Correction of Distortion Aberration in Electron Magnetic Lenses

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Abstract

In this research, a theoretical investigation had been done to study and correct distortion aberration which happened in electron magnetic lenses while it is used as projector lenses in transmission electron microscope. In this study, inverse design had been used MATLAB environment and by representing the axial magnetic field for doublet magnetic lens with axial magnetic function as a target function.

Keywords: *electron optics , electron magnetic lens , doublet magnetic lens.*

I. INTRODUCTION

The projector magnetic lens is regarded as one of the most important lenses of transmission electronic microscope after the objective lens which magnifying the image produced by objective lens and falling on the screen of electron microscope, but this suffers from defects which made from distortion in the produced image but it doesn't effect on resolving power of microscope. One of the most defects which appear on the image during starting the lens beside its rotation round the optical axis is the radial and spiral distortion .Spiral distortion is considered as one of special defects of magnetic lenses due to the unequivalent rotation of the image through radius of axial bore of the lens and it increases conversely with the excitation of the lens. Because the projector lens works at the minimum of its focal length to get the greatest magnifying for the image , the spiral distortion will be high at the excitations and to improve the quality of the final image, the distortion must be detected or reduced. Among the ways which used in reducing the spiral distortion is using the doublet magnetic lens.

The first sincere trial to get rid of radial and spiral distortion in the image of electronic microscope was done by Tsuno and Harada where they designed a doublet magnetic lens with unequal axial bores which give in the first rotation distortion images and with a percentage of spiral distortion 0,07% [1]. Al Obadi was able to get images free spiral and radial distortion in the first region of rotation only by designing doublet magneticlens consisted of cylindrical double polepiece magnetic lenses[2].

After that many studies have been submitted using similar procedure in the recent study but lenses were , one was double pole piece and the other wassingle polepiece by using cylindrical polepiece[3],spherical polepieces [4] and cone polepieces with plane face [5]. With the worth to mention that all the previous studies were following the conventional procedure in designing and studying the optical properties of free distortion doublet magnetic electron lenses. In fact, modern studies have appeared recently to tackle the subject of studying projector optical properties of free distortiondoublet magnetic lenses by using inverse design and through suggesting of axial magnetic function like scalar magnetic potential [6,7]. In this study , one of the known functions has been used in the field of electron optics to represent the axial magnetic field of free distortion doublet axial lens.

II. MATHEMATICAL MODEL

Using analytic mathematical function in this research as a target function to represent axial magnetic field for magnetic lens and it's mathematical form as follows:

$$B(z) = \frac{B_{max}}{\left[1 + \left(\frac{2z}{W}\right)^2\right]} \text{.......... ....}(1)$$

From the relation above it is noticed that this model is represent distribution of axial magnetic flux density and it's a function of maximum magnetic flux density (B_{max}) and a half width of axial magnetic field(W) which represent optimization parameters in which can change the form of the field, and (z) represents the length of optical axial of the lens. This function has been used to have an axial magnetic field for doublet lens where the optical axial has been divided into two regions, the first represents the negative flux of the optical axial (the field of the first single lens) and the second region represents the positive flux (the field of the second sigle lens). Here each region works away alone,i.e, the target function has been represented values Z at B_{max1} and W_1 whereas B_{max2} and W_2 used to negative values.

In fact this situation gives the ability of changing doublet lens properties or its operational performance by changing the geometrical and physical parameter for its single lens. The equation which describes show half width of axial magnetic field. (W_2=2,4,6,8,10 mm) with the constancy of the maximum magnetic flux density B_{max2}= -0.5 T.

Figure (1) shown the distributions of axial magnetic field B_z for the doublet lens and it is noticed that the change of second lens field according to the change half width of axial magnetic field in addition to that , the figure explains that the distance between the centre of both lenses (the first and second) is fixed at 40mm and it is the focal length for first and second single lens and also the doublet when both lenses are identical.

The most feature of doublet lens from the single is that having curves of projector focal properties (D_s,D_r,F_p) two loops at the same period of excitation parameter NI/ SQRT(Vr) . The first rotation called the first magnification region and the other called second magnification region. In this research , it has been treated with each rotation in a single way regarding that each one is representing independent operation mode.Projector lenses are working at minimum of projector focal length $(F_P)_{min}$ to get maximum magnification where projector focal length is known as inverse of electron beam trajectory gradient after penetration the lens field. Figure (2) shows curves of projector focal length as a function ofexcitation parameter NI/SQRT(V_r) in the first rotation region 0.01≤NI/SQRT(Vr) ≤4.5 and for each value of W_2. It is noticed from the Figure that each curve has minimumvalue in the first rotation region $(F_P)_{min1}$ and decreases with the increase values W_2, see table (1) . The reason behind that is related to decreases the values of acceleration voltage(V_r) , and also noticed that the minimum of projector focal length in first rotation region$(F_P)_{min1}$ at value W_2=2mm is equal to the distance between position of maximum valuesof two fieldswhen the lenses are identical in geometrical figure.

