The Effect of the Geometrical Parameters on the Characteristics of the Saddle Magnetic Deflector

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ABSTRACT

In this research work the saddle magnetic deflector has been designed, and studied the effect of the geometrical parameters on the characteristics of the magnetic deflector by using one of the simulation programs known as Electron Optical Design (EOD), which is written in Compaq Visual Fortran 6.6 uses the finite elements method. It has been found that the variations of the axial bore diameter and length of deflector have a great effect on its properties as well as the amount of magnetic deflections. The effect of variation of the thickness of deflector was very small. The effect of the angle of the deflector and its excitation was also studied and found that there is a direct effect on the value of a magnetic deflection only.

Keywords: Magnetic deflector design, Scanning coils, Saddle magnetic deflector, Scanning electron microscope, Magnetic deflection, Magnetic deflector aberrations.

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INTRODUCTION

The deflection of electron beams using magnetic fields is used in applications where the medium speed and high deflection sensitivity are required. Typical uses are in display instruments such as television receivers, data display tubes and electron probe instruments, etc. In all of these devices, the electron beam is focused on the screen before deflection. (Munro, 1997).

Deflection systems are needed for two purposes: either, the deflection of the focused probe over the specimen in order to form an image or to position it at a particular point in order to make a

measurement, or the use for a beam-blanking purposes. The former function is invariably carried out by magnetic deflection, whereas the latter is usually achieved through an electrostatic deflection. The reasons for this come from the need to have precise deflection in scanning probe with minimum aberration, while for beam blanking, the priority is speed (Khursheed, 2011). The other purpose of deflection coils are used to align optical axes of mechanical units with each other to minimize the influence of the misalignment.

A significant difference between electrostatic and magnetic deflection is their relative deflection sensitivity, (which is the ratio of the displacement of the spot on the screen (surface) to the deflection voltage or to the current flowing in the deflection coil). Electrostatic deflection has low deflection sensitivity and thus needs high driving voltages, while magnetic deflection has high deflection sensitivity and thus require low driving currents. Magnetic deflectors are simpler to design, lower aberration, and low-cost fabrication process.

The major disadvantage of magnetic deflector comes from its eddy currents, which limit its scan frequency. This can be overcome by using ferrite cores or air core.

The numerical analysis of magnetic deflector in electron-beam lithography system was carried out by (Munro and Chu, 1982).

(Nakagawa and Nakata, 2000) proposed an improved power-series expansion method for the analysis of magnetic deflection yoke in a cathode-ray tube (CRT). The magnetic field is expanded to either of two different power-series formulations, depending on the radial position from the central axis of the deflection yoke. The coefficients of the power series are calculated by symbolically differentiating the magnetic field expressed by the surface magnetic charge method formulation.

(Liu and Gu, 2005) introduced a new structure to correct eddy current in electron beam focusing-deflection system; where the new double ferrite structure not only corrects the eddy current, but also increases the sensitivity of the deflection without decreasing the performance.

A novel magnetic micro deflector has been developed for controlling electron beam deflection in EBMCS, were the deflector consist of four micro poles, (Rong *et al.*, 2006).

(Elster *et al.*, 2008 (a,b)) calculated fields in magnetic deflection systems (especially saddle coils) in a rotationally symmetric ferromagnetic surrounding by using the FEM and a vector potential approach.

(Andris *et al.*, 2009) present equations for computing the magnetic field of saddle-shaped coil based on the Biot-Savart law.

The optimum design of the magnetic deflector with the lowest values of the radial and spiral distortion aberration coefficients was computed by (Hussein *et al.*, 2013).

Design and fabrication of the objective-deflector focusing system for the electron microscope by (Al-Salih, 2014).

The aim of this work is to design saddle magnetic deflector and to study the effect of geometrical parameters on their characteristics such as (bore diameter, length, thickness, angle and its excitation).

