Investigation of the optical properties for bipolar magnetic lenses

Ali A. Al-Azawy

Ph.D. in Physics/Department of Medical Physics/College of Science/ Al-Karkh University of science Baghdad/ Iraq

E-mail: aliphysics74@gmail.com

Abstract

In the current work, inverse design of symmetric double pole piece magnetic lenses has been introduced by using a VDTML software mentioned before, mathematical function as target function which has been used for Clarify the axial magnetic field, A mathematical function containing physical and geometric coefficients of the magnetic lens is adopted. Electron beam path was calculated using the distribution of the axial magnetic field along the lens axis in a telescopic magnification pattern using the fourth order Runge-Kutta method. And that is by calculating the distribution of the axial magnetic field and its first derivative, the path of the electron beam and its first derivative, in order to calculate the objective focal characteristics. There is a possibility to find the optimal shape of the magnetic pole piece after calculating the numerical axial magnetic potential parallel to the axial magnetic field and its derivative of the first and second order.

Keywords: symmetric lens, pole piece lens, cardinal points, magnetic lenses.

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Introduction

One of the problems facing the issue of finding specific geometrical designs for magnetic lenses with very small aberration coefficients is the dependence of the properties of the lens on a large number of engineering and physical variables. The inverse design method used in this research is one of the methods of optimizing electronic magnetic lenses, as this method is based on the calculation of fist-order properties and the emergence of the third order, (third-order aberrations) for lenses, which are determined entirely using axial functions, which are called target functions such as numerical magnetic potential, axial magnetic overflow or pathway of the charged particle beam (Szilagyi, 1988). It is noted that these distributions and their derivatives manifest in the equation of the axial rays and the aberration factors. Accordingly, the designer sets a standard by which the optical system is known as a prerequisite in the design, that is, the design in this way is chosen by choosing an analytical mathematical function to clarify the axial magnetic field path of the lens or The path of the electron beam inside the lens is then the axial ray equation is resolved analytically or numerically, and then the calculation of the electronic magnetic lens aberration is calculated. If the lens has good optical properties, the electrode is rebuilt as a final stage in the design (Chernosvitov, 2002).

Mathematical treatment

The mathematical relationships has been suggested to clarify the distribution of the axial magnetic field as a target function in the synthesis procedure adopted in this study and its mathematical form is:

$$B(z) = \left(\frac{NI}{2}\right)\tanh\left(\frac{Z}{0.40D}\right) \quad \ldots(1)$$

The reason for using this function is the great resemblance between the distribution of the axial magnetic field of the symmetrical bipolar

magnetic lenses and the curve of this function, as well as the mathematical structure of this function containing the optimal variables representing the most important necessary engineering and physical parameters of the lens, namely the diameter of the axial aperture (D) and lens irritation (NI)). The reverse design method used in this study can be divided into:

First: Determination of the axial magnetic field (Bz), at this stage the distribution of the axial magnetic field (Bz) is determined by determining the magnitude of the optimization variables shown in the proposed function equation (1). After that, the distribution of the axial numerical voltage (Vz) and its first derivative is calculated And the second (Vz ") analytically using the following relationship (Al-Jubori, 2001).

$$V_z = \frac{1}{\mu} - \int_{-\infty}^{+\infty} B_z dz \ldots (2)$$

Second: Calculating the path of the electronic beam along the lens axis and object properties. This is done by solving the paraxial-ray equation equation (3) numerically by using the fourth-level Runge-Kutta method (Szilagyi, 1988).

$$r'' = -\left(\frac{e}{8mV_r}\right) B_z^2 r \quad (3)$$

The aberration coefficients are then calculated equation (4), (5) by using the Simpson's rule (Grivet, 1972) and (Kato, and Tsuno, 1990).

$$C_c = \frac{\eta}{8V_r} \int_{Z_o}^{Z_i} B_z^2 r_\alpha^2 dz \ldots . (4)$$

$$C_s = \frac{\eta}{128V_r} \int_{Z_o}^{Z_i} \left[\left(\frac{3\eta}{V_r}\right) + B_z^4 r_\alpha^4 + 8B_z'^2 r_\alpha^4 - 8B_z^2 r_\alpha^2 r_\alpha' \right] dz \ldots . (5)$$