electron motion in the magnetic field called the paraxial rays equation , which is given in:

$$r'' + \left(\frac{e}{8mV_r}\right)B_z^2 r = 0 \qquad \text{.......... ....(2)}$$

(r) represents electron trajectory inside magnetic field andV_r represents relativistically corrected acceleration voltage. In solving the paraxial rays equation numerically by using (Rung-Kutta) for the fourth order , then electron trajectory has been counted inside the magnetic lens at the initial conditions (r = 1, $r' = 0$). Finally radial distortion coefficient has been counted (D_r)and spiral (D_s) numerically by using technology of (Simpson's rule)[8]

$$D_r = \left(\frac{\eta}{128\ V_r}\right)\int_{z_s}^{z_f}\left(\frac{3\eta}{V_r}B_z^2(z) + 8B^2(z)\right)r_\alpha r_\gamma^3 - \text{.......... ....(3)}$$

$$4B_z^2(z)(r_\gamma'^2 r_\alpha r_\gamma + r_\gamma' r_\alpha^2 r_\alpha')\,dz$$

$$D_s = \int_{z_s}^{z_f}\left[\frac{3}{128}\left(\frac{\eta}{V_r}\right)^{3/2} r_\alpha^2 B_z^3 + \frac{1}{16}\left(\frac{\eta}{V_r}\right)^{1/2} r_\alpha'^2 B_z\right]dz \text{ ,......... ....(4)}$$

where r_γ r_α are solutions of paraxial rays equation.

III. RESULTS AND DISCUSSIONS

Optimization parameters have been fixed for the first single magnetic lens at the values W_1=2mm , B_{max1} =0.5 T (axial magnetic field in the negative part of optical axial) while the second single lens (axial magnetic field in the positive part of optical axial) ,different values have been chosen to

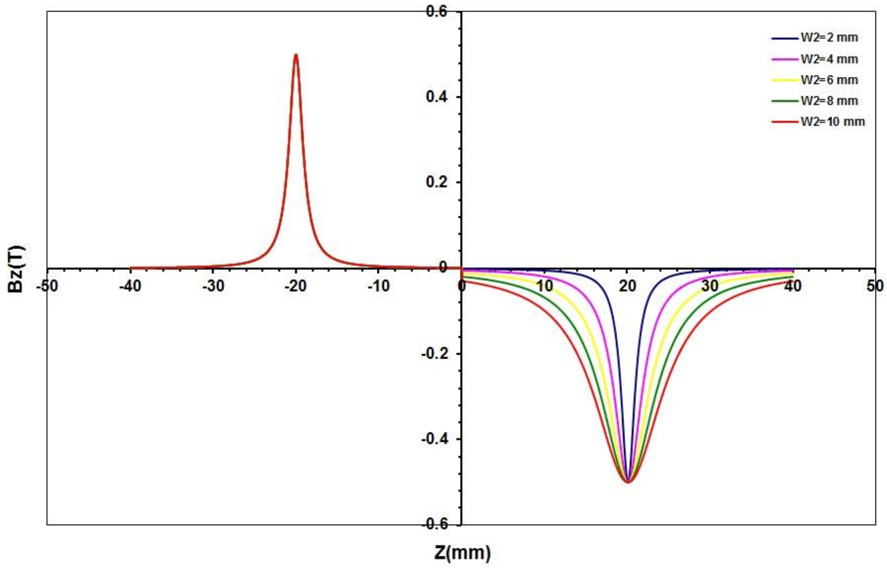

Figure (1): Distributions of Axial Magnetic Fieldfor Doublet Lens at The Different Valuesof Half Width of Second Field W_2