Magnetic Deflection

The force which a magnetic field B exerts on an electron of charge e moving with velocity v is given by:

$$F = -e(v \times B) \qquad \qquad \text{...(1)}$$

In uniform field, the particle follows a circular trajectory of radius $r = \dfrac{mv}{eB}$,

In the Fig. (1), at the point S, The electron leaves the magnetic field so quickly that its movement become straight, the angle $\alpha = (OC, OS)$ is called an angular deviation; So that $\sin \alpha = \dfrac{l}{r}$ and

$$\tan \alpha = \frac{\overline{O'P}}{\overline{OO'} - \overline{OI}} = \frac{D_m}{L - l}$$, since α is very small in machines used and $l \ll L \rightarrow (\sin \alpha = \tan \alpha)$,

Therefore;

$$\frac{l}{r} = \frac{D_m}{L} \rightarrow \quad D_m = \frac{q.B.L.l}{mv} = \frac{B.L.l}{\sqrt{V_a}} \sqrt{\frac{e}{2m}}$$; D_m is magnetic deflection and V_a is the accelerating
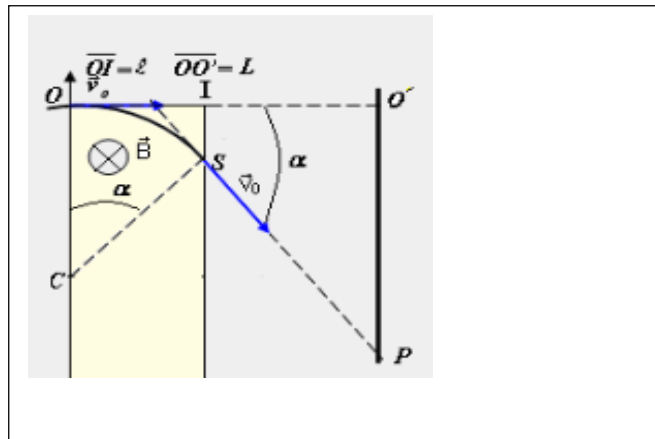
voltage (Ghosh, 2007).

Fig. 1: The trajectory of the electron in the magnetic field.

The deflector is more complicated to simulate than magnetic lens, because they are three dimensional structures without rotational symmetry.

When magnetic deflector is in free space regions, the deflector fields can be calculated analytically using the Biot-Savart law, The analytic formulae for computing the deflector field function $d_1(z)$ for saddle deflectors is given in equation (2) (Munro, 1997).

$$d_1(z) = \frac{\mu_0}{\pi} NI \sin \phi \left[\frac{H(H^2 + 2R^2)}{R(H^2 + R^2)^{3/2}} - \frac{h(h^2 + 2R^2)}{R(h^2 + R^2)^{3/2}} \right] \qquad \dots (2)$$

Where NI is the excitation of each coil, in Amp-turns, $\phi =$ is the coil half-angle, $r =$ coil inner radius, $R =$ coil outer radius, $H =$ distance from left-hand end of coil to sample point z, and $h =$ distance from right-hand end of coil to sample point z.

And if magnetic deflectors are near rotationally symmetric ferromagnetic materials, e.g. for a deflector inside a magnetic lens the fields can be computed using the finite element method.

The Analysis Simulation

For design and optimization of electron and ion beam equipment, numerical simulation methods are indispensable. When digital computers first became widely available, methods were developed for computing fields, trajectories and aberrations in electron lenses, and such simulations played a key role in improving the design of electron microscopes. (Munro, 2011).

The finite element method is the use of numerical technique. This method has been used for drawing the geometrical shapes of the designed deflectors and the generation of the triangular finite element meshes for each design. EOD program (Electron Optical Design) version 3.069, by (Lencov´a and Zl´amal, 2008) is used for the design and evaluation of the electron-beam system properties. The

software package offers a design environment, field calculation, ray tracing, and evaluation of paraxial properties and aberrations.

Magnetic Deflector Design and Results

The magnetic dipole is constructed from coil windings to create a constant magnetic field in transverse direction; it means the direction of the beam travelling is perpendicular to the direction of magnetic field.