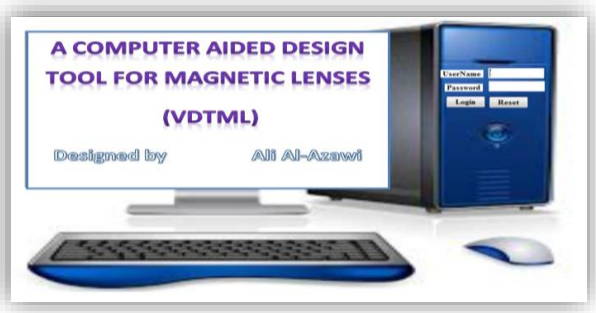
Third: Determining the shape of magnetic poles capable of generating axial magnetic field distributions, using the following relationship (A1-Obaidi, 1995) (Al-Saadi, 2007).

$$R_p = 2\left(\frac{V_z - V_p}{V_z''}\right)^{\frac{1}{2}} \ldots (6)$$

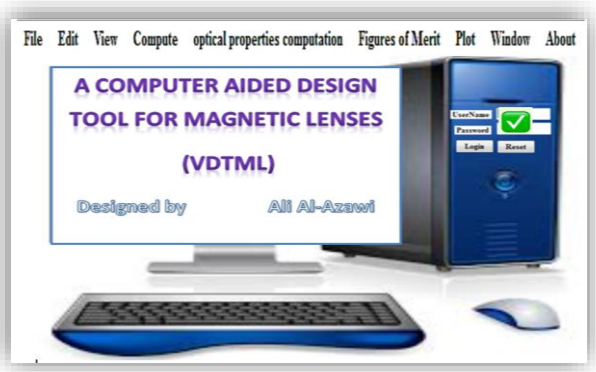
Whereas, Rp(z) is the diagonal height of the lens electrode along the axis and (Vp) is the voltage at the magnetic pole which is equal to (0.5 NI).

Code interface and Calculations

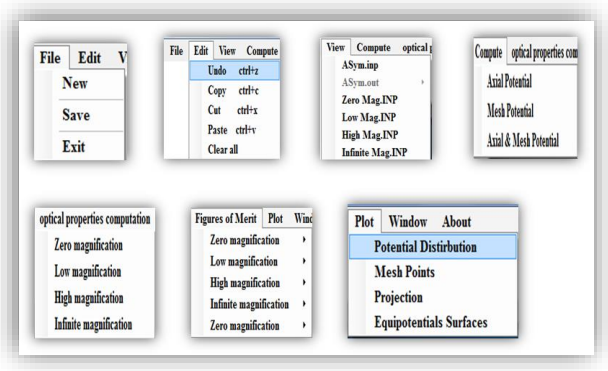
A supplementary program written in Visual Basic.net which designed to supply an easier and more flexible tool to analyze any magnetic lens systems. Once the software starts executing, the first front appears as shown in Figure 1A. This front shows the author's name and the program's name. On this page, information is represented by entering the user name and password in order for the program to start working as shown in Figure 1B. After entering the user name and password, a page interface appears that contains all the command lists, which were collected in Figure 1C, to facilitate the calculation process (Al-Azawy, 2016).



(A)



(B)



(C)

Figure 1. A) The main Interface of (VDTML) Software. B) The Execution Interface of (VDTML) Software after enter the User Mane and Password. C) main Command Lists of the Software.

Effect of axial aperture diameter (D)

To study the effect of this variable on the function of the distribution of the axial magnetic field, the following values were chosen to represent it (D = 10, 12, 14, 16 mm) with the confirmation of the other optimization variable, which is the irritation of the lens (NI = 2000 At), as Figure 2. shows the magnetic flux density distributions Axial (Bz) has different values for the axial aperture diameter with lens irritation constant.

It is noted from this figure that the maximum magnitude of the axial magnetic flux density (B_{max}) which decreases with increasing diameter of the axial aperture (D) while the value of the width of the half of the magnetic field (W) increases as shown in Figure 3. As it is observed from this figures that increasing the diameter of the axial aperture (D) with the constant irritation of the lens leads to a decrease in the voltage slope at the middle of the lens gradually while it is fixed outside this region (the ends of the lens) and the reason for this is due to the increase in the width of the half-field Magnetic (W).

It is noted from this figure that the general behavior of the electrode shape does not change with the increase of the diameter of the axial aperture (D) as well as the ability to determine the diameter of the aperture The pivot is in a way that largely conforms to the predetermined values and this is consistent with its findings.

To study the effect of aperture diameter (D) to the optical properties on the magnetic lens, the electronic beam path was used to calculate the focal objective properties. Figure 4. shows the path of the electronic beam along the axis of the lens (z) and the pattern of the observational zoom and different values for the diameter of the axial aperture (D). It is noted from the figure that the increase in the diameter of the axial aperture (D) leads to a decrease in the gradient in the path of the electronic beam gradually.

