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Studying the Properties of the Magnetic Optical Lenses by Using Mathematical Functions

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***Abstract*— A suggested new mathematical function has been used for representing the axial magnetic flux density distribution along the optical axis of the magnetic lens. The main feature of this function is that it has more than one optimization parameters to let more flexible for the designer to test more one parameter that suggested in this function to reach the best axial magnetic flux density which gives optimum objective focal properties with available reconstruction pole pieces.**

Keywords-electron optics, Optimization, design of magnetic lens

I. INTRODUCTION

Today, the charged-particle devises are considered to be important scientific and technical tools. This importance come from the rapid growth in various field like material science, semiconductors technology, plasma physics, biology and advanced nano-technology. The branch of physics that deals with the problems of motion of charged particle beams in electric or magnetic fields is called the electron and ion optics [1].

In sense of electron and ion optics there are two entirely different optimization approaches which are analysis and synthesis. In the conventional design of electron lenses, , the approach of analysis is taken under consideration. According to this approach, design process of magnetic lens consists of two steps: the first one is the design of electron optics while the second one is the design of magnetic circuits including coils, yokes, and poles. If experimentally obtained electron optical properties are far from what is expected, the second part must be checked. The first step of the lens design is the optical design to determine the optimum polepiece shape and ampere– turns (A-t) under given external conditions. The second step is the coil design. The main task here is the estimation of heat conduction. The third is the design of yokes and poles. It is noted that the conventional design based on the trial and error until a satisfactory performance is achieved according to the constraints taken under consideration [2].

Optimization by synthesis has been one of the most ambitious goals of electron and ion optics which is sometimes called "inverse design procedure". This approach is based on the fact that any imaging field, its optical properties and aberrations are totally determined by the axial distribution of the field. Only the axial distributions and their derivatives appear in the equation of motion of charged particle (i.e. paraxial ray equation) and in the expressions of aberration coefficients. Then instead of analyzing a vast amount of different electrode or pole-piece configurations. One can take the criteria defining an optimum system as initial conditions and try to find the imaging field distribution that would produce it. The final step in the synthesis procedure is to synthesize the electrode or pole-piece profiles that generate this field distribution [3,4].

I1.THE MATHEMATICAL MODEL

The present investigation is based on the optimization by synthesis. Accordingly, the magnetic field distribution of rotationally double polepiece magnetic lens along the optical axis can approximated by the following target function.

$$B(z)=\left(\frac{\mu_o NI}{S}\right)\left(\frac{\sinh(2.636\frac{S}{D})}{\cosh(2.636\frac{S}{D})+\cosh(5.272\frac{Z}{D})}\right) \qquad (1)$$

It can be seen that the target function represented in eq. 1 has three main control parameters Axial bore Diameter (D), Width of air gap between two polepices (S) and excitation of the lens.

III.Polepiece Reconstruction

With aid of equation $B(z)=(\mu_o \frac{dV(z)}{dz})$ the axial symmetric scalar potential distribution corresponding to field given by equation (2) can be determined by the following integral along the optical axis.

$$V(z)=-\frac{1}{\mu_o}\int_{z_s}^{z_f} B(z)dz \qquad (2)$$

Where z_s and z_f are the axial coordinates of the starting and final of magnetic fields distribution. The shape of the equipotential surfaces (polepieces in the present work) can be reconstructed by using analytical solution of the Laplace's equation as given by**[4]**.

(3) $$R_p(z) = 2\left[\frac{V(z)-V_p}{V''(z)}\right]^{\frac{1}{2}}$$

Where V(z) is the axial magnetic scalar potential distribution, $V''(z)$ is the second derivative of V(z) with respect to z, $R_p(z)$ is the radial height of the reconstructed polepiece shape, and $V_p = \left(\frac{NI}{2}\right)$ if the field of a double polepiece lens is symmetrical about the symmetry plane(z=0), while if the field is asymmetrical, then V_p would be equal to the area under the field curve for each side about the position of the maximum value of the field distribution **[3]**. However, in the case of asymmetrical lens field, the potential values in the object and image spaces are not equal.