A magnetic saddle deflector is designed with certain geometrical parameters as, length of the coil (L = 30 mm), thickness (Th = 3 mm), bore diameter (D = 20 mm), coil angle $(\emptyset = 60°)$ and excitation (NI = 1 A-t). Fig. (2) shows a schematic diagram of the saddle magnetic deflector.
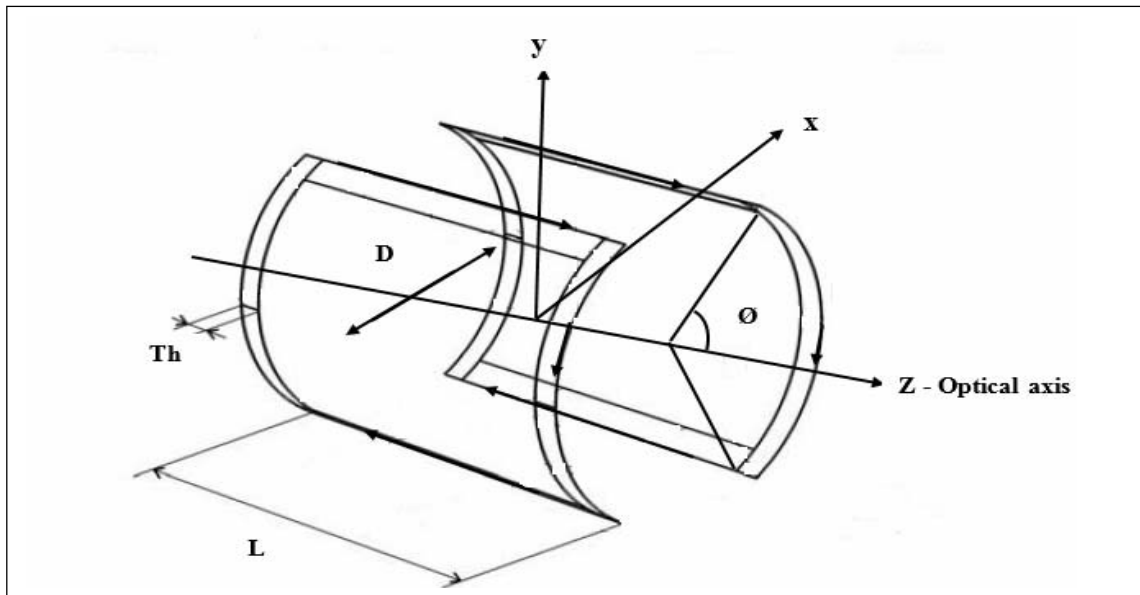

Fig. 2: Schematic diagram of the saddle magnetic deflector.

The axial magnetic deflector potential was computed by the aid of program (EOD). Fig. (3) illustrates the color representation of the potential densities, axial magnetic deflector potential and the equipotential lines trajectories around the magnetic deflector.
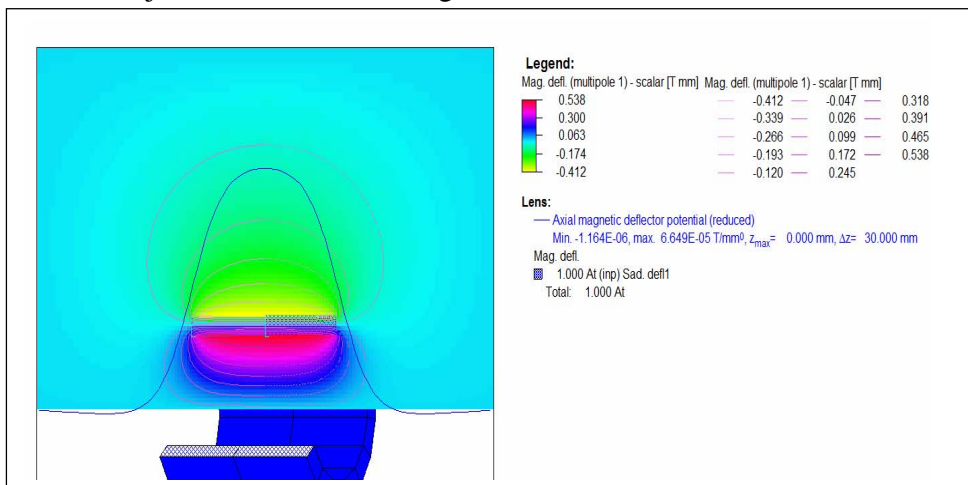

Fig. 3: The color representation of the potential densities, axial magnetic deflector potential and the equipotential lines trajectories around the magnetic deflector.

