Design of Magnetic Lens Depending on Mathematical Shape Function

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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.

الخلاصة

تم اقتراح دالة رياضية جديدة لتمثيل توزيع كثافة الفيض المغناطيسي المحوري على طول المحور البصري للعدسة المغناطيسية. الميزة الأساسية لهذه الدالة احتوائها على أكثر من متغير أمثلية مما يتيح للمصمم حرية أكثر في اختبار كل متغير من متغيرات الدالة المقترحة في هذا البحث لغرض الوصول إلى أفضل توزيع مجال مغناطيسي محوري الذي يعطي أفضل خواص بؤرية شيئية بأقطاب مغناطيسية مناسبة.

Key words: optic, electro optics, design of magnetic lens, mathematical shape of magnetic lens

1. Introduction

It is well known that, when the axial magnetic field of the lens is expressed by a suitable mathematical function, a rapid and approximate evaluation can be performed for the lens properties. Hence, lens quality may outline without actually carrying out a complex detailed analysis. Many investigations have been carried out in the first of electron and ion optics to synthesis the parameter lens by using mathematical expressions to represent the magnetic scalar potential distribution along the lens axis [1].The trajectory of the electron beam inside the lens has been represented by a mathematical formula, when the paraxial ray equation solved for the assigned beam trajectory to obtain the magnetic field distribution of the lens[2,,7,8] .

Present work is concerned with modifying a new function to a new form. This modified form, however, are put to increasing the degree of function for this function.

2. Mathematical Structure

1. Modified Field Formula

The magnetic field distribution of the symmetrical polepiece magnetic lens has been represented by the following new mathematical expression:

$$B_z(z) = B_{max}\left[\frac{\left(1+\tanh\left(\frac{z}{a}\right)\right)^{(k-1)}}{\cosh^2\left(\frac{z}{a}\right)}\right] \qquad (1)$$

where B_{max} is the peak value of $B_z(z)$ distribution and a its axial half halfwidth and k power of numerator. It can be seen that equation (1) compromise on three optimization parameters namely B_{max} ,a and k .It is often desirable to increasing the number of these parameters so that the curve of equation (1) become more flexible. However, the present work, propose to add a new parameter to that goal. This parameter represented by an exponential power for the function such as:

$$B_z(z) = B_{max}\left[\frac{\left(1+\tanh\left(\frac{z}{a}\right)\right)^{k_1(k-1)}}{\cosh^{2k_2}\left(\frac{z}{a}\right)}\right] \qquad (2)$$

The influence of the new optimization parameter, which has been called (Shape Factor) on the objective focal properties of the imaging field and its reconstructed polepieces will be studied extensively.

2. Objective lens aberrations

When the axial magnetic field distribution along the domain of solution is assigned according to equation (2), the paraxial ray equation [2,5]

$$r'' + \frac{\eta}{8V_r} B_z^2(z) r = 0 \tag{3}$$

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 (3) 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 [3.4,5] .

$$C_s = \frac{\eta}{16V_r} \int_{z_o}^{z_i} \left[\left(\frac{3\eta}{8V_r} B_z^4(Z) + B_z'^2(z) \right) r^4 - B_z^2(z) r'^2 r^2 \right] dz \tag{4}$$

$$C_c = \frac{\eta}{8V_r} \int_{z_o}^{z_i} B_z^2(z) r^2 dz \tag{5}$$

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.

3. Pole piece Shape Reconstruction

The final task of any synthesis optimization procedure is to reconstruct the polepiece that can producing the proposed target function. According to that the analytical solution of Laplace's equation technique [6] . for electrostatic lenses and modified [7,8].to handling magnetic lenses has been used to determine the polepieces profile that can generate distributions like that in equation (2). Therefore, the radial height $R_p(z)$ along the domain of solution has been calculated by means of:

$$R_p(z) = 2\sqrt{\frac{(V_z - V_p)}{V_z''}} \tag{6}$$

Where V_z is the magnetic scalar potential corresponds to B_z and V_p is the value of V_z at any terminal point of B_z distribution [8] .

