Al-Mustansiriyah Journal of Science
ISSN: 1814-635X (print), ISSN:2521-3520 (online) Volume 33, Issue 3, 2022 DOI: http://doi.org/10.23851/mjs.v33i3.1143

Research Article Open Access

Study of the Effect of the Geometry of the Inner Pole Arm of a Bipolar Lens

Rafa Y. J. AL-Salih, Hana Essa Jasim, Hafsa Yakdan Ismaeel*

Department of Physics, College of Science, University of Tikrit, Salahaddin, IRAQ.

*Correspondent contact: hafsa.y.ismaeel.phys515@st.tu.edu.iq

Article Info

Received
14/03/2022

Accepted
29/05/2022

Published
25/09/2022

ABSTRACT

Several innovative designs were designed for magnetic lenses, a bipolar lens with innovative and different geometric shapes, where the outer Inner pole side of the iron shroud, which is symbolized by the symbol (L), was changed. 2,4,6 A/mm^2) and after it was designed, the engineering parameters were studied in terms of magnetic properties, i.e., calculating the magnetic flux density with different current densities, and then studying the optical properties in terms of spherical aberration as well as chromatic aberration. Which made slight changes to the magnetic and optical properties of the bipolar lens and led to an improvement in the performance of the lens because the resolving power increased its amount when the change was made, as well as the aberration where both spherical aberration and chromatic aberration decreased

KEYWORDS: inner pole; bipolar lens; chromatic aberration; spherical aberration.

INTRODUCTION

Electronic optics the origin of optoelectronic science occurred in 1926, when H. Busch [1], showed the use of electronic lenses to produce magnified electron images was first developed by Ruska [2], who worked primarily with magnetic lenses. The electron microscope is perhaps the most important instrument in electronic optics. There are different types of electron microscopes such as Transmission Electron Microscope (TEM) [3], High-Resolution Electron Microscope (HREM) [4], Scanning Electron Microscope (SEM) [5] and Scanning Transmission Electron Microscope (STEM) [6]. The optical performance of these electron microscopes can only be improved by correcting aberrations [7]. A magnetic lens is a device that produces an intense magnetic field within a very small volume and is the basic component of an electron microscope. The lens is the basic component or component of an electron microscope, as the main defect of aberrations in the electron lens has an impact on accuracy to improve the accuracy of the electron microscope, the lens must have very small aberration coefficients [8].

Electromagnetic lenses can be classified according to the number of their poles, the monopolar lens, the bipolar lens, also called the same double pole, and the tripolar lens, and there is another type called iron-free lenses [9].

Bipolar Magnetic Lens The bipolar magnetic lens is one of the most widely used and most common types of magnetic lenses [10]. Where this lens consists of a circular coil and is surrounded by a circle of iron on its axis, there are two poles of magnetizing iron material with high magnetic, separated by an air gap and width (S). The air gap is often small to accumulate the high magnetic flux density. Moreover, since the electrodes of the axial aperture penetrate its diameter (D) where it is along the axis of the lens in order to allow the electron beam to pass through the axial aperture to the so-called air gap [11].

The current study in this paper aims to build innovative designs for several magnetic dipole lenses with different geometries and different current densities. To obtain the best magnetic and optical properties (i.e., the lowest deflection coefficients and the highest analysis ability) using (MELOP) [12], (LENS 2 Shortcut), and Electron Optics Design (EOD) programs. A program for designing optical systems for charged particles allows calculating the fields for rotationally symmetric magnetic and electrostatic lenses, as well as calculating multi-pole fields using the First

