Theoretical Study of Geometrical Properties and Aberrations in Doublet Magnet Lenses

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Abstract

Some of the essential geometrical properties of the lens, like bore diameter, air gap length, half-half width, magnetic flux density, projector focal length, focusing power, magnification, and spherical aberration are studied in the present work. Computational results are obtained for the geometrical properties and spherical aberration in doublet magnetic lenses by using computer programs based on the theoretical methods. In this work, increasing the distance between the lens and screen caused a linear increase in the magnification. The effective length, half-half width, and the minimum projector focal length increased the slope when the air gap width and the diameter of the lens are growing. The increase in the bore and air gap width of lens resulted in an exponential decreasing in the magnetic flux density, the maximum value of the focusing power, and the, but the most significant values of the diameter and air gap length caused a minimal effect on these properties. The increase of ampere-turns resulted in a linear increase in the magnetic flux density. Finally, the increasing in the air gap length and the diameter of the lens caused a ramp increase in the spherical aberration coefficient.

Keywords: Magnetic Lenses, Doublet Lenses, Lenses Properties, Spherical Aberration.

1. Introduction:

The electron microscope is the essential electro-optical instrument and is manufactured in different types, such as the conventional transmission electron microscope, high voltage electron microscope, scanning electron microscope and the scanning transmission electron microscope. Magnetic lenses are mostly utilized to create a focused electron beam or probes, and to create an excellent magnification image of a little thing put close the focal point of the lens. The design and focal properties of the objective lens determine the main characteristics of the electron microscope [1].

The most common form of the magnetic lens is the conventional symmetrical double pole piece lens. Chalab [2] carried out a theoretical, computational study to describe the optimization of the symmetrical double pole piece magnetic lenses. It designed a pole piece shape for double pole piece magnetic lenses by studying the variation of the parameters air gap width, axial bore diameter and lens excitation for the tapered cylindrical, tapered spherical and conical double pole piece magnetic lenses. It was shown that the double pole piece magnetic lens with a tapered spherical pole piece is the desirable objective properties among the three unsaturated lenses. Chalab [3] used the finite element method to design asymmetrical lenses with double tapered cylindrical pole pieces. He [4] developed the doublet project magnetic lens with different pole pieces and corrected the radial and spiral distortions by utilizing that lens at high and low magnification zones. Chalab and Al-Ateiah [5] studied and designed the triplet projector magnetic lens each consisting of two double pole piece lenses and one single pole piece lens and suggested that the triplet projector lens can eliminate the radial and spiral distortions in the first and second maximum magnification region.

Al-Khashab et al. [6] investigated the objective focal properties of a single pole piece magnetic electron lens. Abbas and Nasser [7] designed double pole piece lens of asymmetrical type, studied their properties and computed some of the essential features, like optical properties and the density of the magnetic flux. Yaseen [8] calculated by using Glaser model the properties of the magnetic projector lens, and proved that the half-width of the field is a vital principle parameter for the proposed lens. EL-Shahat et al. [9] investigated the objective properties of a single pole piece lens with different shapes and indicated that the lens with a spherical pole face has the best resolution and the pole piece shape has a small effect on the electron optical parameters. Smallest optical properties were obtained, and they can lead to the better decision in the electron microscope. Yaseen [10] suggested a target function of conventional parameters to investigate the symmetrical double pole piece magnetic projector lens.

Naser [11] designed and constructed magnetic projector lens with tapered- cylindrical pole pieces, consisting of two double magnetic lenses. The electro-optical properties were computed and obtained by using this lens the rotation and distortion of free images. Hasan [12] investigated the effect of geometrical parameters, like bore diameter, air gap width, and the distance between the center of lens and screen on the focusing power and magnification of double pole piece projector magnetic lenses by using square top or rectangular field distribution model. It was concluded that the rectangular field model is almost correct of the lens in that the air gap length is considerable and parallel to the bore diameter. Naser and Abbas [13] investigated theoretically and designed the doublet projector magnetic lens with cylindrical pole pieces and corrected the radial and spiral distortions. They computed the magnetic field by using computer programs based on the finite element method (FEM). The distortion at the first magnification region was cancelled by making the axial magnetic flux density of the first lens lower than that of the second.

Al-Batat et al. [14] introduced a new mathematical target function to represent the field distribution of the doublet magnetic electron lens. The doublet magnetic electron lenses in electron optical device were used to obtain the rotation and distortion of free images in the first and second loop, and the design of this instrument was investigated under the effect of the half-half width for the field distribution as a primary useful optimization parameter included in the target function. Different values of parameter were chosen to simulate the electron optical device under some constraints and transformations.

This work aims to study the properties of a double pole piece of magnetic lens and compute how the lens behaves when its features are changing to get the optimal design for this lens.

2. Theory:

The current work involve with the effects of geometrical properties in double polepiece magnetic lenses by using the rectangular field distribution model. The rectangular field model is a approximation in the lens when the air gap width is substantial compared with the bore diameter [1].