In order to investigate the variation of the bore diameter of the deflector (D) on the optical performance we get different values of D, where D = (12, 14, 16, 18 and 20) mm and the other geometrical parameters are constant. Fig. (4) shows the effect of the bore diameter on axial magnetic deflector potential (d_1). It is clear that the maximum of axial magnetic deflector potential (d_1) increases as the values of the bore diameter decrease, while the half-width is approximately constant ~ (29 mm). Fig. (5(a,b)) shows the magnetic deflections and aberration coefficients as a function of bore diameters. In Fig. (5a) we found that there is an inverse relationship between the amount of deflections and the values of the axial bore diameter, and in the Fig. (5b) we found that the field curvature and stigmatism aberration coefficients decrease while the distortion aberration coefficient has a small increase with increasing the axial bore diameter.
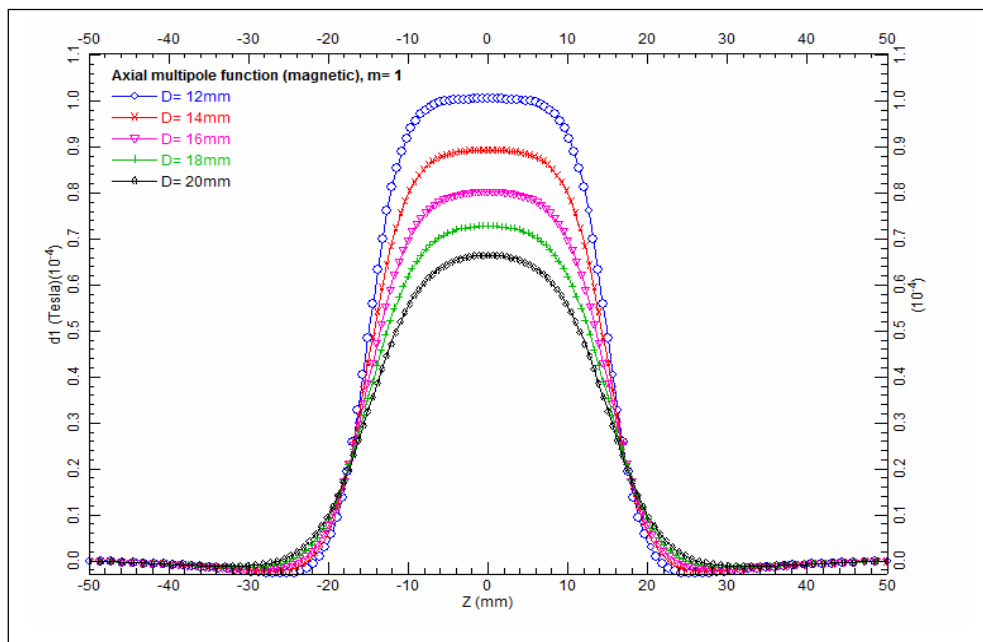

Fig. 4: The axial magnetic deflector potential d_1 as a function of Z for different values of bore diameter D = (12, 14, 16, 18 & 20) mm.

In order to evaluate the variation of the lengths of the deflector (L) on the optical performance we used different values of L, where L = (25, 30 and 35) mm and with (D = 16 mm) mean value of the bore diameter which achieved intermediate properties among the values studied above, while the other geometrical parameters are constant. Fig. (6) shows this effect on axial magnetic deflector potential. It is noted that the maximum of axial magnetic deflector potential (d_1) nearly constant, while the half-width increases as the values of the length are increasing. Fig. (7(a,b)) shows the magnetic deflections and aberration coefficients as a function of the lengths. In Fig. (7a) we found that the magnitude of deflection is directly proportional to the values of the length, and in the Fig. (7b) we noted that the field curvature and stigmatism aberration coefficients decrease while the distortion aberration coefficient is small increase with increasing the lengths of the deflector.
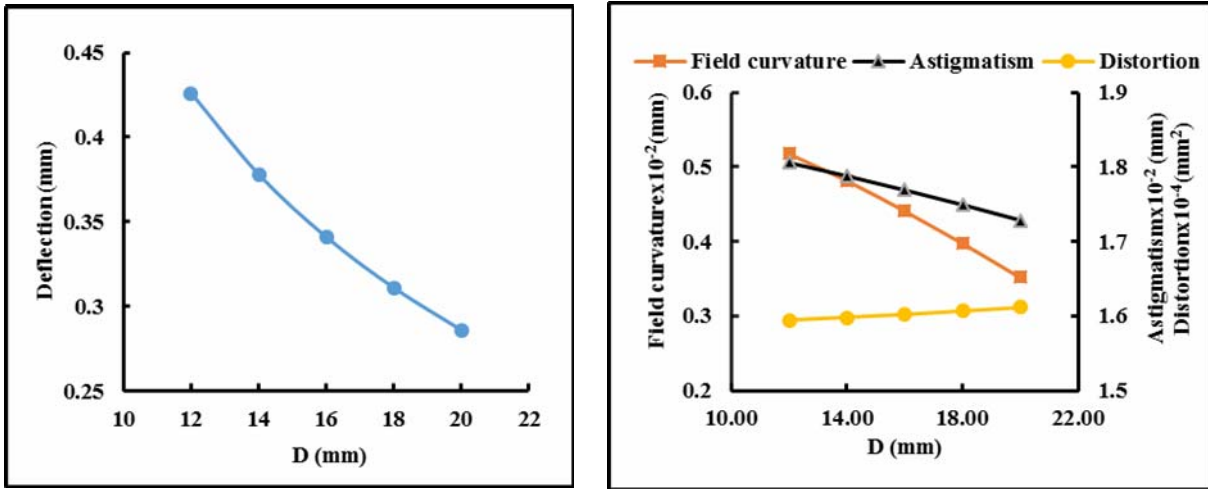
(a)   **(b)**