Order Finite Element Method. Magnetic and electric fields with properties can be obtained and plotted along the ray axis or at specific levels. As well as calculating the spherical and chromatic strobe coefficients for these optical systems [13]. In 2017, Talib Mohsen Abbas and Qutaiba Ahmed Sahi studied the design and study of the optical properties of symmetrical electromagnetic dipole lenses. Further, he studied the effect of the diameter of the axial aperture of these lenses on the focal length and aberration coefficients (spherical and chromatic); where they found that, the optical properties improve significantly as the aperture values decrease Axial [14]. In 2018, Najwan Hussein Numan studied a theoretical study of the geometric properties and aberrations of dual magnetic lenses, where some basic geometric properties of the lens were studied, such as the bore diameter, gap length and half-width, magnetic flux density, focal length of the projector, the focus of energy magnification, and spherical aberration. Obtaining computational results for geometric properties and spherical aberration using computer programs [15]. In 2021, Zeina Aidan and Talib Muhammad Mohsen studied the computer-aided design of double-deformation and free-rotation electromagnetic lenses after the design was done using the EOD program. This lens consists of two identical lenses. The focal characteristics and the projector of this lens were calculated in the two regions of maximum magnification by changing the axial magnetic flux density in one of the two monocular lenses by changing the axial bore diameter [16]. In 2021 AD, Basma Fayez Abdel Ghani and Ahmed Kamal Ahmed studied the design of magnetic lenses similar to its optimal conditions, where the geometric and optical properties of the magnetic lens were designed and analyzed using the EOD program. Where the effect of the diameter of the axial aperture, the air gap between the poles, the thickness of the poles, and the excitation coefficient was studied to obtain the best optical properties [17]. In 2022, Muhammad Al-Jubouri and Mardin Ahmed studied the design and manufacture of magnetic lenses. The object used in the scanning electron microscope, and the study of its optical properties [18].

THEORETICAL PART

Electron microscopes or lenses have a specific property known as the resolving power, which is defined as the ability of the lens or electron microscope to form two separate images of two adjacent points on the model. The prevailing belief was that it is possible to see the smallest details in the internal structure of the material using the microscope if it is good to make perfect lenses with high magnification. However, the scientist Abbe concluded that analytical ability is determined by the phenomenon of diffraction. Any type of lens or microscope is not able to form a separate image of two adjacent points on the model if their separation from each other is less than the resolvase limit of that lens or microscope. These limits are called the critical distance and are given by the following [19]:

$$\delta = \frac{K\lambda}{n \sin\theta} \tag{1}$$

where:

δ: Analysis limits (critical distance).
λ: Wavelength.
$n \sin\theta$: Numerical aperture.
n: Refractive index.
θ: The corner.
K: Constant.

Equation (1) is derived according to the Rayleigh Criterion scale. Decreasing the wavelength and increasing the numerical aperture contribute to an increase in the analytical ability, but there are limits to the increase in the numerical aperture due to the emergence of spherical aberration [20], and decreasing the wavelength (λ) it cannot be exceeded, and it is the closest wavelength of Ultra Violet. This means that the wavelength and the numerical aperture are the two factors that determine the analytical power of the electron microscope. We also note that the largest value for the denominator is one when it is (90° = 0), meaning that the only way to reduce the value of (δ) is to reduce the value of the wavelength (λ) therefore, write equation 1 in the following form [21]:

$$\delta = \frac{0.16\lambda}{\theta} \tag{2}$$

The ability of analysis in the electron microscope is very high compared to the optical microscope. Due to the small value of (λ), and to better analysis ability can be obtained by decreasing the value of (λ) by increasing the relatively corrected acceleration voltage, as the wavelength measured in nanometers (nm) is related to the acceleration voltage Relatively corrected (V_r) measured in volts (Volt) by the following equation:

$$\lambda(nm) = \sqrt{1.5\backslash Vr} \tag{3}$$

Calculate the magnetic flux density

The equation of the axial ray shows that there is no way to determine the path of the electron beam without knowing how the axial magnetic field Bz is distributed. Where different mathematical models are used to distribute the axial flux density of magnetic lenses [22].

1. Glaser's bell-shaped model: In this model, the "axial distribution of the magnetic field B_z" is given by [23]:

$$B_z = \frac{B_m}{1+\left(\frac{z}{a}\right)^2} \tag{4}$$

Where:
B: is the maximum magnetic flux density.
Z: is the optical axis of the system.
a: is the half-width at half maximum.