The rectangular field model of proposed lens is represented as below [1]:

$$f(z) = f(z)_{max} \qquad \text{when } -z_{L'} \leq z \leq z_{L'} \qquad (1)$$

$$B(z) = B_{max} \qquad \text{when } -z_{L'} \leq z \leq z_{L'} \qquad (2)$$

At points when $|z| > z_{L'}$ the function B(z) = 0,

Where:

$z_{L'}$ equal to $L'/2$, L' is the effective length.

$B(z)$ is the axial magnetic flux density.

B_{max} is the maximum flux density.

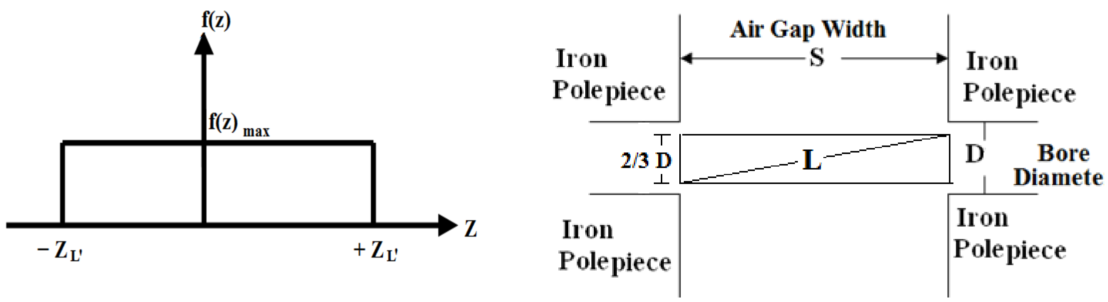

Figure (1): The rectangular field and the equivalent coil

The geometrical constant (L) is related to a half width (W) of the field distribution of real- axial magnetic flux density, with the relation [15];

$$W = 2a = 0.97L \quad (4)$$

Where, a is the half- half width

The following form gives the relationship of the geometrical constant (L) with air gap width (S) and bore diameter (D):

$$L = (S^2 + 0.45D^2)^{1/2} \quad (5)$$

The geometrical constant (L) is related to the minimum projector focal length for symmetric double polepiece lenses as below:

$$(f_p)_{min} = 0.5(S^2 + 0.45D^2)^{1/2} = 0.5L \quad (6)$$

The following equation represents the maximum value of magnetic flux density Bmax of a rectangular field model:

$$B_{max} = \mu_o NI/L \quad (7)$$

The magnification is the relationship between the size of the image and the size of the object or the ratio of the final (r_2) to the initial beam diameter (r_1) in the radial axis

$$M = \frac{r_2}{r_1} = \frac{r_{image}}{r_{object}} \quad (8)$$

The magnification of proposed lens model can be computed from the equation:

$$M = \frac{\left[l - (f_p)_{min}\right]}{(f_p)_{min}} \quad (9)$$

Where, (l) is the distance between the lens and screen.

The focusing power (β) in general is the reciprocal of focal length (f).

Where,

$$\beta = \frac{1}{f} \quad \text{and} \quad \beta_{max} = \frac{1}{(f_p)_{min}} \quad (10)$$

The spherical aberration is the only geometrical aberration, which causes the unsharpness of image on the optical axis. CS is the spherical aberration coefficient of the lens and related to the objective focal length [16]:

$$C_S = \frac{1}{3}(f_p)_{min} \quad (11)$$

3. Results and Discussions:

The relationship of varying values of the distance between the lens and screen with the magnification at different diameters of lenses at values of air gap S = 2, 5, 8 mm are studied in this work. Figure (2) shows that the magnification increases linearly when the distance between lens and screen is increased, but when the diameter of the lens is increased, the slope decreases. The same behaviour can be seen in Figures (3) and (4), so it can be concluded from these Figures that the increase in the air gap width of the lens caused a decreasing in the slope.

Figure (5) depicts the variation of sufficient length with the length of the air gap at different diameters of lenses. In this Figure, it is that found the effective length increases the ramp when the length of the air gap is growing. The sufficient length also rises when the diameter of the lens increases too. The variation of the half width with the diameter of lenses at different air gap lengths is illustrated in Figure (6). From this Figure, it can be concluded that the increase in diameter and the air gap of the lens caused a ramp increasing in the half width.

Figure (7) reveals the variation of the minimum projector focal length with a diameter of lenses at different air gap distances. One can be deduced that the increase in the width of the lens caused a ramp increase in the minimum projector focal length. The increasing in air gap produced the same effect on it.

Figure (8) manifests the relationship between the maximum values of magnetic flux density with the diameter of lenses. From such Figure, it can be concluded that the increase in the width of the lens caused an exponential decrease in the magnetic flux density. Also, one can see the increase in the air gap resulted in a reduction of it. But, it can be noted that the most significant values of diameter and air gap caused a small effect on the benefits of magnetic flux density. The same relationship of the maximum amount of the focusing power behaved as the magnetic heat flux; one can see that apparently in Figure (9). The relation between the magnification and the diameter at different widths of air gap of lenses is shown in Figure (10). In this Figure, it can be noted that the increasing diameter of the lens caused an exponential decrease in the magnification.

