BioGecko Vol 12 Issue 02 2023

ISSN NO: 2230-5807

Effect Thickness Back Plate on the properties Immersion Magnetic Lens

Othman M. A. AL-Bayati*, R.Y.J. AL-Salih

Department of physics, College of Sciences, University of Tikrit, Salahaddin, Iraq.

E-mail: Othman.mahmood.ali@gmail.com*,r.y.jasim@tu.edu.iq

ABSTRACT

In this paper, an innovative design of the immersion magnetic lens was proposed and some improvements were made to it, such as changing the thickness of the back plate of the lens. The axial magnetic field of these lenses was calculated by the Finite Element Method and computer programs were used to study the optical properties of these lenses for several changes of thickness 5-10 mm to reach the best design from the proposed changes when the coil is excitation 3300 A.t and it turns out that the thickness of 10 mm achieved the best results compared to other changes because it has the lowest values of the focal length, which corresponds to the highest values of the magnetic field.

Key words: Magnetic Lens; Immersion Lens; Electron Microscope; Electron Optics.

1. Introduction

magnetic lens its main function is to focus the electronic beam that falls on the sample to form first image of the sample. The ability of the electron microscope is determined by the analytical capabilities of this lens, and it is considered one of the most important parts of electron microscopes [1]. Because this lens contributes to chromatic aberration and spherical aberration more than other lenses, so it is necessary to take into account the accuracy of manufacturing and designing this lens [2]. It can be defined as an axial magnetic field that affects the charged particles that pass through it. importance in any electron microscope [3]. The simplest magnetic lens is an iron-free coaxial circular coil, but most magnetic lenses contain iron and electrodes. Therefore, magnetic lenses are not physical lenses, but rather a magnetic field generated in a coil due to the passage of an electric current through it, which works to focus the electronic beam that passes through it [4]. This lens is commercially available more than other types due to its ease of manufacture, accurate work, and low cost. Another advantage of it is that it has a high analysis ability and does not require high voltage to operate. It is more suitable than permanent magnets for the possibility of changing the value of the magnetic field by changing the amount of current through the coil. Or change the number of coil turns [5]. In a scanning electron microscope there are three basic designs of objective lenses, depending on the position of the sample and the magnetic flux [6]. One of these lenses is the magnetic objective lens immersed in this lens. The sample is placed inside the lens and within its magnetic field. Its focal length is very small (2-5 mm), which makes it suitable for use in high-resolution instruments. One of the disadvantages of this lens is the determination of the sample size, which does not exceed (5 mm). It is also not suitable for the examination of samples containing magnetic materials [7].

The researchers Zeina and Taleb, studied in 2021 AD the design of a double distortion electromagnetic lens consisting of two identical lenses using the EOD program. The focal properties of this lens were calculated by changing the magnetic flux density of one of the two monocular lenses by changing the diameter of the axial aperture [8]. In 2021, researchers Basma and Ahmed studied the design of a symmetrical magnetic lens under optimal conditions. The lens was designed using the EOD program and its geometric and optical properties were studied by studying the effect of the diameter of the axial aperture, as well as the air gap between the two poles, the thickness of the electrodes, and the irritation coefficient to obtain the best optical properties [9]. The researchers, Rafi and others, studied in 2022 AD the effect of the geometric shape of the arm of the pole head on the bipolar lens and studied its magnetic and optical properties in terms of coefficient of spherical and chromatic aberration, and it was found that there were slight changes in them, but the focal length did not occur in it a noticeable change [10]. Also, in 2022 AD, Mardin and Muhammad were able to study the effect of the distance between the two poles on the focal properties of the immersed magnetic lens, and found that the distance between the two poles has a direct effect on the focal properties, and they obtained the best distance of 2 mm because it has the lowest values for the focal length and the highest value for analysis [11].

2. Theory Part

The principle of the magnetic lens when passing a continuous current (I) in a circular coil containing a number of turns (N) generates a magnetic field B_z that affects the electronic beam inside the track and deflects electrons towards the optical axis [12]. Expressing it according to Ampere's law [13]: $\int_{-\infty}^{+\infty} B_z dz = \mu_o NI$ …(1)

Where: NI is the irritation of the lens in units of Ampere-turn (A.t).