3. Results and Discussions

1. The influence of (a)

It is important to mention that throughout this work, the effect of varying any optimization parameter was investigated when the other four parameters are maintained constant. Figure (1) shows the $B_z(z)$ distributions for several values of a namely (1,2,3,4,5)mm at B_{max}=0.1T, k=1.0, k_1=1.0 and k_2=1.0 . It can be seen that as a parameter a increases lens

Excitation increases too so, that the axial excitation of $B_z(z)$ along the optical axis increases. Since calculations are carried out at excitation parameter ($NI/V_r^{1/2}$=20), V_r increases too during the increasing of a as can be shown in figure (2). This behavior of V_r can be observed with the aid of figure (3). It can be seen that the electron trajectory bending further as a increasing.

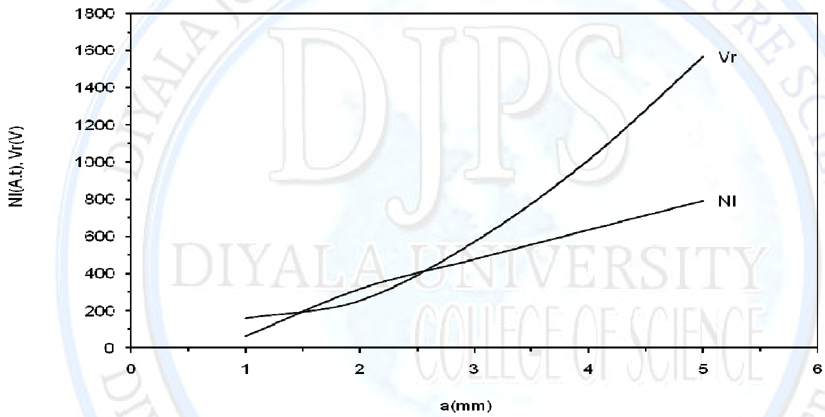

Figure (1): The $B_z(z)$ distribution at various values of a when the other optimization parameter are kept constant.

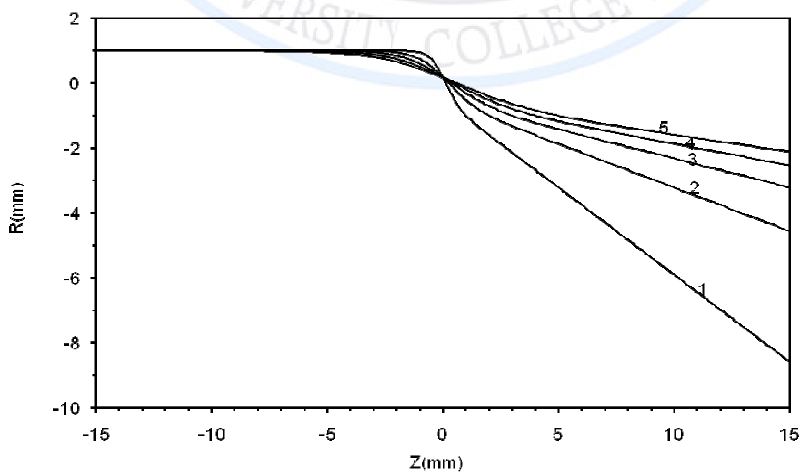

Figure (2): The excitation of the lens NI and the accelerating voltage V_r as a function of a.

The electron optical properties as a function of a are shown in figure (4). The figure shows the fact that as long as $B_z(z)$ its half halfwidth increases the quality of this distribution will deteriorate and Via versa. Hence, as the imaging field confined in a short region its objective focal properties will enhanced.

The total reconstructed polepiece shapes (four quarters) of each $B_z(z)$ distribution for a specific value of a are plotted in figure (5). It is clear that when the magnetic field distribution extended more and more along optical axis the iron width increases. In addition to that its gap and bore increase as a increases.