The same effect caused in magnification when the air gap length increased. Apparently, in this Figure, the most significant values of the diameter and air gap length resulted in a minimal effect on the magnification values. The relationship of varying values of the ampere-turns with the maximum amount of magnetic flux density at values of air gap S = 2, 5, 8 mm is displayed in Figures (11, 12, and 13), respectively. It can be noted from these Figures that the ampere-turns increasing caused a linear increase in the magnetic flux density, and the increasing in the diameter and the length of air gap of lenses resulted in a decrease in the magnetic flux density. The relationship between the spherical aberration and air gap length is revealed in Figure (14). It can be inferred from this Figure that the increasing of air gap length of the lens that resulted in a ramp increasing in the spherical aberration coefficient, and the increasing in the diameter of the lens caused the same effect in the spherical aberration.

4. Conclusions:

The main conclusions in this work are the magnification increasing linearly when the distance between lens and screen is increasing. The effective length, half width, and the minimum projector focal length showed a ramp increasing when the length of the air gap and the diameter of lens increased. The increase in the bore and air gap length of the lens caused an exponential decrease in the magnetic flux density and the maximum value of the focusing power.

The most significant amounts of diameter and air gap width that created a small effect on the values of magnetic flux density. The increasing of diameter and air gap length of lens resulted in an exponential decrease in the magnification. The most significant amounts of the diameter and air gap length caused a minimal effect on the magnification values.

The increasing of ampere-turns resulted in a linear increase in the magnetic flux density, and the increasing in the diameter and the length of air gap caused a decreasing in the magnetic flux density.

Finally, the increasing in the air gap length and the width of lens resulted in a ramp increasing in the spherical aberration coefficient.

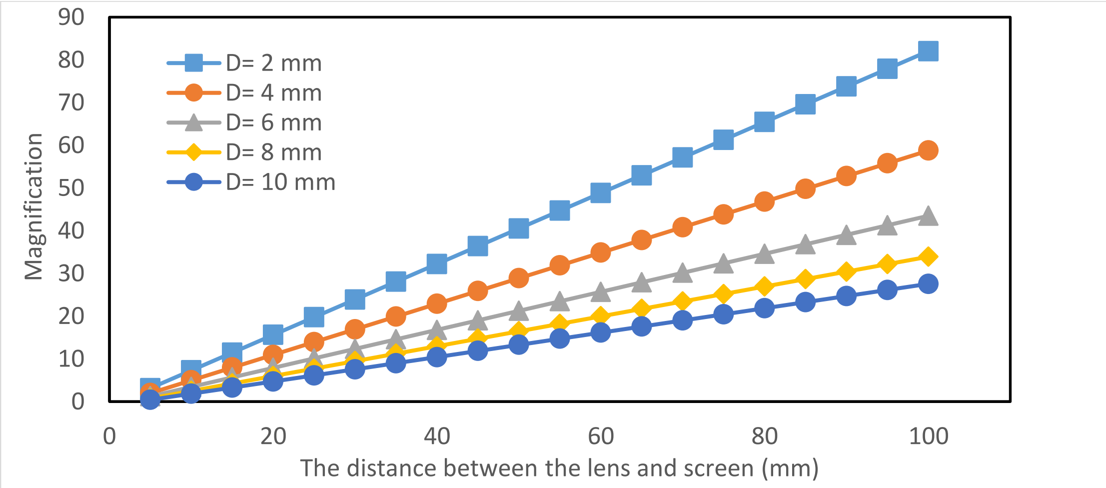

Figure (2): Variation of the distance between the lens and screen with the magnification at different diameters of lenses at S=2 mm