Figure 5. shows the change of the objective focal length (f_o), the spherical aberration factor (Cs) and the chromatic aberration factor (Cc) of the objective magnetic lens with the increase of the diameter of the axial aperture (D). Note from the figure that increasing the diameter of the axial aperture (D) with the constant irritation of the lens leads to increasing the focal length values Objective and aberration coefficients, and this is shown in Table 1., as it is noticed from this table that the increase in the diameter of the axial aperture (D) leads to obtaining focal properties and the reason for this is due to the increase in the width of half of the axial magnetic field (W) and this is consistent with Findings.

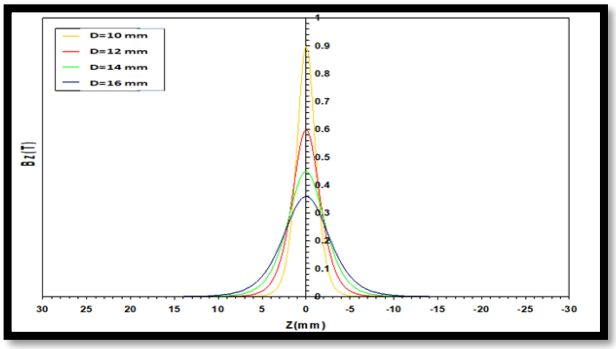


Figure 2. magnetic flux density distributions

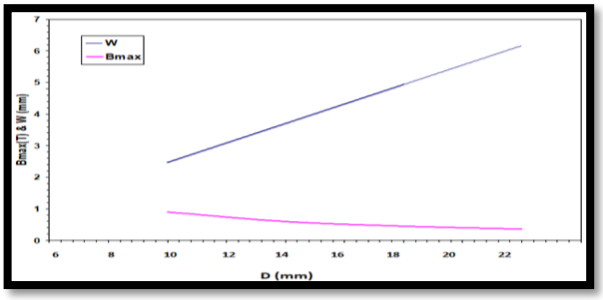


Figure 3. maximum value change of B_{max}.

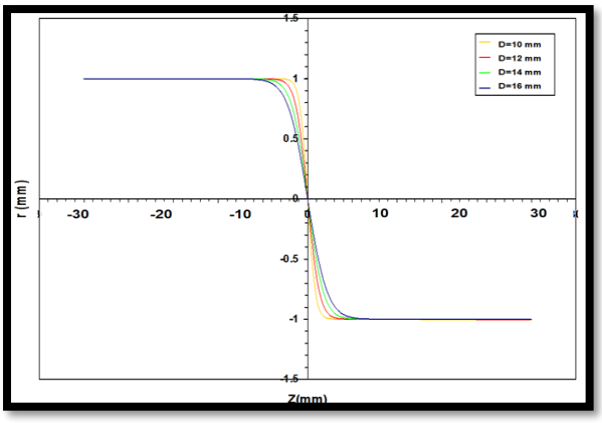


Figure 4. electronic beam paths along the optical axis of lens.

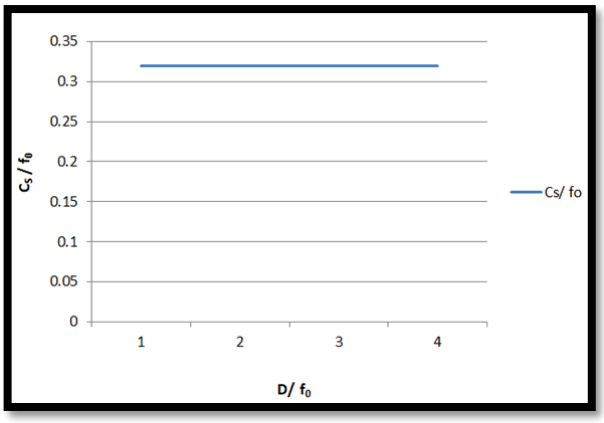


Figure 6. spherical aberration coefficient as function to (D/f_0)

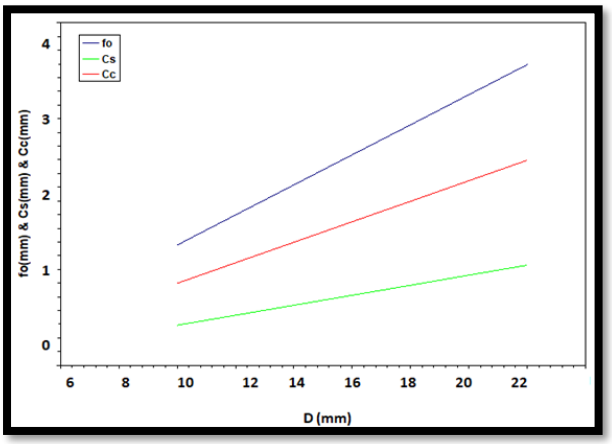


Figure 5. change of objective focal length f0. Spherical aberration Cs. chromatic aberration Cc with increasing D, with NI=2000.