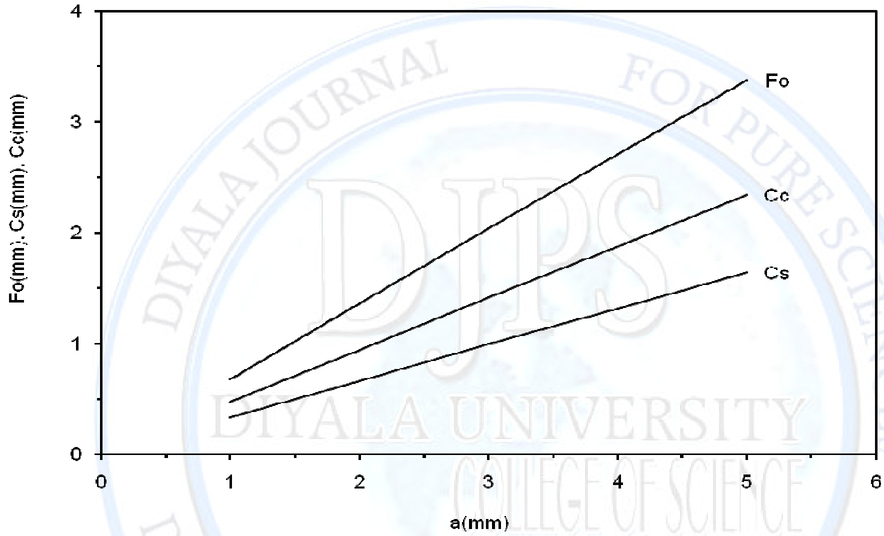

Figure (4): The electron optical properties Cs, Cc and Fo as a function of a.

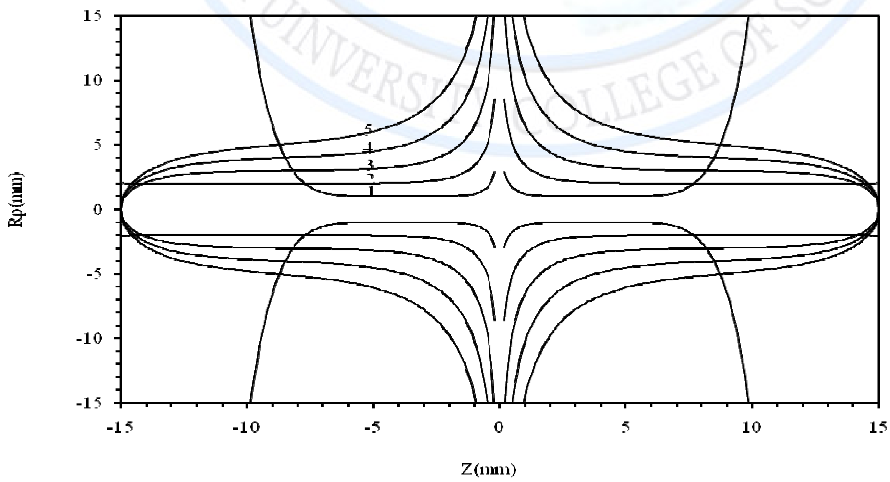

Figure (5): The total reconstructed polepieces shapes at different values.

2. The influence of (n)

At the value of B_{max}=0.1T, a=1.0mm, k=1.0 and ($k_1=k_2$=n) the following values of n have been chosen; (1, 2, 3, 4, and 5) to study the effect of varying the shape factor. The $B_z(z)$ distribution corresponds to each of n value quoted later are plotted in figure (6). This figure reveals that when n increases, the magnetic field distribution is compressed towards the symmetry plane. According to this variation in $B_z(z)$the focal properties are noticed to get better as shown in figure (7).Hence, the add of n to the mathematical function is led to an advantageous for this distribution. In other words for same values of B_{max} and with a increasing the shape factor will enhance the properties of mathematical function. Figure (8) shows the total reconstructed polepieces profile for the different values of n. Where it can be seen that, as n is increased the polepieces gaps and bores decreases.

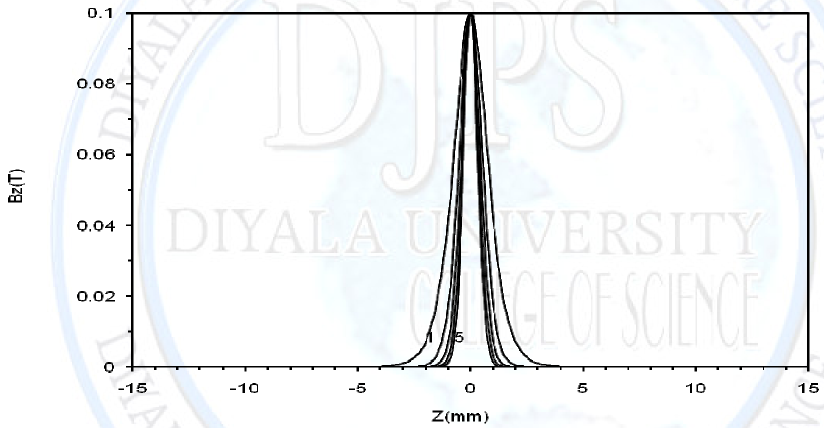

Figure (6): The $B_z(z)$ distribution at various values of n.