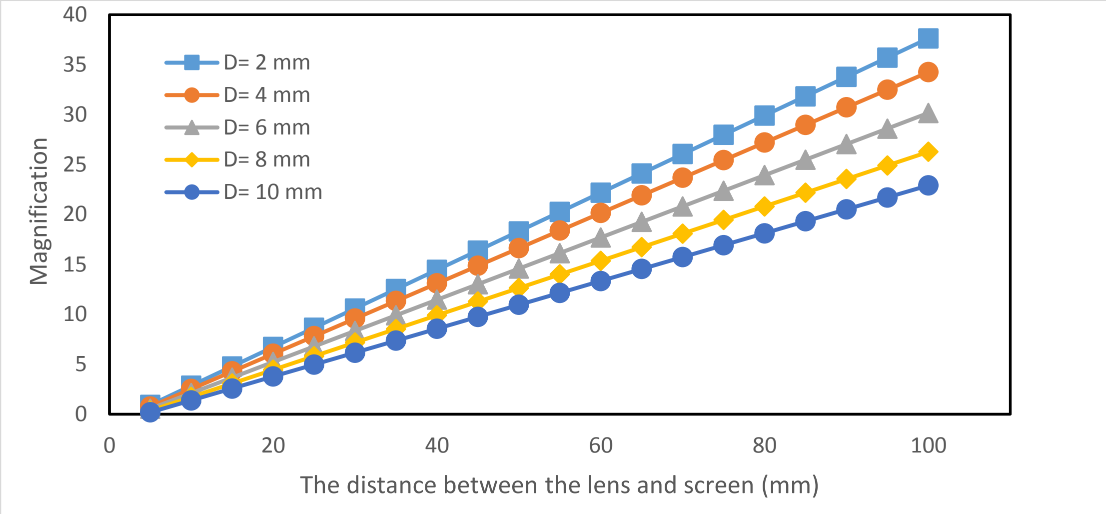

Figure (3): Variation of the distance between the lens and screen with the magnification at different diameters of lenses at S=5 mm

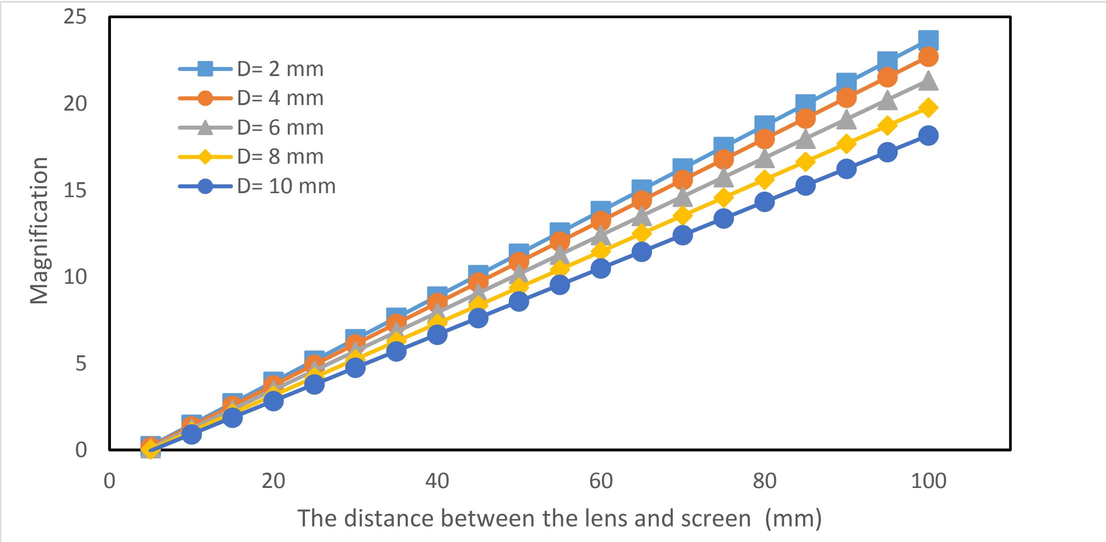

Figure (4): Variation of the distance between the lens and screen with the magnification to varying diameters of lenses at S=8 mm

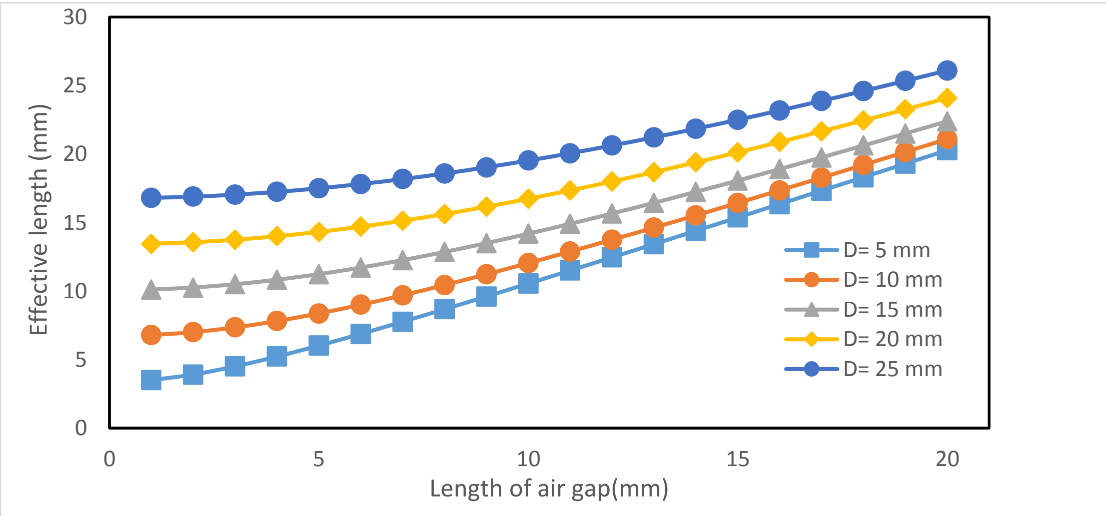

Figure (5): Variation of effective length with the length of air-gap of lenses at different diameters of lenses