IV.Objective lens aberrations

When the axial magnetic field distribution along the domain of solution is assigned according to equation (1), the paraxial ray equation **[2]**.

$$r'' + \left(\frac{\eta}{8V_r}\right)B_z^2 r = 0$$

(4)

can be solved in order to deducing electron beam trajectory r and its slope r/ . In this work the Fourth-Order Runge-Kutta method has been used to achieve this task. It should be mentioned that the parameters η and V_r appears in equation (4) are the electron charge to mass quotient and the relativistically accelerating voltage respectively. The spherical and chromatic aberration coefficients C_s and C_c expressed respectively . **[5]**

$$C_s = \frac{\eta}{128V_r}\int_{z_o}^{z_i}\left[\frac{3\eta}{V_r}B_z^4 r_\alpha^4 + 8B_z'^2 r_\alpha^4 - 8B_z^2 r_\alpha^2 r_\alpha'^2\right]dz$$

(5)

$$C_c = \left(\frac{\eta}{8V_r}\right)\int_{z_o}^{z_i} B_z^2 r_\alpha^2 dz$$

(6)

which can be computed using any suitable technique . In the present paper Simpson's rule will be used to computed C_s and C_c.

V.PHYSICAL PARAMETERS

The defect of spherical aberration has a special importance overits counterpart defects, since it is affects many of the lens characteristics. Among many of them are the resolution distance δ and semi-angle aperture α. So these two parameters have been considered asa figure of merit for the evaluation of the resultant lens in accordance with the present work procedure. However, the resolution distance, for any lens system, in terms of the spherical aberration coefficient may expressed in the following form **[6,7]**.

$$\delta=0.61(C_S\lambda^3)^{1/4}$$

(7)

Indeed, the constant (0.61) appears in equation (7) is come out according to Rayleigh Criterion. The symbol λ refers to the charged particle associated wave length, which in terms of the accelerating potential (V_r) given by the formula for the case of electron **[8]**:

$$\lambda = \sqrt{\frac{1.5}{V_r}}(nm)$$

(8)

Concerning with semi-angle aperture, the formula that correlated this parameter with spherical aberration coefficientis as shown in the following expression **[7,9]**.

(9) $$\alpha(rad)=(\lambda/C_s)^{1/4}$$

Obviously equations (7 and 9) show that the spherical aberration coefficient correlates with the resolution distance and semi-angle aperture through the electron associated wave length. So, they are not a direct relation unless state of wave length being fixed. The focusing power (β) is another important property that characteristic any electron-optical lens system. Thus, it is of more interest to consider such a property to be a figure of merit to evaluate the quality of electron
lens for a specific application. Anyway, this lens property given by the following equation **[10]**.

(10) $$\beta=1/f=[e/8V_r]\int B_z^2 dz$$

Where f is the focal length for the lens of magnetic field distribution B_z. equation (10) is known as Busch's formula for weak lens. However, the counterpart expression for thick lens being more complicated.

VI.The Effect Of The Axial Bore Diameter(D)

The effect of the axial bore diameter on the axial magnetic field distribution and consequently the polepiece configuration is studied keeping the width of air gap, lens excitation and the length of the lens are constants at the following values: S=2 mm, NI=500 a.t L= 40mm. Figures 1 and 2 show the axial magnetic field distribution B_z and its corresponding axial magnetic scalar potential distribution V_z for different values of the axial bore diameter of the lens (D =2, 4, 6, 8, mm). From figure 1, it is noted that the axial field distribution extends out of the air -gap region (i.e., the action region) , However, the axial magnetic field distribution will be more localized in the air -gap region for small values of the axial bore diameter. It is seen that the behavior of the field distribution as a function of the axial bore diameter is similar to that with the half width of the field for the conventional magnetic lens models (for example, Glaser model). As the axial bore diameter increases the maximum value of the magnetic flux density B_z decreases while the half width of the field distribution increasing as shown in figure 3.