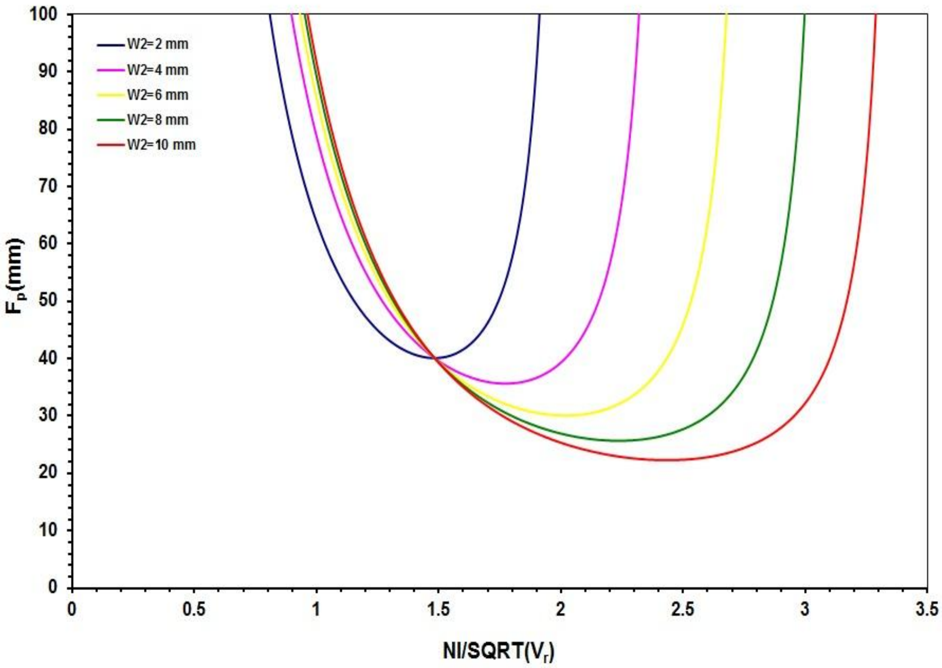

Figure (2):Curves of Projector Focal Length F_p for Doublet Lens as a Function of Excitation Parameter N1/SQRT(V_r) in the First Rotation Regionat The Different Values of Half Width of Second Field W_2

$B_z$for different values of W_2. It is noticed here that each curve has a zerosvalueof spiral distortion coefficient D_s which happens at different excitation parameter and also noticed the increasing W_2 which leads to get zero spiral distortion coefficient at the same excitation parameter which we get zero radial distortion and minimum value ofprojector focal length at value W_2=6vmm , see table (1).

Doublet magnetic lenses can be got from the previous information which give free radialand spiral distortion images at the same excitation parameter which gives minimum valueof the projector focal length in the first rotation region and according suggested mathematical model in this study and at the following values:

W_1=2mm, W_2=6mm,B_{max1}=0.5 T, B_{max2}= -0.5 T

Curves of radial distortion coefficient D_r has been drawn as function of excitation parameter NI/SQRT(Vr) in the first rotation regionand for each distribution B_z as shown in figure (3), and it is noticed from the figure that each curve has zerosvalue (D_r=0) happens at different of excitation parameter and also noticed that radial distortion coefficient disappear at the same excitation parameter which gives minimum of projector focal length when both lenses are identical and also at the value of half width W_2=6mm (i.e. both lenses are not identical) ,see table (1) .

Figure (4) shows that curves of spiral distortion coefficient D_s in first rotation region as a function of excitation parameter for each distribution