2. Related bell-shaped curves: It is shown here for the case n=3/2, the field of a single turn, n=2 and n=∞ Which gives a Gaussian distribution with a weighting and an appropriate given:

$$B_z = \frac{B_m}{1+\left(\frac{z^2}{a^2}\right)^n} \tag{5}$$

3. Grivet- lens model: In this model where the relationship is given:

$$B_z = B_m \operatorname{sech}(z/a) \tag{6}$$

4. The exponential model.

$$B_z = B_m \exp(-z/a) \tag{7}$$

Aberration magnetic lenses

Electron microscopes use a series of magnetic lenses for focusing the accelerated electron beam through a "high voltage" across the sample in a vacuum, as the focus of the image is with the objective lens and through which the magnification is controlled by excitation the lens. Lens aberration, as the real image produced by that lens suffers from aberrations, there are several defects, including spherical aberration and chromatic aberration [19].

Chromatic aberration

The chromatic aberration occurs due to the difference in the energies of the charged particles, the particles of high energies start at farther distances from the particles of the low energy, which leads to a difference in the different forms of their focus, which leads to a difference in the different printing from the printing [20]. Chromatic aberration can also be reduced either by increasing the accelerating voltage or by decreasing the disturbances in the voltage by providing a high stable voltage to obtain a single wavelength beam, or by increasing the diameter of the lens aperture. The spherical aberration is given by the following relationship [24, 25].

$$C_c = \frac{\eta}{8V_r}\int_{Z_o}^{Z_i} B_Z^2 r_\alpha^2 \, dZ \tag{8}$$

Spherical aberration

Electrons exiting at a very small angle from a point located on the axis in the plane of the body (Zo), cross the axis at a farther distance than those exiting at a large angle. This means that the breaking strength of the lens for the electron beam increases as the beam is further away from the optical axis, so it will form an image in the form of a disk and not a point, and it is called the turbulence disk.
The spherical aberration is given by the following relationship [26].

$$C_s = \frac{\eta}{128V_r}\int_{Z_\circ}^{Z_i}\left[\left(\frac{3\eta}{V_r}\right) + B_z^4 r_\alpha^4 + 8B_z^2 r_\alpha^4 - 8B_z^2 r_\alpha^2 r_\alpha'\right] dz \tag{9}$$

PARTICAL PART

In this research, computer graphics programs and graphs were used for the purpose of knowing and studying the magnetic and computational properties of axially symmetric magnetic dipole lenses at variable current densities (J=2 A/m^2), (J=4 A/m^2) and (J=6 A/m^2).

Innovative Design

Five symmetric lenses for bipolar lenses were designed by implementing a basic design as shown in Figure 1 in a cross-sectional table and a three-dimensional figure shown in Figure 2 when engineering data was entered into the EOD program. Where coils of cross-sectional dimensions (30 x 20 mm) coils (750 tons) excite this lens. Internal calendar (6, 10, 14, 18, and 22). Where the magnetic properties and optical properties of these innovative designs are studied.

RESULT AND DISCUSSION

Magnetic Properties

Figure 1 illustrates a cross-section of the shape of the designed magnetic dipole lens. Figure 2 shows the shape of the lens also in three dimensions. The

EOD program designed it by entering its geometric data.

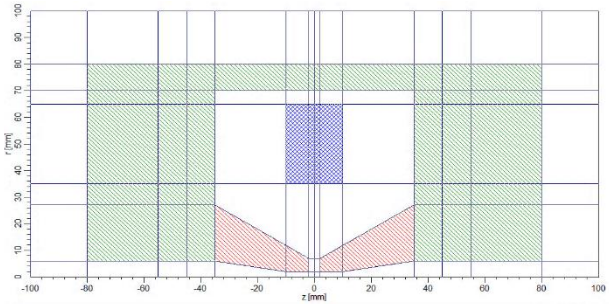

Figure 1. Cross-section of a magnetic bipolar lens prototype.

The figure below shows a three-dimensional symmetrical magnetic dipole lens drawn in the EOD program.