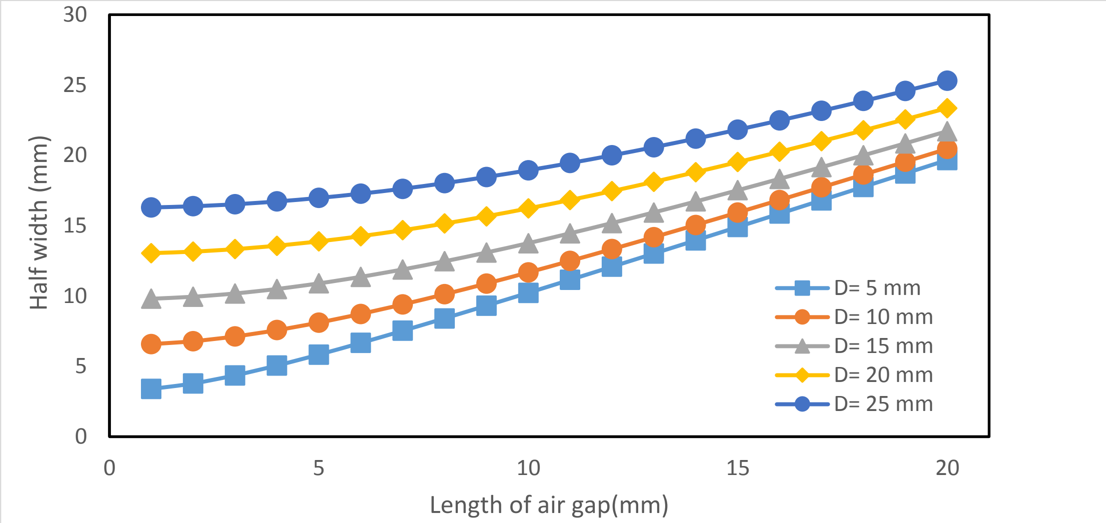

Figure (6): Variation of the half width with the diameter of lenses at different air-gap lengths

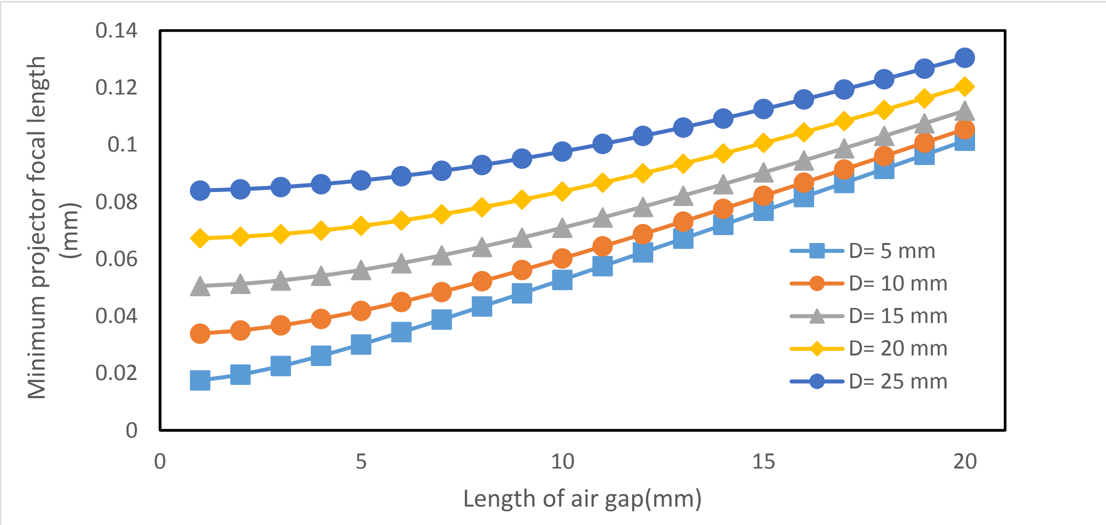

Figure (7): Variation of the minimum projector focal length with the diameter of lenses at different air-gap lengths