μ_o = space permeability and equal to ($4\pi\times10^{-7}$ H/m)

motion of an electron within an axially symmetric magnetic field is given by:

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

Where (r) represents the height of the electron beam path from the optical axis, (e) represents the electron charge, (B_z) represents the axial magnetic flux density distribution, (m) represents the mass of the electron, and (V_r) represents the proportionally corrected acceleration voltage of the electron beam and is equal to [14]:

$$v_r = v_a(1 + 0.978 \times 10^{-6} v_a) \qquad \text{…(3)}$$

Where (v_a) represents the acceleration voltage of the electronic beam.

The high precision of the objective lens design helps to reduce spherical aberration significantly, as Scherzer pointed out. Spherical aberration cannot be completely eliminated in the symmetric lens as it occurs in the glass lens, but it can be reduced by using an asymmetric lens that has less aberration than the symmetric lens [15]. The spherical aberration coefficient C_S of a magnetic lens with magnetic flux density B_z can be calculated according to the following relationship [16]:

$$C_s = \frac{e}{128mV_r}\int_{Z_0}^{Z_i}\left(\frac{3e}{mV_r}B_z^4R_\alpha^4(z) + 8(B_z')^2R_\alpha^4(z) - 8B_z^2R_\alpha^2(z)(R'_\alpha(z))^2\right)dz \qquad \text{…(4)}$$

Where the magnetic flux density B_z is:

$$B_z = B_z - \frac{R_\alpha{}^2(z)}{4} B_z'' + \frac{R_\alpha{}^4(z)}{64} B''''_z \qquad \ldots(5)$$

$R_\alpha(z)$ It is a solution to the axial beam equation.

The chromatic aberration arises due to the difference in the energy of the charged particles, where the particles with higher energy diffuse to a farther distance than the particles with lower energy causing different focal points, resulting in the formation of a disorder disk with diameter d_c given by the equation [17]:

$$d_C = C_C \frac{\Delta V}{V_r} \alpha \qquad \ldots(6)$$

Where C_c is the chromatic aberration coefficient and $(\frac{\Delta V}{V_r})$ the percentage change in the acceleration voltage, and the chromatic aberration coefficient C_c of the magnetic lens can be obtained from the following relationship [18]:

$$C_c = \frac{e}{8mV_r} \int_{z_o}^{z_i} B_z^2 \, R_\alpha^2(z) dz \qquad \ldots(7)$$

The chromatic aberration can be reduced either by increasing the acceleration voltage or by providing a highly stable voltage to obtain a single wavelength beam or by increasing the aperture diameter to reduce voltage disturbances [19][20]. The lens or electron microscope has a specific characteristic called resolving ability, which is defined as the ability of the lens to form two separate images of two points on the sample, where it was generally believed that if the lens was well made, ideally, and with high magnification, the material could be seen using the microscope with the smallest details of the internal structure, but The scientist Abbe concluded that the analytical ability is limited by the phenomenon of diffraction, that is, a lens that cannot form separate images of two adjacent points on the model if their separation from each other is less than the limits of analysis, and these limits are called the critical distance given by the following relationship [21]:

$$\delta = \frac{k\lambda}{n \sin\theta} \qquad \ldots(8)$$

where δ is the resolving power, k is the resolving power constant, λ is the wavelength, n sinθ the numerical aperture, θ is the angle of the beam cone and n is the refractive index of the medium between the lens and the sample.

3. Experimental Part

3.1 Lens Design For Four Changes on the Thickness Back Plate

Four changes were chosen for the thickness of the iron back plate of the immersion lens, which are (D = 5, 6, 8, 10), respectively, as shown in Figure (1), Electromagnetic analyzes were carried out using the finite element method on lenses, including the calculation of the axial magnetic flux density distribution using FEM-CMFD program for the four changes at constant excitation NI = 3300 A.t and current density $\sigma = 2$ A/mm^2 and as shown in Figure (2) and through these analyzes the focal properties of those lenses were calculated using the program MELOP represented by the focal length and coefficient of spherical aberration and coefficient Chromatic aberration and analysis ability, which is shown in Figures (3), (4), (5) and (6).