Fig. 5: a: Variation of the magnetic deflections as a function of bore diameters.
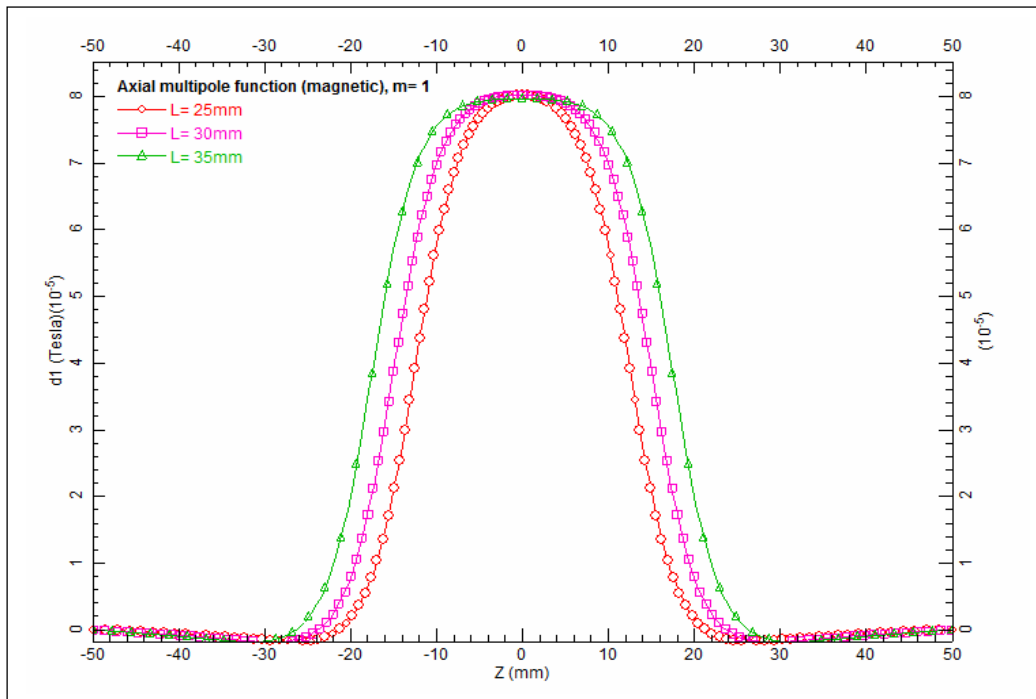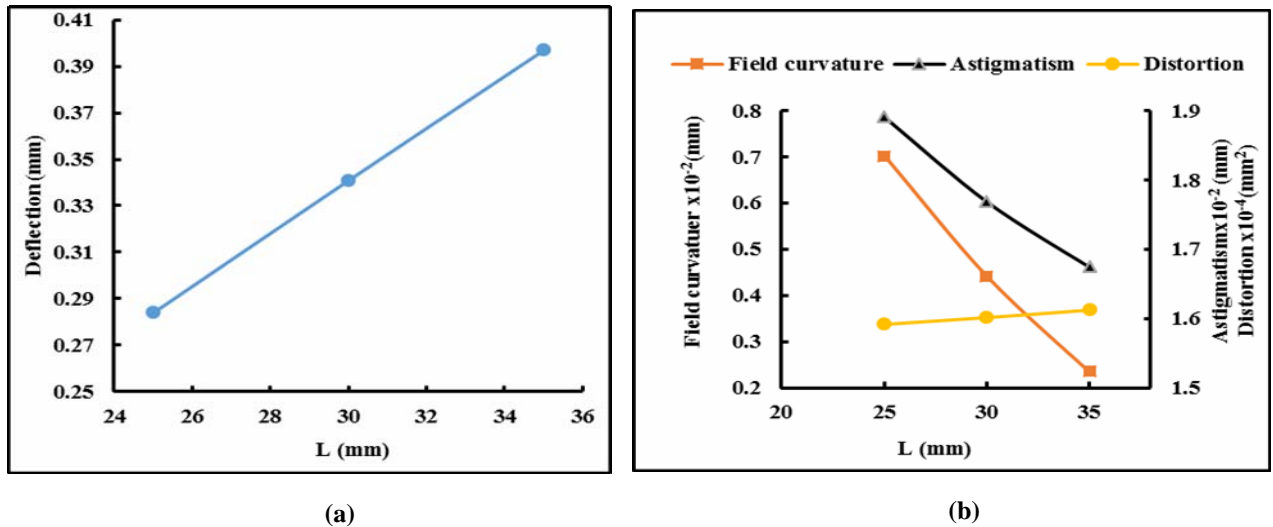**b: Variation of the aberration coefficients as a function of bore diameters.**