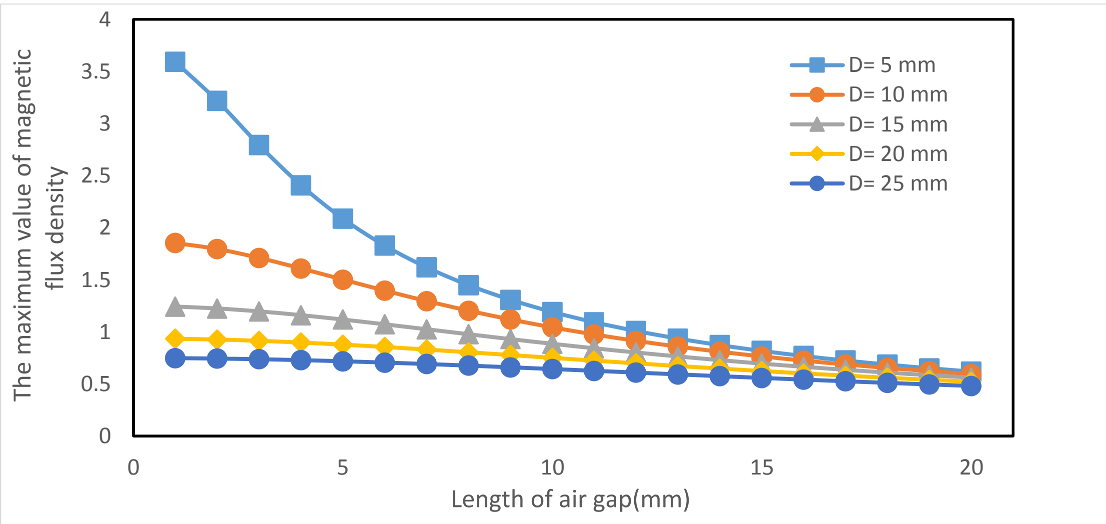

Figure (8): Variation of the maximum value of magnetic flux density with the diameter of lenses at different air-gap lengths

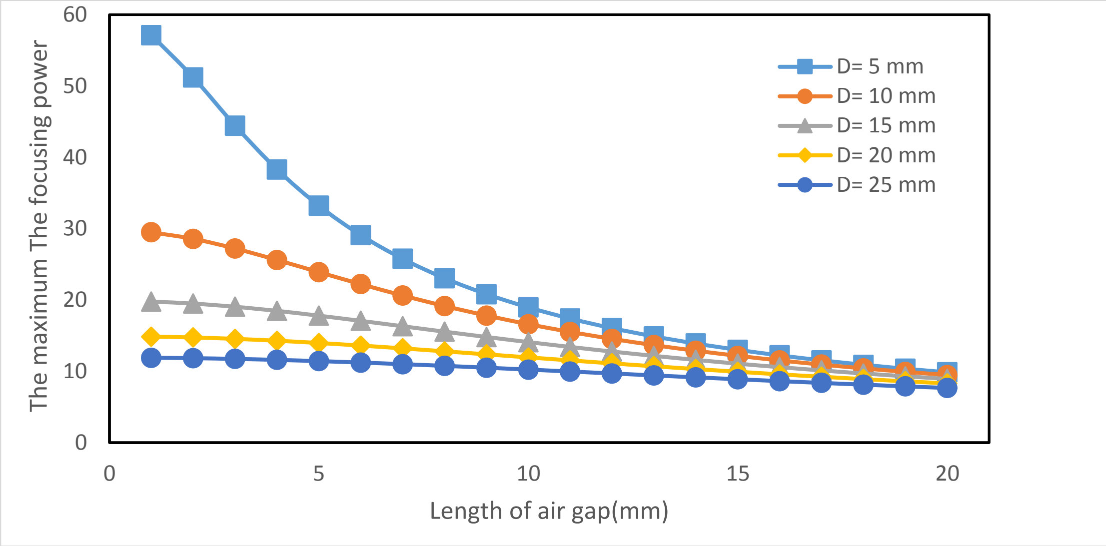

Figure (9): Variation of the maximum value of the focusing power with the diameter of lenses at different air-gap lengths

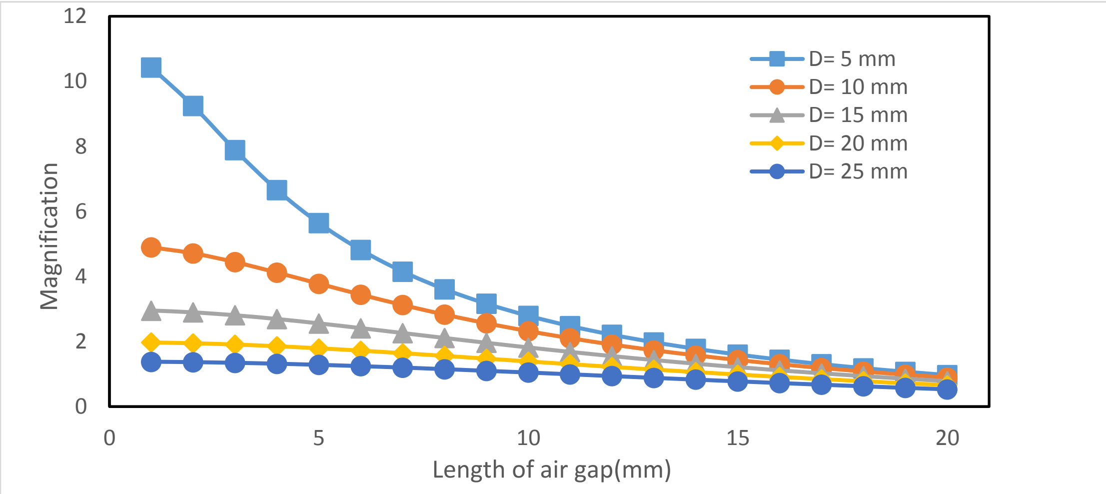

Figure (10): Variation of the magnification with the diameter of lenses at different air-gap lengths