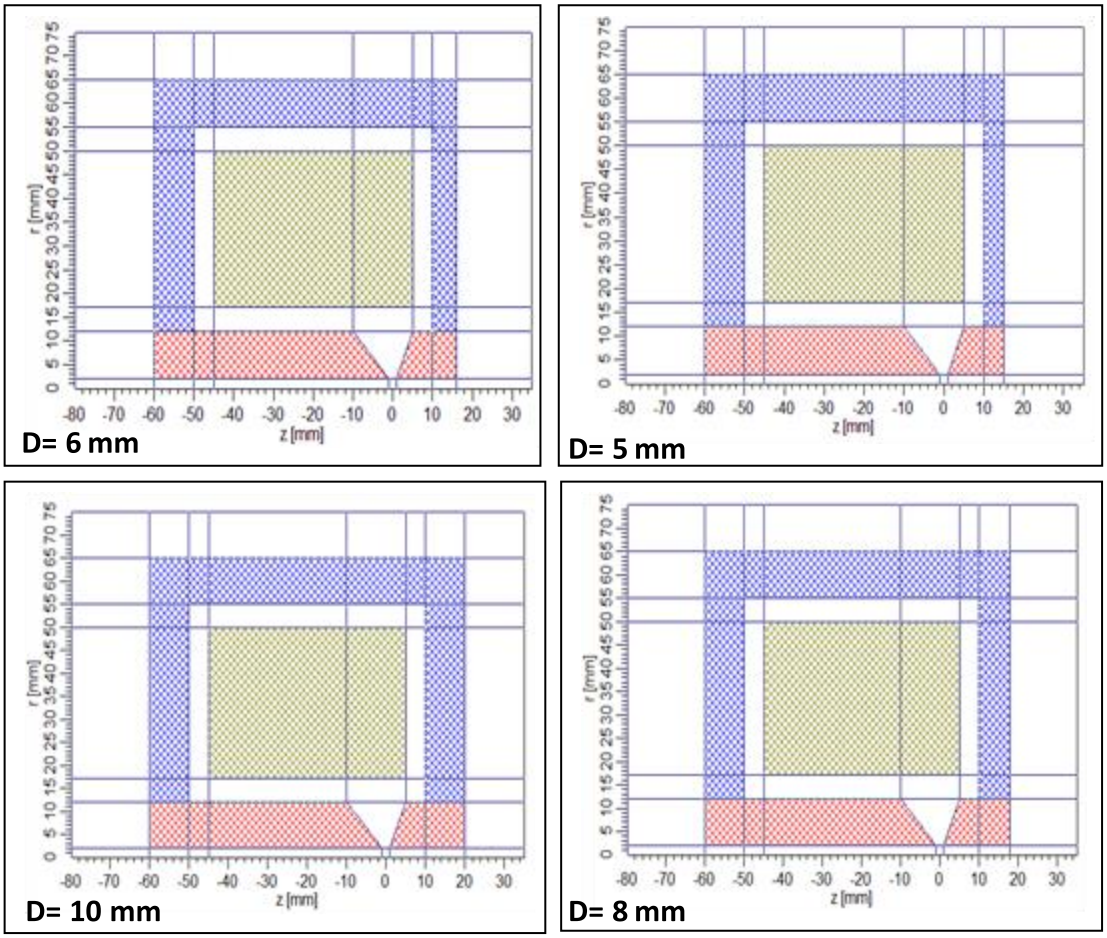

Fig. (1): Diagram of four changes of the immersion lens D= 5, 6, 8, 10 mm.

3.2 Calculation Of Axial Magnetic Flux Density

In order to design a high-efficiency ferromagnetic lens, this lens must generate the highest possible peak axial magnetic flux density and correspond to the smallest bandwidth at the mid-value of its distribution [10]. Using the FEM-CMFD program, the axial magnetic flux density (B_z) distribution of the lens was calculated. The proposed four changes at excitation (NI = 3300 A-t) as shown in Figure (2) below.