Fig. 6: The axial magnetic deflector potential d_1 as a function of Z for different
values of length L = (25, 30 & 35) mm.

(a)   **(b)**

Fig. 7: a: Variation of the magnetic deflections as a function of deflector lengths.
b: Variation of the aberration coefficients as a function of deflector lengths.

In order to study the effect of the thickness of the deflector (Th) on optical performance, different values were selected, Th = (2, 3 & 4) mm while the other geometrical parameters remained constant. Fig. (8) shows the effect of the different values of thickness on axial magnetic deflector potential (d_1). It has been found that this geometrical factor has very little effect on the amount of deflection as well as the aberration coefficients, as illustrated in the Figures (9 (a,b)) below.

In order to investigate the effect of angles $(\emptyset)$ and the excitation (NI) of deflector on its properties, the values were chosen $\emptyset = (30, 45 \ \& \ 60)^\circ$, NI = (1, 2, 3 & 4) A-t. It was found that the maximum of axial magnetic deflector potential (d_1) increases by increasing the $(\emptyset)$ and (NI), while the half-widths are approximately constant, as shown in Fig. (10 (a,b)). Also it has been found that the aberration coefficients remain constant but the magnetic deflections are changing. Fig. (11(a,b)) illustrated that the magnetic deflections increase as the increased values of $(\emptyset)$ and (NI).
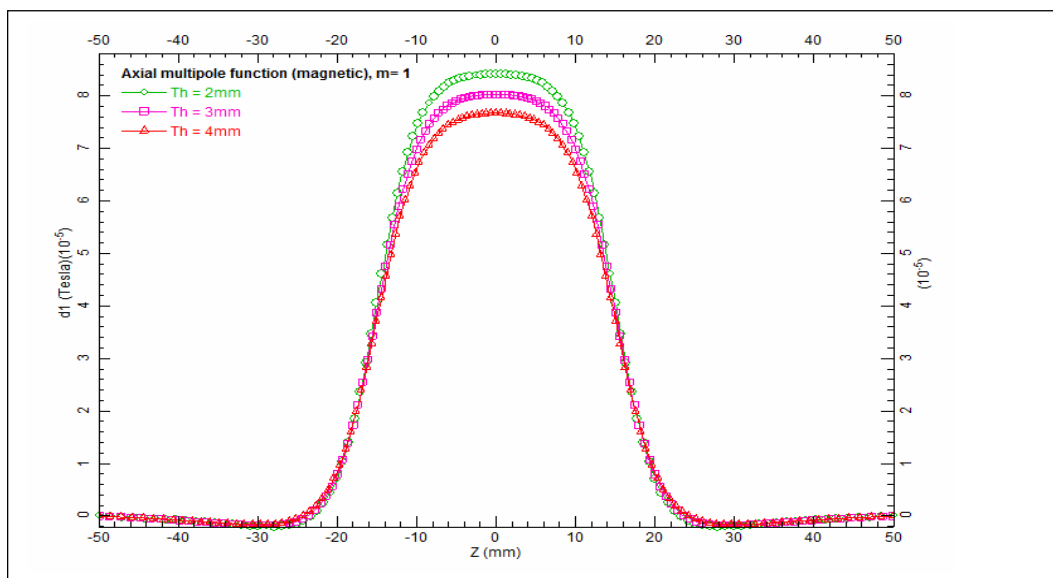