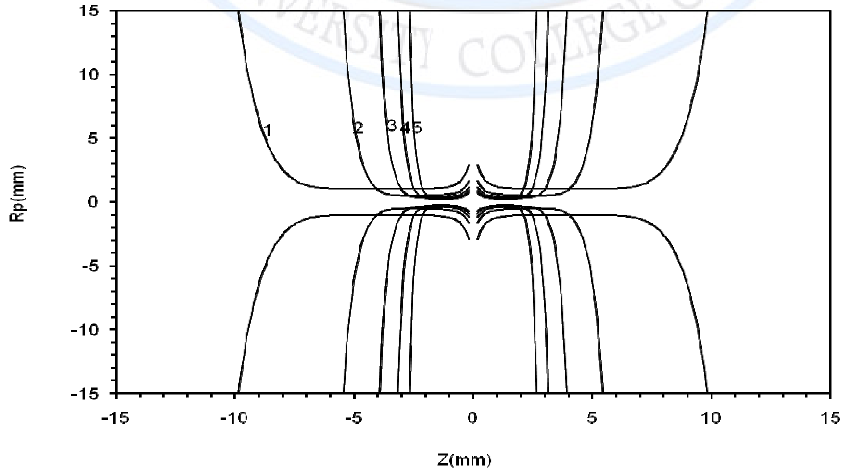

Figure (7): The electron optical properties C_s, C_c and F_o as a function of n.

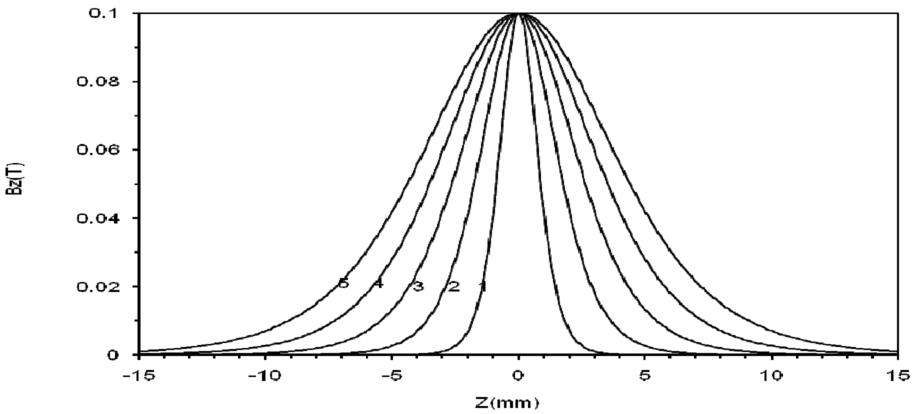

Figure (8): The total reconstructed polepieces shapes at different n values.

3. The influence of numerator power (k1)

At the value of B_{max}=0.1T, a=1.0mm,k=1.0 and (k_2=1) the following values of k_1 have been chosen; (1, 2, 3, 4, and 5) to investigate the effect of varying the numerator power k_1. The $B_z(z)$ distribution corresponds to each of k_1 value are plotted in figure (9). This figure illustrates that when k_1 increases, the peak of the magnetic field distribution is increased, and that's leads to increasing the area under the curve (i.e increasing the lens excitation NI) It should be mentioned that the halfwidth of the field distribution remains constant for different values of k_1. Accordingly, the focal properties are noticed to be unaffected as shown in figure (10). Figure (11) shows the total reconstructed polepieces profile for the different values of k_1.As well known in the field of electron and ion optics, field distributions with the same halfwidth correspond to the same reconstructed polepiece shape[3,4,5,6,7] .