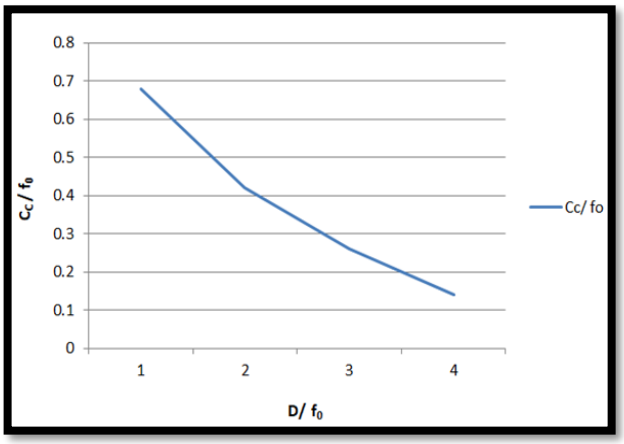


Figure 7. chromatic aberration coefficient as function to (D/f_0)

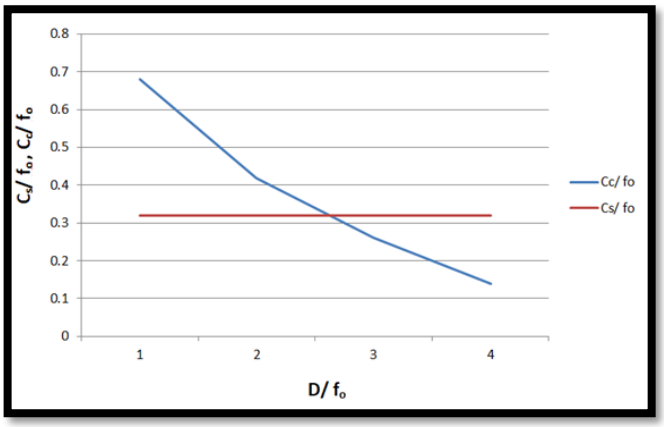


Figure 8. sphericaland chromatic aberration coefficient as function to (D/f_0)

Table 2. show the variation of the relative spherical and chromatic aberration coefficients as function of (D/ f_0) for the case under study which calculated by the software and shown in figures 6,7,8., Figure 6. show The variation of the relative spherical aberration coefficient as function of (D/ f_0) which indicate that relative spherical aberration coefficients act as constant as the function of (D/ f_0) increasing.

Figure 7. show The variation of the relative chromatic aberration coefficient as function of (D/ f_0) which indicate that relative spherical aberration coefficients decrease as the function of (D/ f_0) increasing. In figure 8. merge the variation of the relative spherical and chromatic aberration coefficients as the function of (D/ f_0) increasing To discuss results more easily.

Table 1. The change of objective focal properties with increased diameter of axial aperture D with NI = 2000t.

D (mm)	f_o(mm)	Cs(mm)	Cc(mm)
10	2.17	0.70	1.47
12	2.65	0.85	1.12
14	3.07	0.99	0.79
16	3.53	1.13	0.48

Table 2. The variation of the relative spherical and chromatic aberration coefficients as function of (D/ f_0)

D/ fo	Cs/ fo	Cc/ fo
4.61	0.322	0.68
4.52	0.320	0.42
4.56	0.322	0.26
4.53	0.320	0.14

Conclusions:

The possibility of using mathematical functions in a highly efficient synthesis technique to obtain magnetic dipole lenses with good optical specifications.

Aberration coefficients decrease such that in (Cc) and the lens becomes of good focal properties whenever the axial aperture diameter values decrease, due to a decrease in the width of the half-field.

The maximum value of the axial magnetic flux density increases as the axial aperture diameter values decrease for the magnetic lens, and this is accompanied by a decrease in half width.

From results the variation of the relative spherical aberration coefficient as function of (D/ f_0) which indicate that relative spherical and chromatic aberration coefficients act as constant and as decreasing in magnitude as the function of (D/ f_0) increasing respectively, this indicates success in the relative control of aberration coefficients in the lens under study.

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