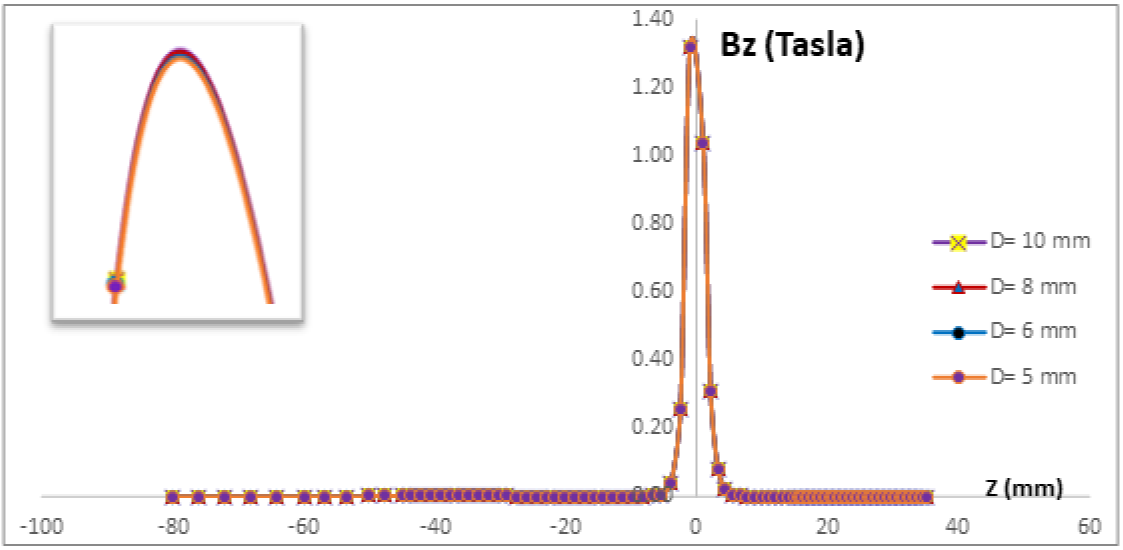

Fig. (2): Distribution of the axial magnetic flux density (Bz) of the lens immersion in different thicknesses of the back plate (D) at constant Vr = 10 kv.

We note from Figure (2) that increasing the thickness of the iron back plate leads to a slight increase in the maximum value of the magnetic flux density B_{max}, and this in turn will give the lens good focal properties. From the figure, we note that the change D = 10 mm represents the best change compared to the rest of the proposed changes. The optical properties of these four changes of plate thickness to choose the best design. The table below (1) shows a summary of the electromagnetic analyzes of the four changes of the immersion lens.

Table (1): Summary of the electromagnetic analyzes of the four changes of the immersion lens.

D(mm)	Apex position Z(mm)	$B_{z\ max}$ (Tasla)
5	1	1.3532
6	1	1.3535
8	1	1.3540
10	1	1.3545

Despite obtaining this clear detail of the values of the magnetic flux density distribution curves above, this result is still not sufficient to distinguish the best lens among these lenses because of the presence of other extremely important properties that have not been studied yet, such as the optical properties. To study the optical properties of the four proposed changes of the magnetic lens Selected for the purpose of obtaining the best change from them, these properties were calculated using the MELOP program at the acceleration voltage range (V_r = 100 v-10 kv)) as shown in the following figures and tables. Figure (3) shows the change in spherical aberration for different thicknesses of the back plate (S) as a function of the acceleration voltage V_r at constant excitation NI = 3300 A.t