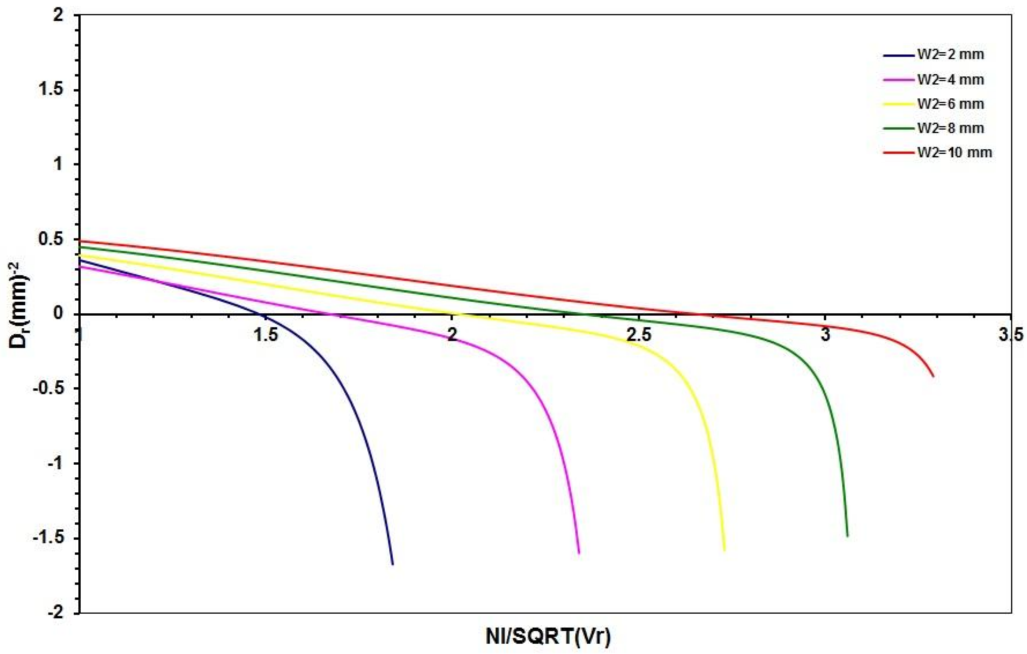

Figure (3): Curves radial distortion coefficientD_r for doublet lens as a function of excitation parameter N1/SQRT(V_r) in the first rotation regionat thedifferent values of half width of second field W_2

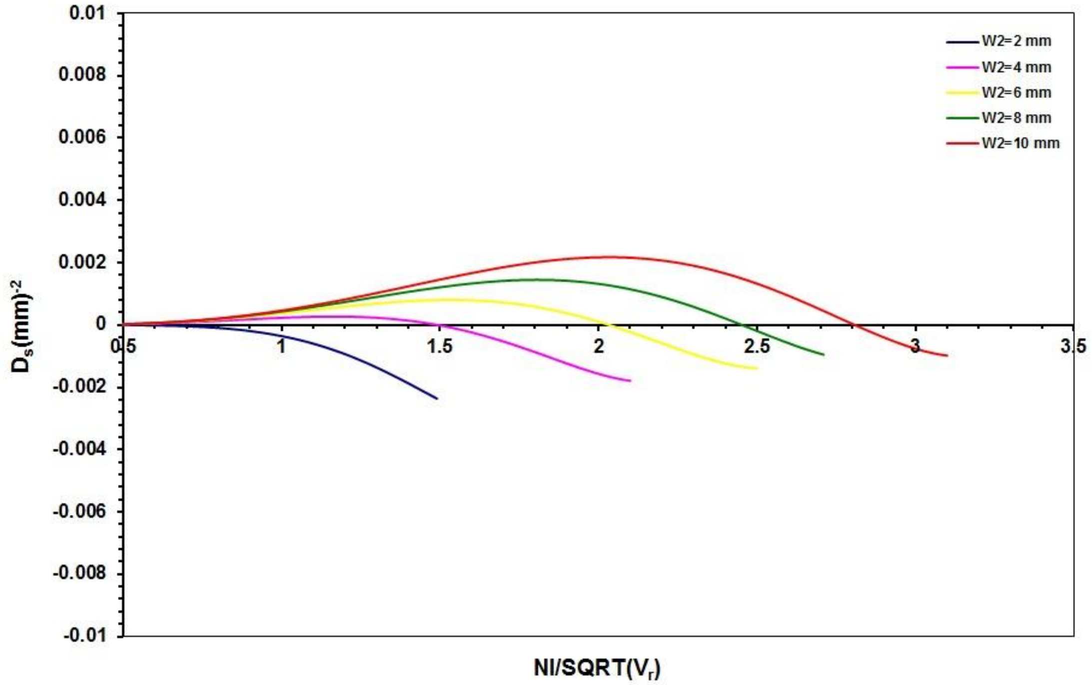

Figure (4): Curves spiral distortion coefficientD_s for doublet lens as a function of excitation parameter N1/SQRT(V_r) in the first rotation regionat thedifferent values of half width of second field W_2

Table(1): Projector optical properties of the doublet magnetic lens in first rotation regionat thedifferent values of half width of second field W_2

		At $NI/V_r^{(1/2)}$		
W_2 (mm)	$(F_p)_{min1}$ mm	$(F_p)_{min1}$	D_r=0	D_s=0
2	40	1.48	1.48	0.4
4	35	1.77	1.69	1.5
6	30	2.02	2.02	2.02
8	25	2.24	2.35	2.46
10	22	2.43	2.65	2.81

IV. CONCLUSIONS

In this study , we can conclude the following points:

1- Ability of using analytic mathematical functions to represent axial magnetic field for distortion free doublet magnetic lens as a target function in technology of establishing and with high efficiency.

2- Getting axial magnetic field forfree radialdistortion doublet magnetic lens at excitation parameter giving minimum valueof projector focal length in first rotation region when the fields of lens are equal with the value of half width and maximum value of axial magnetic flux density.

3- Getting axial magnetic field for doublet magnetic lens free radial and spiral distortion at excitation parameter which happened at minimum projector focal length at the first rotation and at different values for half width of field and maximum of axial magnetic flux density to the field of the lens.

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