The pole piece profiles that can produce each B_z distribution, plot in figure 4. It can be seen that the consequences for increasing D lead to decreasing the pole face curvature.

Figure 5 shows the variation of the aberration coefficients Cs and Cc and the objective focal length f_o as a function of the axial bore diameter D under zero magnification condition at the excitation parameter NI/SQRT(V_r)=20 are amend. However, this amendment of the optical properties is a consequence for the concentration of the flux density distribution within the air-gap region as the axial bore diameter decreases.

Figure 6 shown the physical parameters as a function of D, from the figure it is noted that resolution limits increases while the focusing power and angular aperture decreases. Furthermore, the decreasing of α indicates that a finer details for material sample can be inspect and explored due to the increases of D. The effect of the axial bore diameter D on the objective optical properties and physical parameters of the lens is constant listed in table 1 at constant excitation parameter under zero magnification condition.

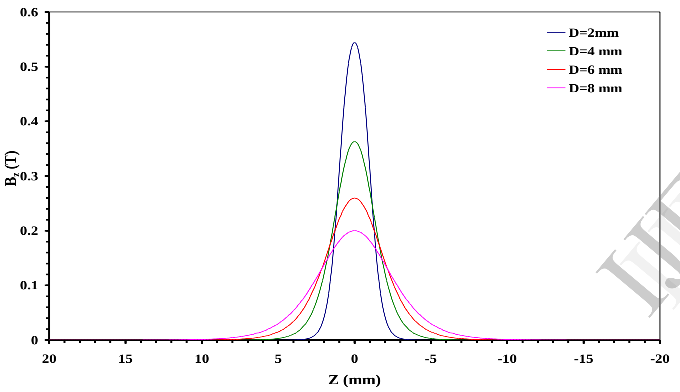

Figure 1: The axial magnetic field distribution curves Bz for different values of axial bore diameter of lens

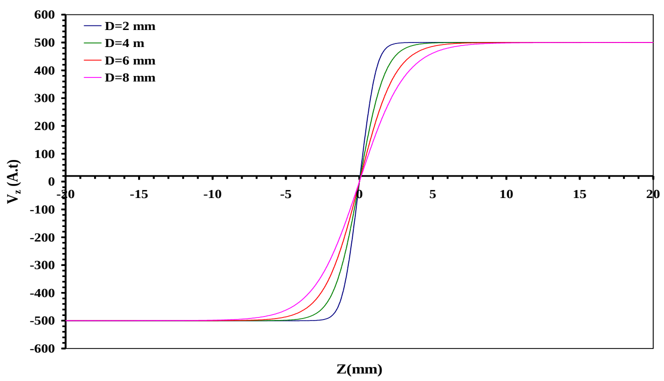

Figure 2: axial magnetic scalar potential distribution curves V_z for different values of the axial bore diameter of the lens.

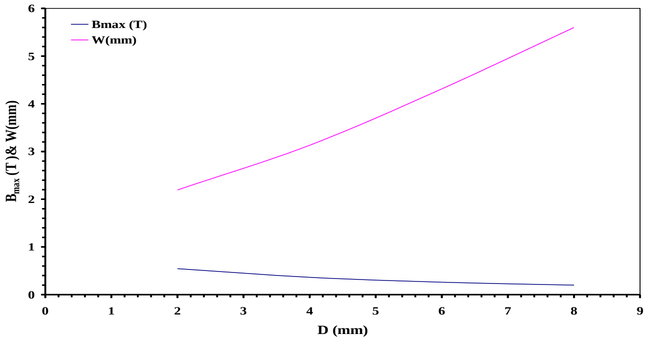

Figure 3: The maximum flux density value B_{max} and the half width W of the lens as a function of the parameter D.