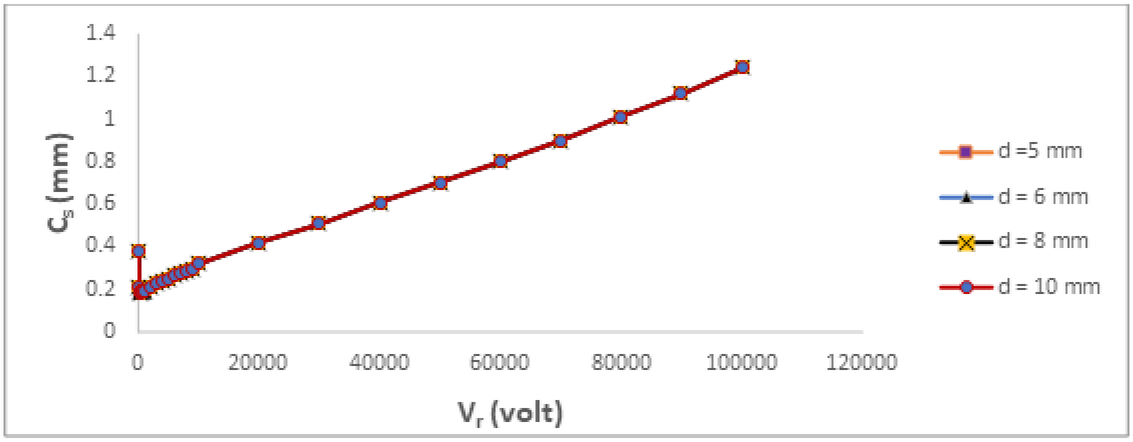

Fig. (3): Variation of spherical aberration for different back plate thicknesses (D) as a function of acceleration voltage V_r at constant excitation NI = 3300 A.t.

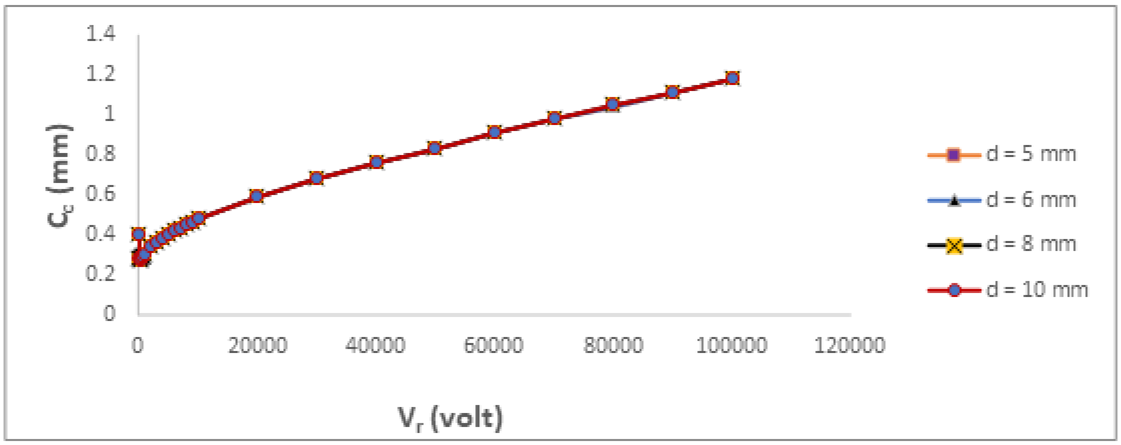

Fig. (4): Variation of chromatic aberration for different back plate thicknesses (D) as a function of acceleration voltage V_r at constant excitation NI = 3300 A.t.

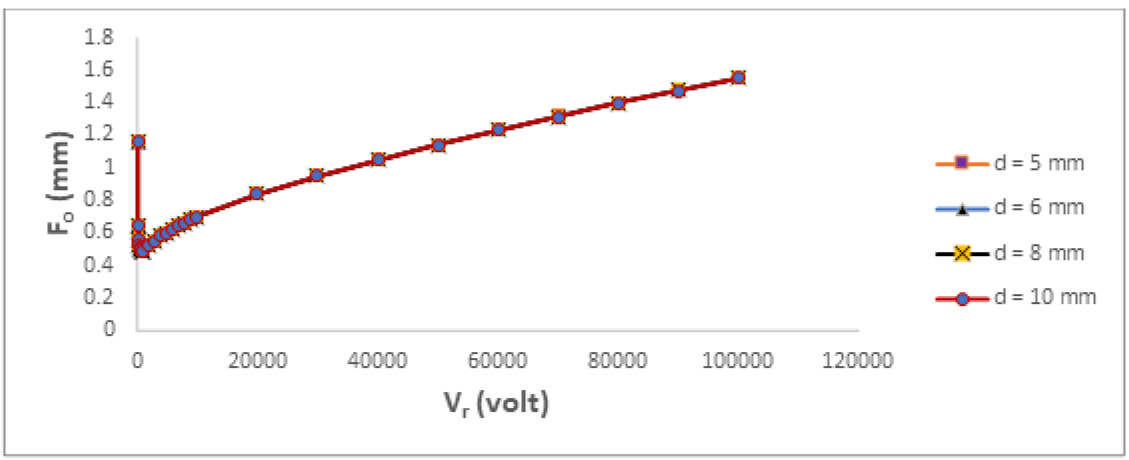

Fig. (5): Focal length variation of different back plate thicknesses (D) as a function of acceleration voltage V_r at constant excitation NI = 3300 A.t.

