordinates.

3. DA description for third-fifth order geometric aberrations

The DA description in fixed coordinates can be obtained by tracking Eq. (1) through a DA integrator from z_o to z_i, where z_o the object plane and z_i the image plane. The description for third- fifth order geometric aberrations have the form:

$$
\begin{aligned}
\Delta X_{3i} &= \sum_{k,l,m,n=0,1,2,3}^{k+l+m+n=3} M_f(1, klmn) X_o^k X_o'^l Y_o^m Y_o'^n,\\
\Delta Y_{3i} &= \sum_{k,l,m,n=0,1,2,3}^{k+l+m+n=3} M_f(3, klmn) X_o^k X_o'^l Y_o^m Y_o'^n,\\
\Delta X_{5i} &= \sum_{k,l,m,n=0,1,\ldots,5}^{k+l+m+n=5} M_f(1, klmn) X_o^k X_o'^l Y_o^m Y_o'^n,\\
\Delta Y_{5i} &= \sum_{k,l,m,n=0,1,\ldots,5}^{k+l+m+n=5} M_f(3, klmn) X_o^k X_o'^l Y_o^m Y_o'^n,
\end{aligned}
\tag{3}
$$

While the DA description in rotating coordinates is obtained by tracking Eq. (2) and have the form:

$$
\begin{aligned}
\Delta x_{3i} &= \sum_{k,l,m,n=0,1,2,3}^{k+l+m+n=3} M_r(1, klmn) x_o^k x_o'^l y_o^m y_o'^n,\\
\Delta y_{3i} &= \sum_{k,l,m,n=0,1,2,3}^{k+l+m+n=3} M_r(3, klmn) x_o^k x_o'^l y_o^m y_o'^n,\\
\Delta x_{5i} &= \sum_{k,l,m,n=0,1,\ldots,5}^{k+l+m+n=5} M_r(1, klmn) x_o^k x_o'^l y_o^m y_o'^n,\\
\Delta y_{5i} &= \sum_{k,l,m,n=0,1,\ldots,5}^{k+l+m+n=5} M_r(3, klmn) x_o^k x_o'^l y_o^m y_o'^n.
\end{aligned}
\tag{4}
$$