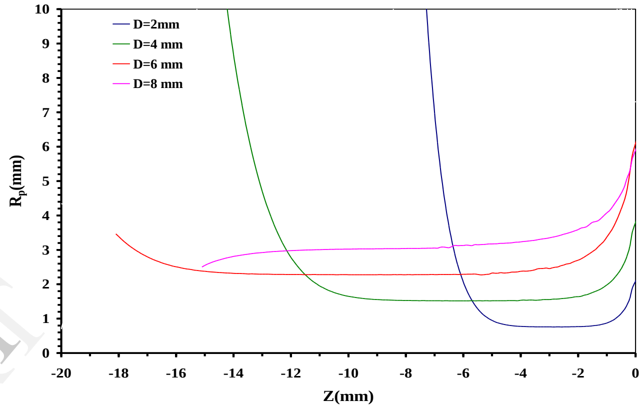

Figure 4: Polepieces shapes for different values of D

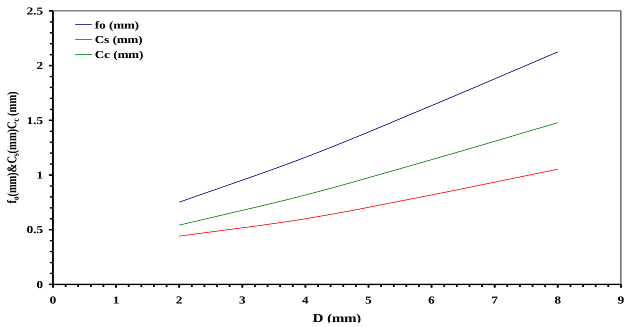

Figure 5 :The objective focal length fo and the aberration coefficients Cs and Cc as a function of D at (NI/Vr1/2=20).

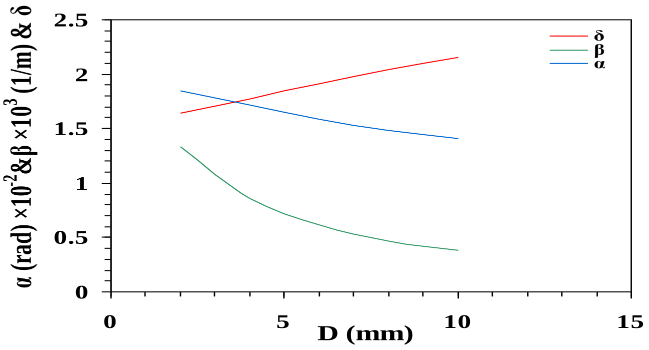

Figure 6: The physical parameters δ, α, and β as a function of D.

Table (1): Some of variables for symmetrical double polepiece magnetic lens for various values of the parameter D when S=2 mm and NI=500 a.t $NI/V_r^{1/2}=20$

D(mm)	f_o(mm)	C_s(mm)	C_c(mm)
2	0.751	0.441	0.542
4	1.162	0.6	0.817
6	1.634	0.818	1.14
8	2.125	1.053	1.478

VII.CONCLUSIONS

From the investigation of unsaturated symmetrical magnetic double polepiece lenses with the aid of the axial magnetic field distribution function taken under consideration, one can conclude the following:

1. The optical focal properties for objective magnetic lenses and the polepiece profile are different for various values of the axial bore diameter when the excitation of the lens is kept constant.
2. The behavior of the properties and the polepiece shape with the axial bore diameter is similar to that with the axial bore diameter in both analytical and synthesis optimization procedures. However, all parameters of the lens and their polepiece shapes are unaffected by the variation of the lens excitation when the bore diameter is kept constant.
3. The present investigation has shown that the favorable values of the important design parameter D are the smallest values which are less or equal 6mm. This conclusion coincides with the applicable shapes of the polepieces to be reconstructed.
4. when the parameter D increases, the axial magnetic field distribution extends out of the air -gap region as well as the maximum value of flex density decreases.
5. It can be seen that the consequences for increasing D lead to decreasing the focusing power and angular aperture while the resolution limits increases.

VIII. REFERENCES

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