Fig. 8: The axial magnetic deflector potential d_1 as a function of Z for different values of thickness Th = (2, 3 & 4) mm.
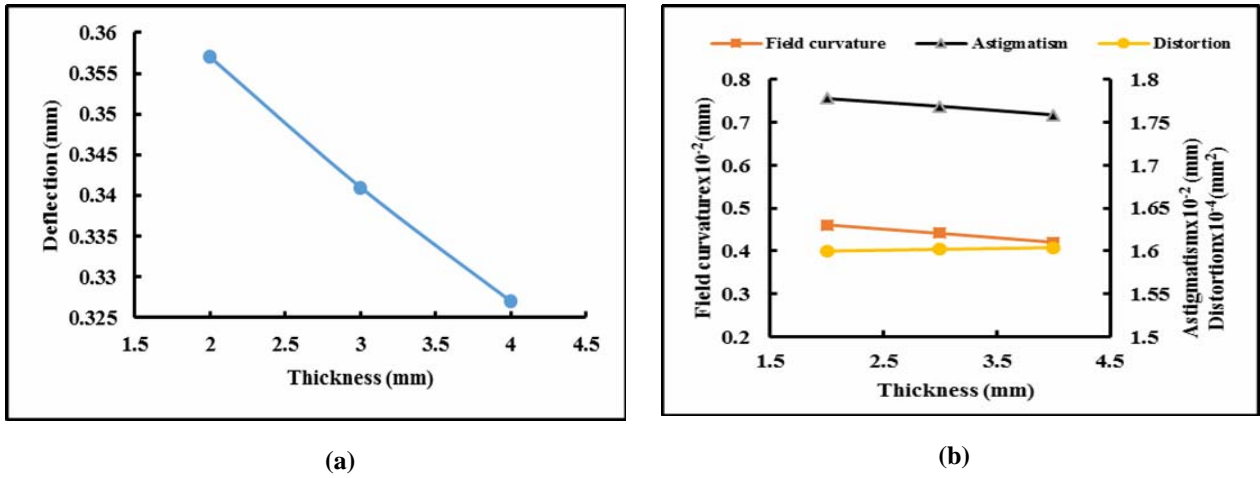
(a)   (b)

