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A study of Glaser's Ball – Shaped Magnetic Lens under the Effect of Current Density

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دراسة على عدسة كلازر المغناطيسية ذات الشكل الجرسي تحت تأثير كثافة التيار

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الخلاصة

تم اجراء بحث حاسوبي عن تصميم وخواص عدسة كلازر المغناطيسة. العامل المحدد في تصميم العدسة المغناطيسية هو كثافة التيار σ الذي مدعوم بواسطة الملف. هذا العامل درسَ لايجاد اقل معامل زيوغ لوني وكروي. اما بالنسبة الى حساب الزيوغ فقد حسبت نسبياً الى البعد البؤري تحت شرط التكبير الصفري.

Abstract

A computational investigation has been carried out on the design and properties of Glaser's lens. The limiting factor in magnetic lens design is the current density σ that can be supported by the coil. The current density was used as parameters of the magnetic lens design. These parameters were studied for finding the minimum spherical and chromatic aberration coefficients. The computed aberration has been normalized in term of focal length under zero magnification condition.

1. Introduction

Magnetic lenses are in general used for focusing electron beams and, as a particular case, the focusing of an axially symmetric electron beam is usually performed using an axially symmetric magnetic field. For example, in the case of the electron microscope [1]. The electron microscope (EM) is the important electron optical instrument and is manufactured in different types. An objective lens is the most critical lens in EM. The design and focal properties of the objective lens determine the main characteristics of the electron microscope. For example, the resolving power of the microscope is ultimately limited by the spherical aberration of an objective lens. Current density σ is a significant parameter in the design of EM through the optical properties of objective magnetic electron lens [2].

The purpose of the present investigation is to study the favourable particular current density regions suitable for Glaser's model.

2. Axial Field Distribution

In 1941, Glaser introduced the field model [3]:

$$B(z) = \frac{B_o}{1+z^2/a^2} \quad \ldots\ldots (1)$$

where B_o is the maximum flux density [4]

$$B_o = \frac{\mu_o S}{2}\left[\ln \frac{R_2 + \left(R_2^2 + (S/2)^2\right)^{1/2}}{R_1 + \left(R_1^2 + (S/2)^2\right)^{1/2}}\right]\sigma \quad \ldots\ldots (2)$$

And a is the half width, which it is take in our work $(a = B_o/2)$

$$B_o \,\alpha\, \sigma \quad \ldots\ldots (3)$$

i.e. B_o proportional to σ, where $\mu_o = 4\pi * 10^{-7} H.m^{-1}$, R_1 is the inner radius, R_2 is the outer radius and S is the coil thickness.

The current density σ (define as the current per unit cross – sectional area of the conductor) in a coil of N turn can be written as [2]

$$\sigma = \frac{NI}{A} \quad \ldots\ldots (4)$$

where A is the cross – sectional of the energizing coil, which is given by

$$A = \gamma(R_2 - R_1)S \quad \ldots\ldots (5)$$

where γ is the packing of factor ($\gamma = 0.9$ for a copper tape winding).

Figure (1) shows the axial field distribution of magnetic lens according to the equation (1). The magnetic flux has the maximum value of 0.2112 T at z = 0 and the half width a is equal to 0.1056 m.

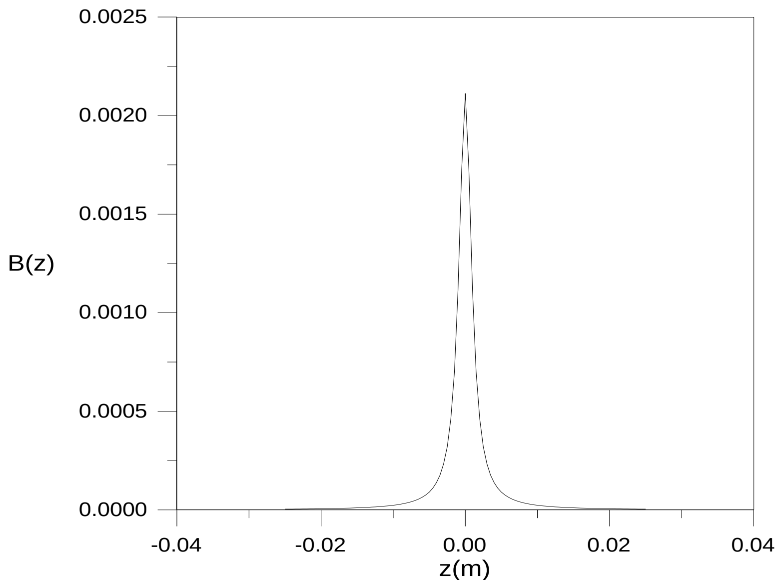

Figure (1): The axial potential distribution of Glaser's lens.