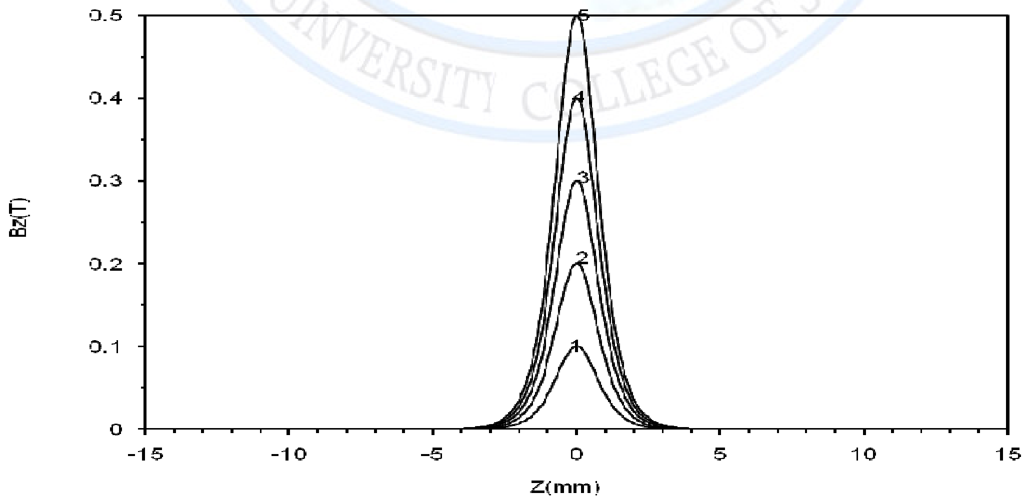

Figure (9): The $B_z(z)$ distribution at various values of k_1.

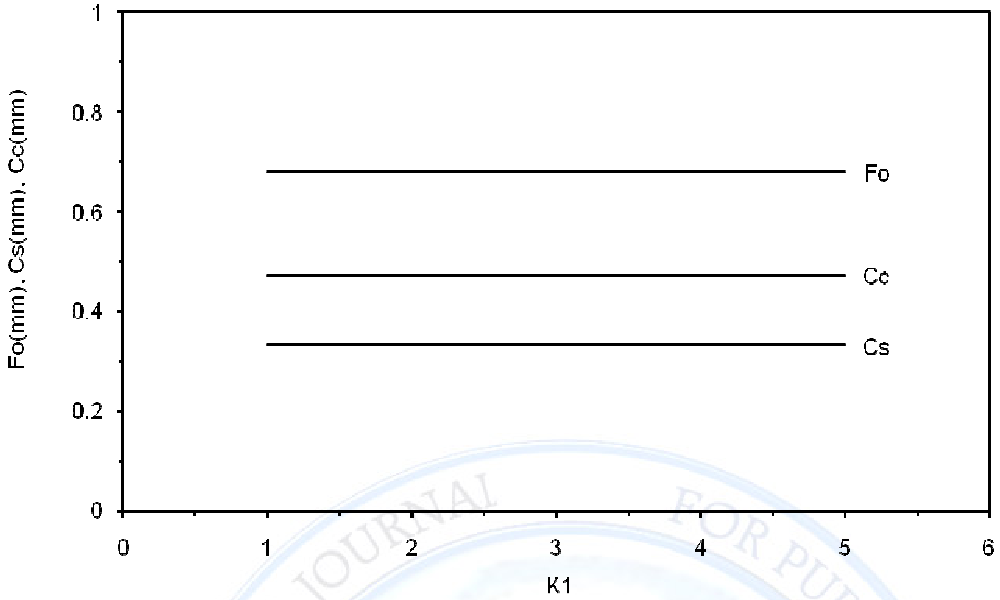

Figure (10): The electron optical properties C_s, C_c and F_o as a function of k_1.