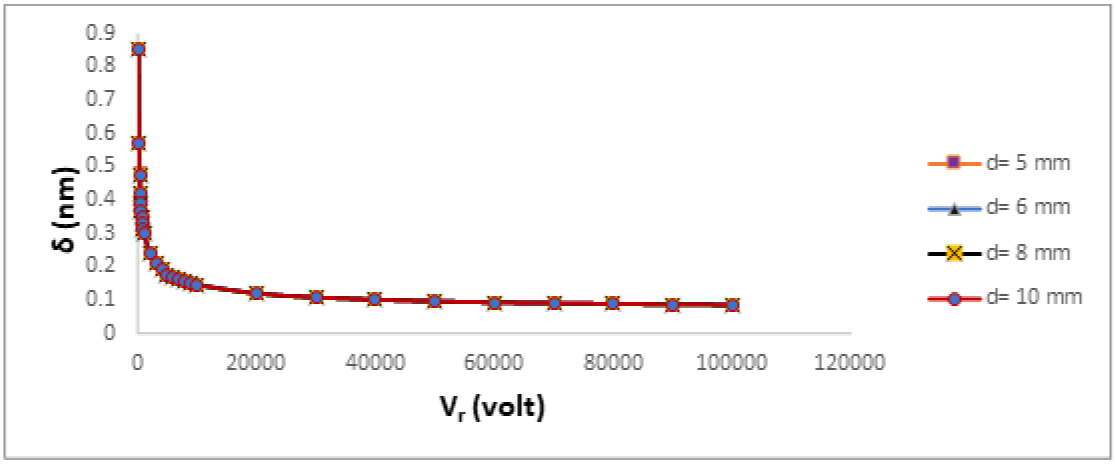

Fig. (6): Variation of resolving power for different back plate thicknesses (D) as a function of acceleration voltage V_r at constant excitation NI = 3300 A.t.

We note from the figures above that there is a great agreement for the values of the different changes in the thickness of the plate for the optical properties as a function of the acceleration voltage V_r at constant excitation NI = 3300 A.t. To make sure of this, the values are shown in Table (2) below when starting the change from voltage V_r = 10 kv-100 kv.

Table (2): The optical properties of the four changes of the ferrous back plate of the lens.

D	V_r(volt)	C_s	C_c	F_o	δ
5 mm	70000	0.9	0.98	1.32	0.091084
	80000	1.01	1.04	1.4	0.08917
	90000	1.12	1.11	1.48	0.087551
	100000	1.24	1.18	1.55	0.086328
6 mm	70000	0.9	0.98	1.31	0.091084
	80000	1.01	1.04	1.4	0.08917
	90000	1.12	1.11	1.48	0.087551
	100000	1.24	1.18	1.55	0.086328
8 mm	70000	0.9	0.98	1.31	0.091084
	80000	1.01	1.05	1.4	0.08917
	90000	1.12	1.11	1.48	0.087551
	100000	1.24	1.18	1.55	0.086328
10 mm	70000	0.9	0.98	1.31	0.091084
	80000	1.01	1.05	1.4	0.08917
	90000	1.12	1.11	1.47	0.087551
	100000	1.24	1.18	1.55	0.086328

From the foregoing and by comparing the theoretical results of the figures and tables shown above, it is clear to us that there is a great match in the properties and slight changes occurred at the thickness D = 10 mm, despite its slight difference in values, but it achieved the best results because it has the lowest values for the focal length, which corresponds to the highest value of the magnetic field at A constant value of the irritation factor (NI) relative to the rest of the changes, so the best thickness of the iron back plate of the immersion lens will be chosen.

4. Conclusions

The immersion magnetic lens with a thickness of D = 10 mm for the iron back plate achieved the best results because it had the lowest values for the focal length that corresponds to the highest value for the magnetic field. As for the coefficients of spherical and chromatic aberration, there was a great agreement at a constant value of the irritation factor (NI = 3300 A.t), and this means The higher the thickness of the plate, the better the magnetic and optical properties. And that the lens has a maximum value for the distribution of the axial magnetic flux density ($B_{z\,max}$ = 1.3545 Tasla) at the location Z = 1 mm.