Figure (1) comes out at geometrical parameters $R_1 = 0.00095$ m, $R_2 = 0.0975$ m, $S = 0.008 m$ and $NI = 80$. Because the current density depends on the geometrical shape of lens, in our calculations, we show that the current density is proportional to the maximum flux density B_o.

3. The Trajectory Equation And Magnetic Lens Aberration

The paraxial – ray equation of an electron in a magnetic field of axial symmetry is given by [5]:

$$\frac{d^2 r(z)}{dz^2} + \frac{e}{8mV_r} B^2(z) r(z) = 0 \qquad (6)$$

where $B(z)$ is the magnetic flux density distribution, $r(z)$ is the radial displacement of the beam from the optical axis z, e is the charge of electron, m is the mass of electron and V_r is the relativistically corrected accelerating voltage which is given by:

$$V_r = V_a \left(1 + 0.978 * 10^{-6} V_a\right) \qquad (7)$$

where V_a is the accelerating voltage. It can be easily realized from equation (6) that the force driving the electrons towards the axis is directly proportional to the radial distance $r(z)$.

In order to perform the calculations it is assumed that a potential $V_a = 1000 kV$ is applied on the Glaser's magnetic lens. The electron beam path along the magnetic lens field under zero magnification condition and accelerating mode of operation has been considered. Figure (2) shows the trajectories of an electron beam traversing the magnetic lens field various values R_m, where $R_m = (R_2 + R_1)/2$.

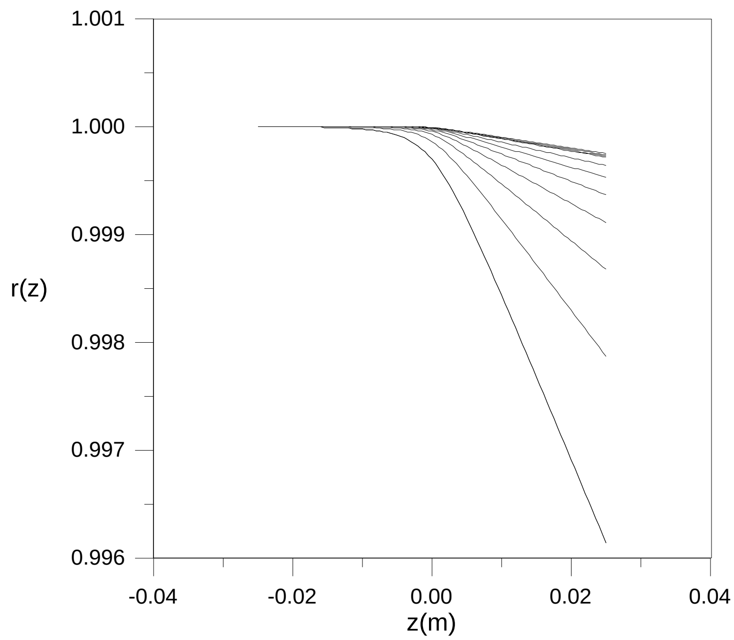

Figure (2): The electron beam trajectory at various values R_m .

These trajectories have been computed with aid of equation (6) which solves it by fourth order – Runge – Kutta method. Computation has shown that as the beam emerges towards the optical axis when the R_m decreases, (i.e. the electron beam converges towards the optical axis when the current density increases). Hence, the current density is inversely proportional to the radius of lens (see equations (4) and (5)).

The most important aberrations in an electron – optical system are spherical and chromatic aberration. The spherical and chromatic aberration coefficients are denoted by Cs and Cc respectively. In the present investigation the values of Cs and Cc are normalized in terms of the image side focal length. The Cs and Cc are calculated from the following equation [6]:

$$Cs = \frac{\eta}{128V_r}\int_{z_o}^{z_i}\left(\frac{3\eta}{V_r}B^4(z)r^4 + 8B'^2(z)r^4 - 8B^2(z)r^2r'^2\right)dz \quad \ldots\ldots\ldots\ldots(8)$$

$$Cc = \frac{\eta}{8V_r}\int_{z_o}^{z_i} B^2(z)r^2 dz \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

where η is the charge – to – mass quotient of the electron.

The integrals given in the above equations are executed by means of Simpson's rule. Figure (3) shows the relative spherical aberration coefficient Cs/f_i of the magnetic lens as a function of the radius R_m .