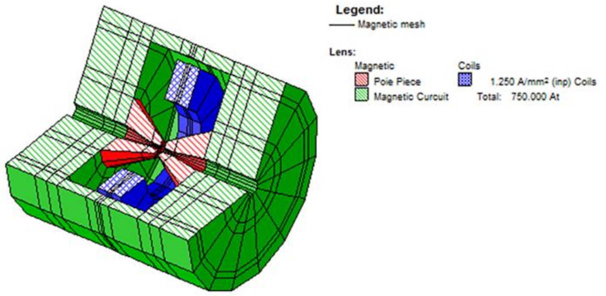

Figure 2. 3-D of a magnetic unipolar prototype lens.

Figure 3 displays the magnetic properties of the lens depending on different densities to find out which is the best for the purpose of use, and thus it was found that the density J=6A/mm^2 is the best density among the proposed densities

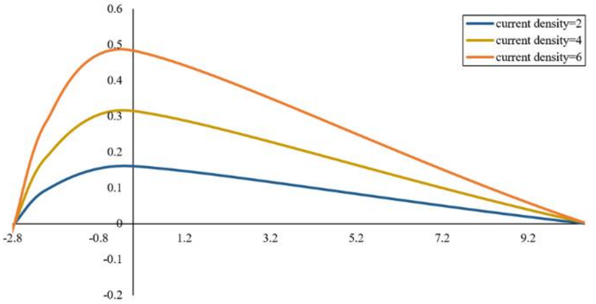

Figure 3. Distribution of axial magnetic preamble (B_z) as a function of the designed lens at a variable current density (J=2, 4, 6 A/mm^2).

Optical Properties

The drawings below show the knowledge and study of the optical properties of the proposed lenses, and this was done when using different current densities (J=2A/m^2), (J=4A/m^2) and (J=6A/m^2). Figure 4 illustrates the relationship between the rectified voltage V_r and chromatic aberration Cc and its value is shown in Table 1.

Table 1. chromatic aberration at different density

L	Vr (volt)	Cc (J=2A/m^2)	Cc (J=4A/m^2)	Cc (J=6A/m^2)
6	60000	18.46	5.4	3.02
	70000	21.09	6.12	3.35
	80000	23.76	6.85	3.67
	90000	26.46	7.59	3.98
	100000	29.13	8.35	4.3
10	60000	18.46	5.4	3.02
	70000	21.09	6.12	3.35
	80000	23.76	6.85	3.67
	90000	26.46	7.59	3.98
	100000	29.12	8.35	4.3
14	60000	18.46	5.4	3.02
	70000	21.09	6.12	3.35
	80000	23.76	6.85	3.67
	90000	26.46	7.59	3.98
	100000	29.12	8.35	4.3
18	60000	18.47	5.4	3.02
	70000	21.1	6.12	3.35
	80000	23.77	6.85	3.67
	90000	26.47	7.59	3.98
	100000	29.13	8.35	4.3
22	60000	18.47	5.4	3.02
	70000	21.1	6.12	3.35
	80000	23.77	6.85	3.67
	90000	26.47	7.59	3.98
	100000	29.13	8.35	4.3

Through the observation to Figure 4 as well as Table 3, it is clear that the relationship between the corrected voltage and chromatic aberration is that there are slight changes as shown above. Despite these minor changes, they mean a lot, because the resolving power was reduced, and this decrease or decrease in aberration means a lot, meaning that this change resulted from a decrease in chromatic aberration and thus the lens was improved.

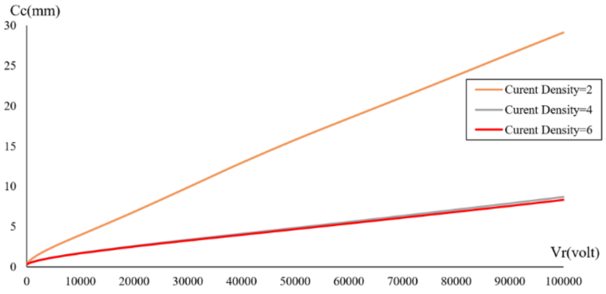

Figure 4. The relationship between Cc as a function of relatively corrected voltage V_r (volt) shows the value of chromatic aberration coefficient Cc (J=2, 4, 6A/mm^2).

where Figure 5 highlights the relationship between the rectified voltage V_r and spherical aberration Cs and its value at different current densities.