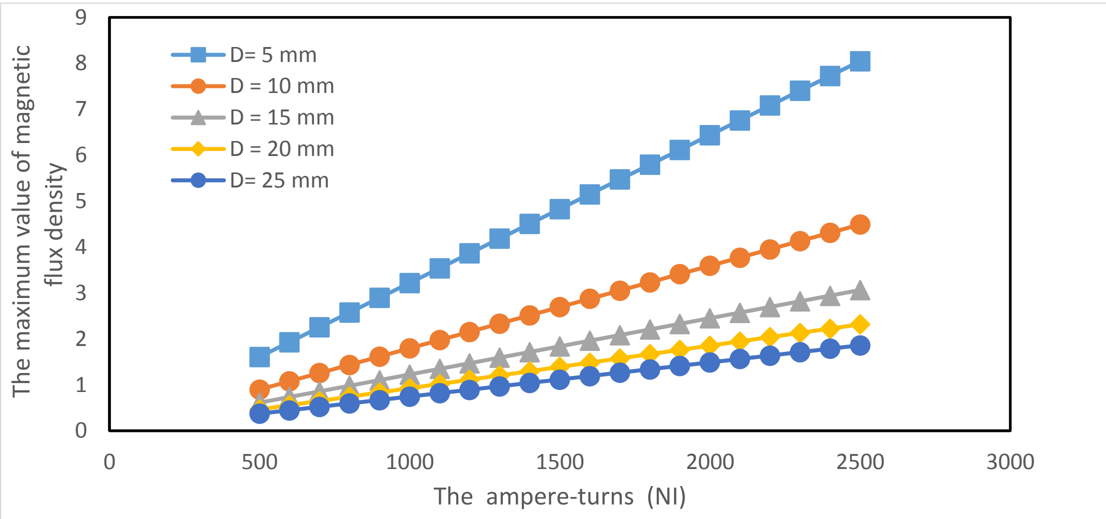

Figure (11): Variation of the maximum value of magnetic flux density with the ampere-turns at S=2 mm

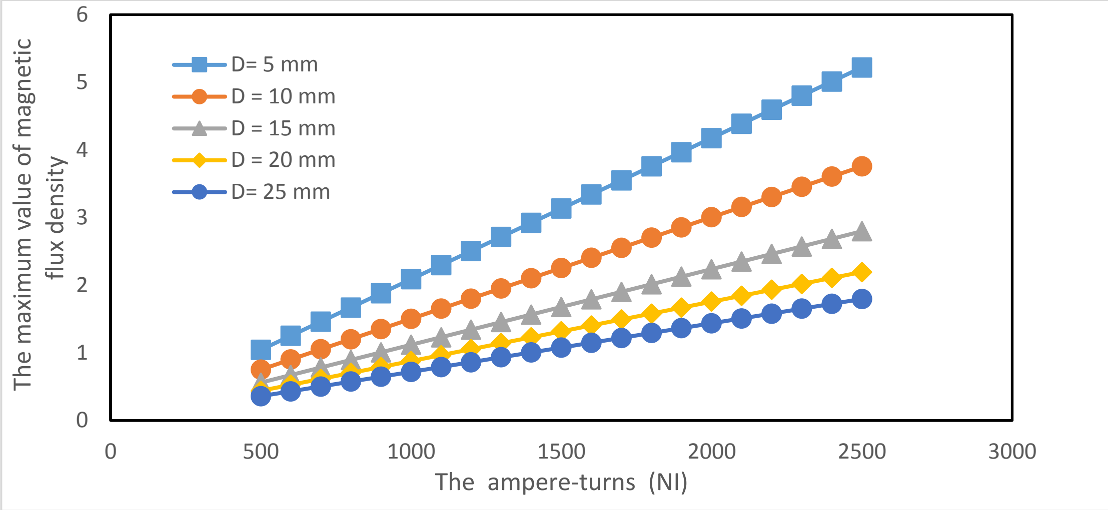

Figure (12): Variation of the maximum value of magnetic flux density with the ampere-turns at S=5 mm