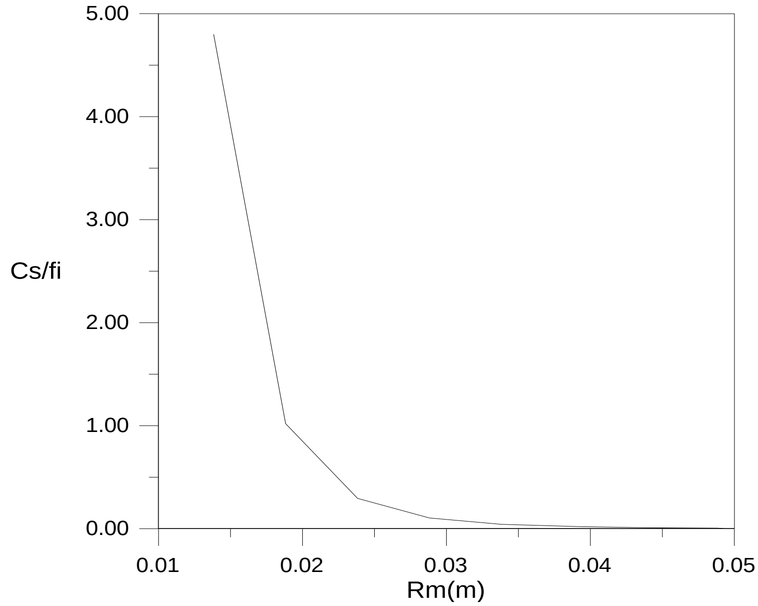

Figure (3): The relative spherical aberration coefficient as a function of R_m

The trajectories shown in figure (2) have been used for computing the relative spherical aberration coefficient as a function of radius R_m . It is seen that Cs/f_i has a minimum value equal to 0.00359 at $R_m = 0.0492$ m. in the same case; the relative chromatic aberration coefficient Cc/f_i has been computed as a function of radius R_m . Figure (4) shows the minimum value of Cc/f_i (=0.00041) at $R_m = 0.0492$ m.

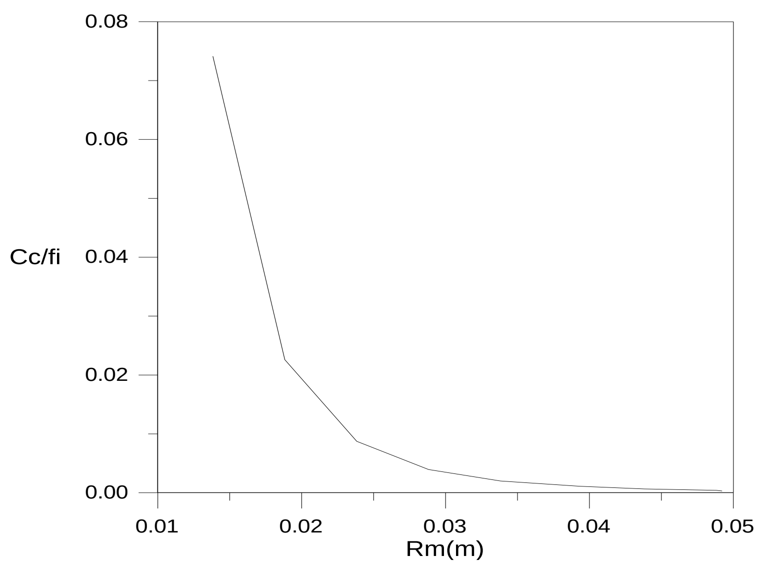

Figure (4): The relative chromatic aberration coefficient as a function of R_m

All results were computed at $NI = 200(A - turn)$, for more expansion in our study about the current density and it affects the magnetic lens aberrations. We change the number of turn of coil which is proportional to the current density (see equation (4)). Figure (5) shows that Cs/f_i and Cc/f_i decreases when NI decreases too. We get the $(Cs/f_i)_{\min} = 2.5*10^{-6}$ and $(Cc/f_i)_{\min} = 1.26*10^{-6}$ at $NI = 80(A - turn)$, while all results were computed at $NI = 200(A - turn)$ as written above.

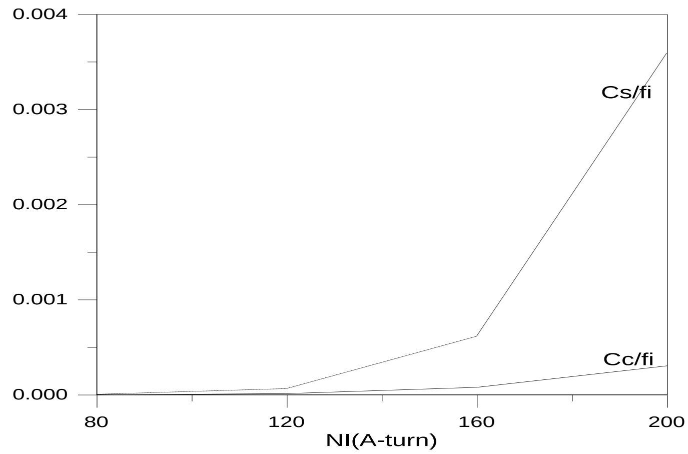

Figure (5): The relative spherical and chromatic aberration coefficients as a function of NI

Conclusions

The current density σ is good parameter which the magnetic lens depends on. We found the spherical and chromatic aberration coefficients decrease when the current density decreases too. The present investigation shows the excellent electron optical properties of magnetic lens which gives the minimum aberrations.

References

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