Fig. 9: a: Variation of the magnetic deflections as a function of deflector thickness.
b: Variation of the aberration coefficients as a function of deflector thickness.
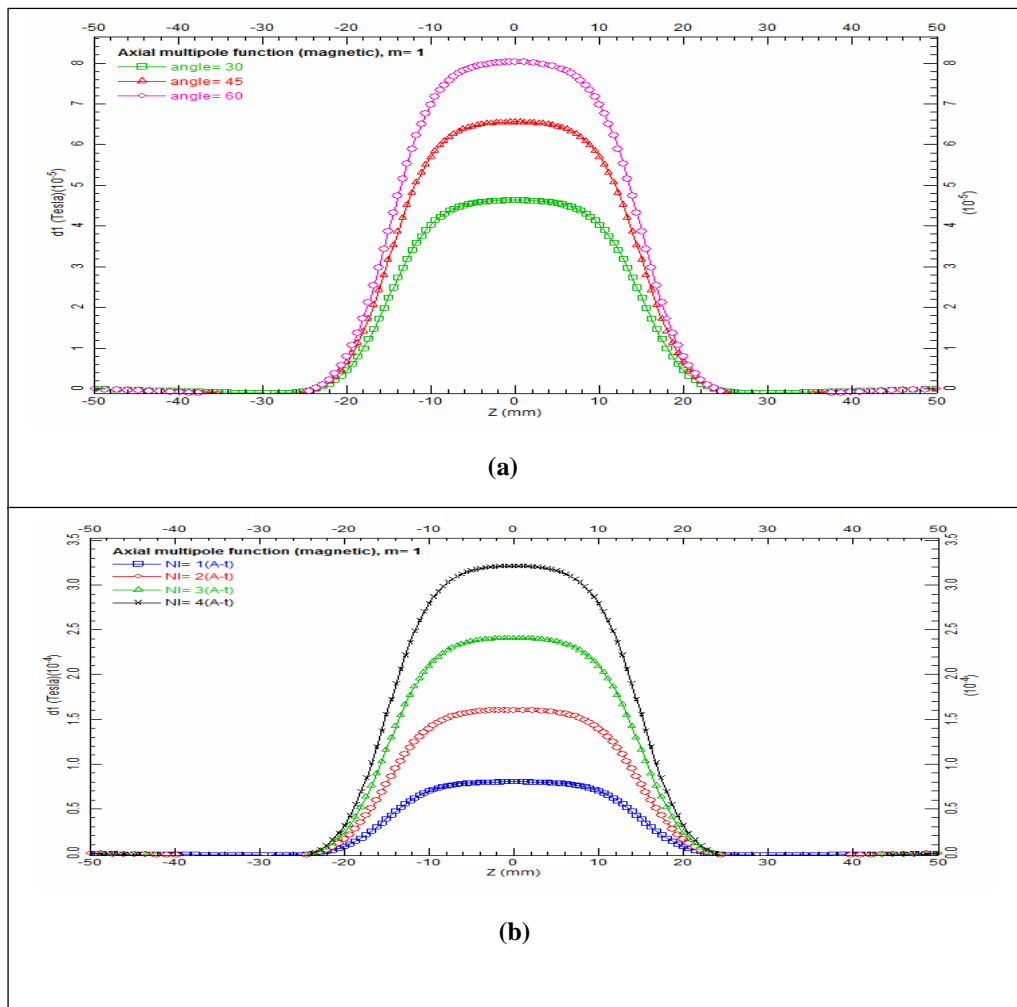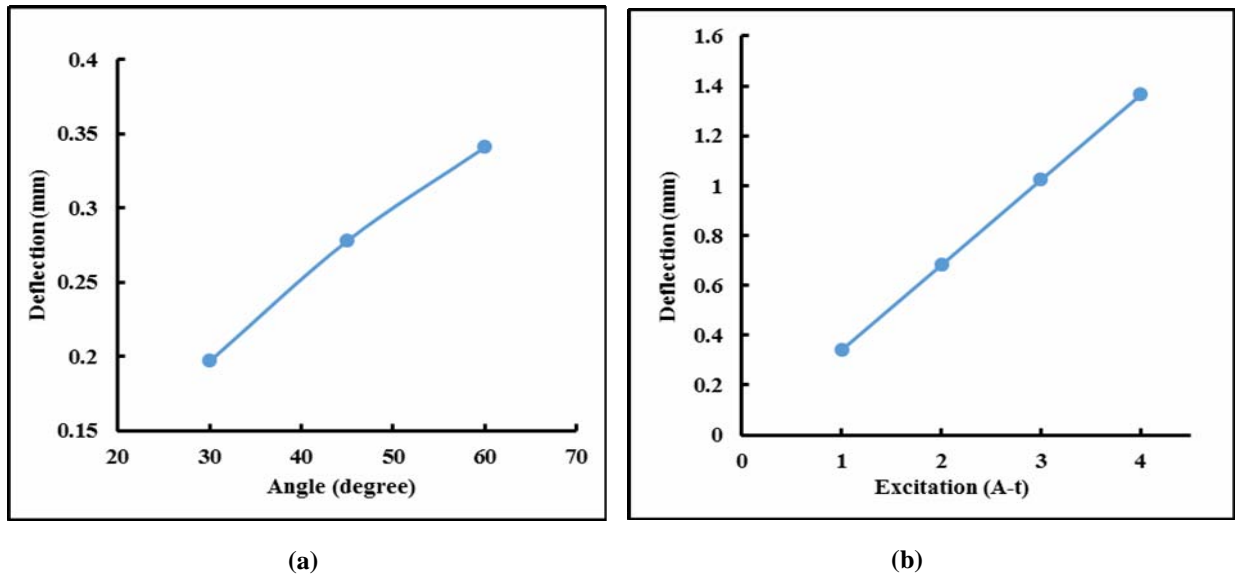

(a)

(b)

Fig. 10: a: The axial magnetic deflector potential d_1 as a function of Z for different values of angle
$(\emptyset = 30, 45 \ \& \ 60)°$.

b: The axial magnetic deflector potential d_1 as a function of Z for different values of
excitation NI = (1, 2, 3 & 4) A-t.

Fig. 11: a: The magnetic deflections as a function of angle $(\emptyset = 30, 45 \,\&\, 60)°$.
b: The magnetic deflections as a function of NI = (1, 2, 3 & 4) A-t.

CONCLUSIONS

1. It was found that the bore diameter and length of deflector have a significant and direct effect on the amount of magnetic deflection and on the aberration coefficients. Also it has been shown that there is an inverse relation between the values of bore diameter and the amount of deflection, while the values of deflector length have directly proportional with the amount of deflection.

2. It was observed that by increasing the bore diameter and length of the deflector decreases in field curvature and astigmatism aberration coefficients while slightly increase in distortion aberration coefficient.

3. It was found that the thickness of deflector has a little effect on the optical performance.

4. The angle of the deflector and excitation have a direct effect only on the amount of magnetic deflection.

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