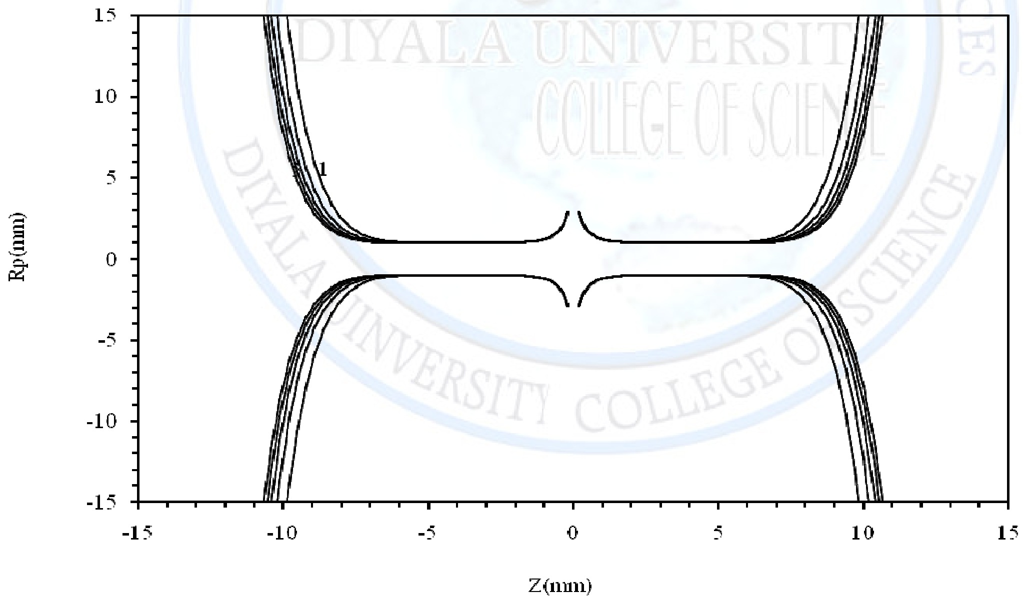

Figure (11): The total reconstructed pole pieces shapes at different k_1 values.

4. The influence of denominator power (k2)

Different values the optimization parameter k_2 have been chosen; (1,2, 3, 4, and 5) to investigate the effect of this parameter on the magnetic lens design, when the other parameters are kept constant at the values B_{max}=0.1T, a=1.0mm,k=1.0 and k_1=1, The $B_z(z)$ distribution corresponds to each of k_2 value are plotted in figure (12). This figure shows that when k_2 increases, the peak of the magnetic field distribution is decreased, that's leads to decreasing the area under the curve (i.e decreasing the lens excitation NI). According to this variation in $B_z(z)$ the focal properties are noticed to get constant as shown in figure (13).

Figure (14) shows the total reconstructed polepieces profile for the different values of k_1. Where it can be seen that, as k_2 is increased the total reconstructed polepiece is constant.

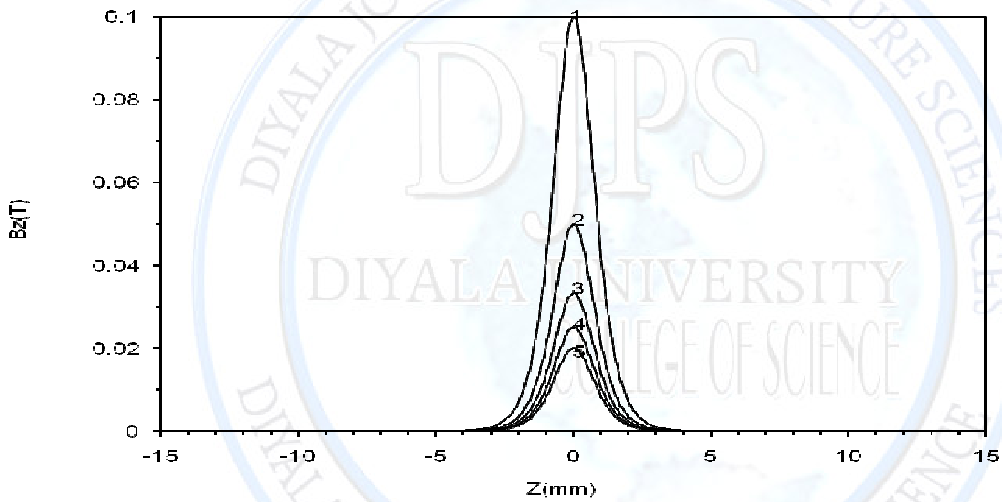

Figure (12): The $B_z(z)$ distribution at various values of k_2.