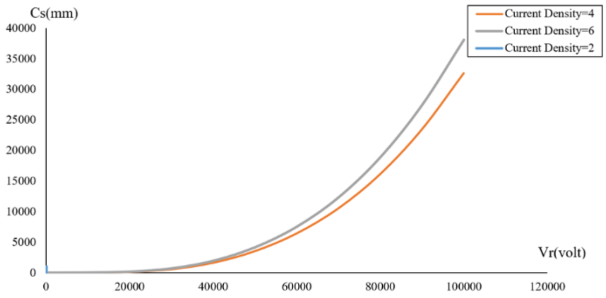

Figure 5. The relationship between Cs as a function of relatively corrected voltage V_r (volt) shows the value of spherical aberration coefficient Cs (J=2, 4, 6A/mm^2).

Table 2 shows the relationship between the relatively corrected voltages V_r with spherical aberration to note the changes that occurred.

Through the observation of Figure 5 as well as Table 2 it is clear that the relationship between the corrected voltage and spherical aberration is that there are slight changes as shown above, despite these minor changes, they mean a lot, because the spherical aberration was reduced, and this decrease or decrease in aberration means a lot, meaning that this change resulted from a decrease in spherical aberration and thus the lens was improved.

Table 2. A spherical aberration at a different density

L	Vr(volt)	Cs(J=2A/mm^2)	Cs(J=4A/mm^2)	Cs(J=6A/mm^2)
6	60000	6445.57	65.97	11.89
	70000	10546.08	102.14	15.38
	80000	16136.61	153.4	19.67
	90000	23452.6	223.91	24.91
	100000	32616.1	318.26	31.31
10	60000	6443.33	65.97	11.89
	70000	10542.45	102.14	15.38
	80000	16131.05	153.4	19.66
	90000	23444.6	223.91	24.9
	100000	32605.2	318.26	31.3
14	60000	6444.89	65.96	11.89
	70000	10544.97	102.13	15.38
	80000	16134.91	153.38	19.67
	90000	23450.16	223.88	24.91
	100000	32612.79	318.21	31.3
18	60000	6452.51	65.96	11.9
	70000	10557.33	102.13	15.39
	80000	16153.81	153.38	19.67
	90000	23477.35	223.88	24.92
	100000	32649.98	318.21	31.32
22	60000	6452.51	66.02	11.9
	70000	10557.33	102.24	15.39
	80000	16153.81	153.56	19.68
	90000	23477.35	224.15	24.93
	100000	32649.98	318.61	31.33

Where Figure 6 below shows the relationship between the rectified voltage V_r and resolving power δ and its value at different current densities.

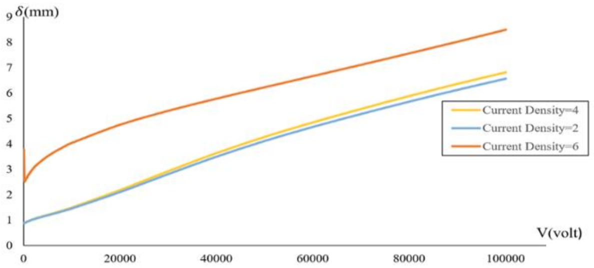

Figure 6. The relationship between δ as a function of relatively corrected voltage V_r (volt) shows the value of the Resolving Power δ (J=2, 4, 6A/mm^2).

Nevertheless, Figure 6 shows the relationship between the rectified voltage V_r and resolving power δ and its value at different current densities. Below is Table 3 showing the relationship between the relatively corrected voltage V_r resolving powers to note the changes that occurred.