5. References

[1] A. R. Lupini, A. Y. Borisevich, J. C. Idrobo, H. M. Christen, M. Biegalski, and S. J. Pennycook, ‘Characterizing the two-and three-dimensional resolution of an improved aberration-corrected STEM’, Microsc. Microanal., vol. 15, no. 5, pp. 441–453, 2009.

[2] P. W. Hawkes and E. Kasper, Principles of Electron Optics, Volume 3: Fundamental Wave Optics. Academic press, 2022.

[3] L. E. Murr, Electron and ion microscopy and microanalysis: principles and applications. CRC Press, 2018.

[4] E. Verney, B. Sauviac, and C. R. Simovski, ‘Isotropic metamaterial electromagnetic lens’, Phys. Lett. A, vol. 331, no. 3–4, pp. 244–247, 2004.

[5] D. Typke, ‘Electron-optical research at the AEG Forschungs-Institut 1928–1940’, in Advances in Imaging and Electron Physics, vol. 220, Elsevier, 2021, pp. 1–24.

[6] R. A. Haight, F. M. Ross, and J. B. Hannon, Handbook Of Instrumentation And Techniques For Semiconductor Nanostructure Characterization (In 2 Volumes), vol. 2. World Scientific, 2011.

[7] J. Pawley and H. Schatten, Biological low-voltage scanning electron microscopy. Springer, 2007.

[8] Z. H. Edan and T. M. Abbas, ‘Computer-aided design of free rotation and distortion doublet electromagnetic lenses’, Mater. Today Proc., 2021.

[9] B. F. Abd Alghane and A. K. Ahmad, ‘Design of symmetric magnetic lenses with optimum operational conditions’, Al-Nahrain J. Sci., vol. 24, no. 1, pp. 30–38, 2021.

[10] H. Y. Ismaeel, R. Y. J. AL-Salih, and H. E. Jasim, ‘Effect of Outer Polepiece Shroud Geometry on Bipolar Lens and Studying its Properties’, Tikrit J. Pure Sci., vol. 27, no. 4, pp. 77–81, 2022.

[11] I. J. Hasan, A. A. Ibrahim, O. K. Tufekci, P. D. J. R. Mahmood, and P. D. S. A. Ibrahem, ‘4th International Conference on Pure Sciences and Agricultural Sciences (ICPAS-2021) Full Texts Book’.

[12] P. W. Hawkes, Magnetic electron lenses, vol. 18. Springer Science & Business Media, 2013.

[13] R. F. Egerton, Physical principles of electron microscopy, vol. 56. Springer, 2005.

[14] L. Reimer, Transmission electron microscopy: physics of image formation and microanalysis, vol. 36. Springer, 2013.

[15] H. Rose, A. Nejati, and H. Mueller, ‘Magnetic Cc/Cs-corrector compensating for the chromatic aberration and the spherical aberration of electron lenses’, Ultramicroscopy, vol. 203, pp. 139–144, 2019.

[16] T. Abbas, ‘Correction of Distortion Aberration in Electron Magnetic Lenses’, Int. J. Appl. Phys., vol. 2, pp. 1–5, 2016.

[17] A. Konečná and F. J. G. de Abajo, ‘Electron beam aberration correction using optical near fields’, Phys. Rev. Lett., vol. 125, no. 3, p. 30801, 2020.

[18] M. A. Al-Khashab and M. T. Al-Shamma, ‘Improvement of the Optical Performance of the Geometrical Parameters of Snorkel Magnetic Lens’, Mosuli Studies Journal, pp. 85–97, 2019.

[19] Q. Ji, Maskless, resistless ion beam lithography Processes. University of California, Berkeley, 2003.

[20] K. Kimoto, K. Nakamura, S. Aizawa, S. Isakozawa, and Y. Matsui, ‘Development of dedicated STEM with high stability’, Microscopy, vol. 56, no. 1, pp. 17–20, 2007.

[21] M. J. Yaseen and H. S. Hasan, ‘Calculating the Resolving Power For Symmetrical Double Pole Piece Magnetic Lenses By Using A Preassigned Analytical Functions’, Ibn AL-Haitham J. Pure Appl. Sci., vol. 22, no. 2, 2017.