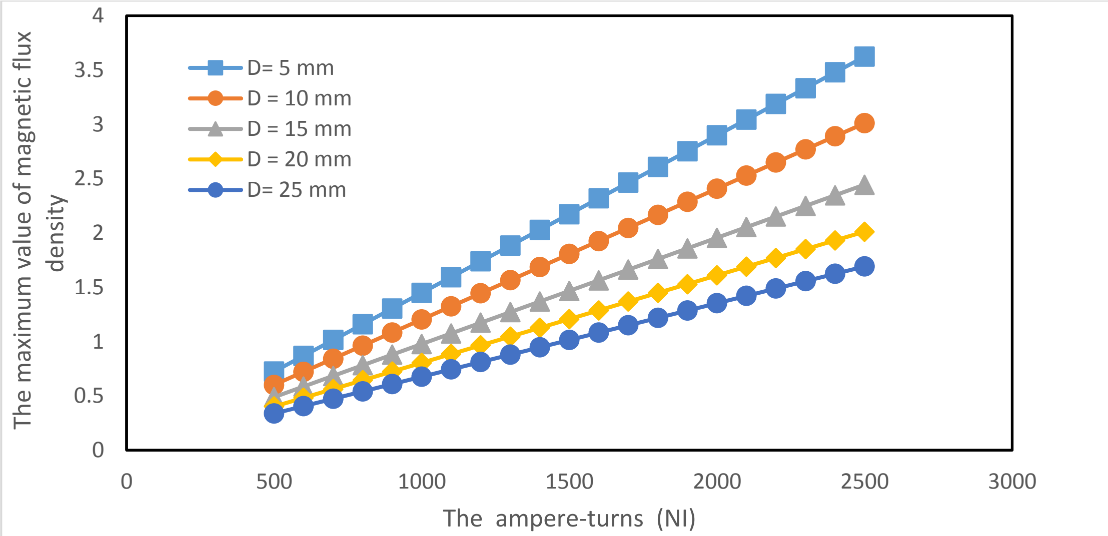

Figure (13): Variation of the maximum value of magnetic flux density with the ampere-turns at S=8 mm

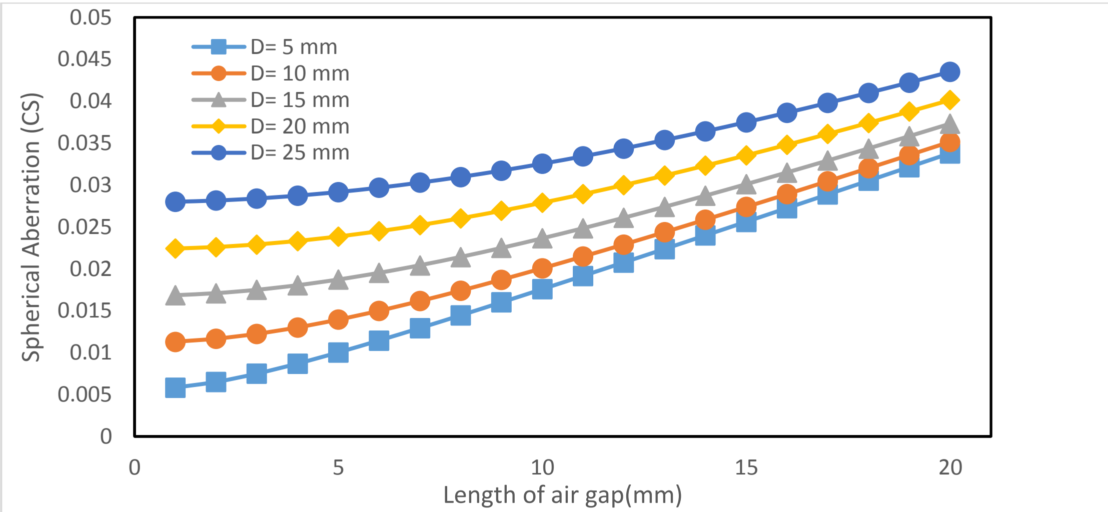

Figure (14): Variation of spherical aberration with the length of air gap of lenses at different diameters of lenses

CONFLICT OF INTERESTS.

There are no conflicts of interest.

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دراسة نظرية للخصائص الهندسية والانحرافات في العدسات الثنائية المغناطيسية

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الخلاصة

في البحث الحالي تمت دراسة بعض الخصائص الهندسية الأساسية للعدسة، مثل قطر التجويف وطول التجويف الهوائي ونصف عرض العدسة وكثافة الفيض المغناطيسي والطول البؤري وتركيز القوة ونسبة التكبير والانحراف او الزيغ الكروي. تم الحصول على نتائج حسابية للخصائص الهندسية والانحراف اوالزيغ الكروي في العدسات المغناطيسية الثنائية بواسطة برمجة المعادلات الاساسية بالحاسوب للحسابات النظرية. في البحث الحالي أدت زيادة المسافة بين العدسة والشاشة إلى زيادة خطية في نسبة التكبير. عندما يتزايد عرض الفجوة الهوائية وقطر العدسة فأن ذلك يؤدي الى زيادة الطول المؤثر ونصف الطول والعرض البؤري والحد الأدنى لجهاز الإسقاط المنحدر. أدت الزيادة في عرض التجويف والفجوة الهوائية إلى تناقص أسي في كثافة التدفق المغناطيسي والقيمة القصوى لطاقة التركيز ونسبة التكبير، لكن عند القيم الكبيرة للقطر وطول الفجوة الهوائية تسببت في تأثير ضئيل على هذه الخصائص. أدت الزيادة في عدد اللفات–الأمبيرية إلى زيادة خطية في كثافة التدفق المغناطيسي. وأخيراً أدى تزايد طول الفجوة الهوائية وقطر العدسة إلى زيادة انحدارية في معامل الانحراف او الزيغ كروي.

الكلمات الداله: – العدسات المغناطيسية، العدسات المضاعفة، خصائص العدسات، الزيغ الكروي.