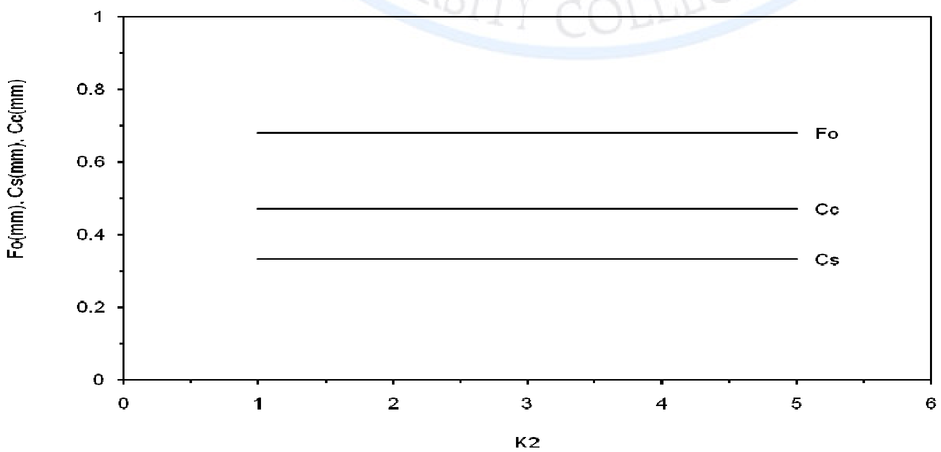

Figure (13): The electron optical properties C_s, C_c and F_o as a function of k_2.

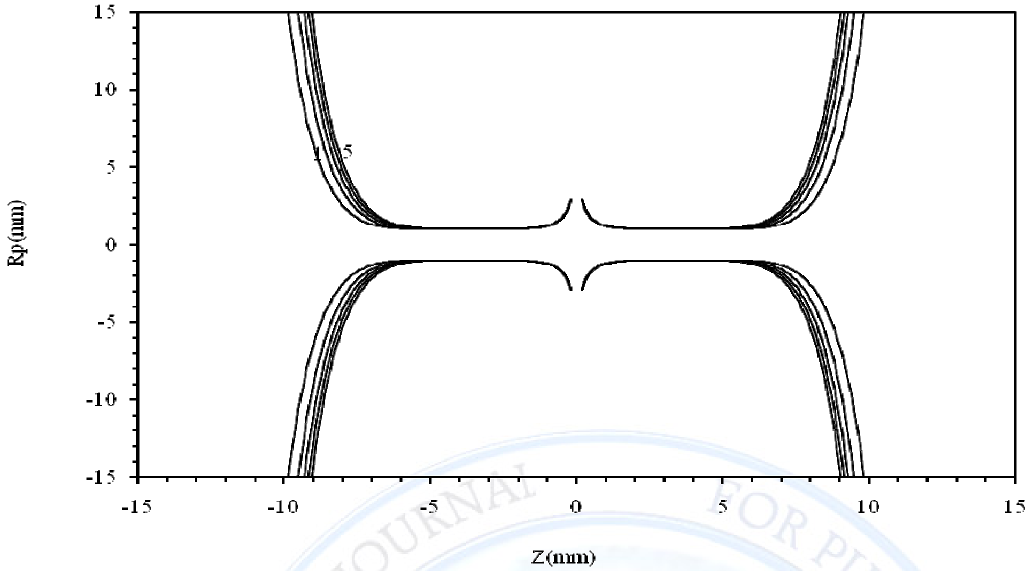

Figure (14): The total reconstructed pole pieces shapes at different k_2 values.

It should be mentioned that the calculations, for variation of B_{max} and the length of the lens parameters has no effect on $B_z(z)$ parameters and hence, their related properties and pole pieces[7,10,11,12 .13,14].

5. Conclusions

According to the results of the present work one may noticed that, variation of the parameters k_1 and k_2 leads to different magnetic lenses with field distributions of constant halfwidth. Also, the behavior of fields under the effect of k_1 and k_2 are in reverse case. Whereas, magnetic lenses with different halfwidths have the well known behavior.

6. References

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