Through the observation of Figure 6 as well as Table 3, it is clear that the relationship between the corrected voltage and resolving power is that there are slight changes as shown above. Despite these minor changes, they mean a lot, because the resolving power was reduced, and this decrease or decrease in aberration means a lot, meaning that this change resulted from a decrease in resolving power and thus the lens was improved.

Table 3. Resolving Power at different density

L	Vr(volt)	*δ* (J=2A/mm^2)	*δ* (J=4A/mm^2)	*δ* (J=6A/mm^2)
6	60000	4.667338	10.23203	6.666849
	70000	5.177955	11.41364	7.109912
	80000	5.663561	12.63518	7.560948
	90000	6.127597	13.88812	8.020816
	100000	6.567208	15.16424	8.492703
10	60000	4.666932	10.23203	6.666849
	70000	5.17751	11.41364	7.109912
	80000	5.663074	12.63518	7.559987
	90000	6.127075	13.88812	8.020011
	100000	6.56666	15.16424	8.492024
14	60000	4.667214	10.23203	6.666849
	70000	5.177819	11.41364	7.109912
	80000	5.663412	12.63518	7.560948
	90000	6.127438	13.88812	8.020816
	100000	6.567042	15.16424	8.492703
18	60000	4.668593	10.23164	6.66825
	70000	5.179336	11.41336	7.111068
	80000	5.66507	12.63477	7.560948
	90000	6.129213	13.88766	8.021621
	100000	6.568913	15.16364	8.493381
22	60000	4.668593	10.23397	6.66825
	70000	5.179336	11.41643	7.111068
	80000	5.66507	12.63847	7.561909
	90000	6.129213	13.89184	8.022426
	100000	6.568913	15.16841	8.494058

CONCLUSIONS

It was discovered that, when the geometric shape of the inner polearm of a bipolar lens with different densities was changed, there was no appreciable change in the lenses proposed in the research, but there was a very slight change that was shown in the tables and the illustrative drawings for the purpose of clarifying the changes. This adjustment will be made in accordance with the researcher's objectives, goals, and any necessary intensity.

ACKNOWLEDGMENTS

I thank Dr. Rafea Younes and Dr. Hana Essa, the supervisors of this work, as well as the head of the Physics Department at the Faculty of Science, University of Tikrit, Dr. Yassin Hamid. I also thank Mr. Mohammad Kurdi for his assistance.

REFERENCES

[1] Egerton, R.F. (2005) Physical Principle of Electron Microscopy. Springer: ISBN. https://doi.org/10.1007/b136495

[2] Melnikov, A.A. and Potapkin O.D. (2008), On Electron Movement through Magnetic Electron Lens. Physics Procedia 1, 207-215. https://doi.org/10.1016/j.phpro.2008.07.098

[3] Harald, H.R. (2008) Geometrical Charged-Particle Optics. Springer-Verlag, Berlin.

[4] Mulvey, T. and Newman , C.D. (1974)New Experimental Lens Designs for High Voltage Electron Microscopes. High voltage electron microscopy, ed. P. R .Swan , C.J. Humbherys and M.J. Goringe , pp.98-102. Academic: London. https://doi.org/10.1111/j.1365-2818.1974.tb03984.x

[5] Ruska, E. (1980) The Early Development of Electron Lenses and Electron Microscopy. Hirzel Verlag, Stuttgart.

[6] Grunberg, G.A. (1948) Selected Problems of Mathematical Theory of Electric and Magnetic Phenomena. A. N. USSS in Russian.

[7] Lencova B. (2001) Recent Development in Methods for Electron Optical Computation Microscopy. Barcelona 93, 432-439. https://doi.org/10.1016/S0248-4900(01)01155-8

[8] El-Kareh , A. B. and El-Kareh , J. C. J. (1970)Electron Beams Lenses and Optics. Vol. 1 and 2, Academic Press: New York and London. https://doi.org/10.1016/B978-0-12-238001-3.50005-X

[9] Electromagnetic lenses can be classified according to the number of their poles, the monopolar lens, the bipolar lens, also called the same double pole, and the tripolar lens, and there is another type called iron-free lenses.

[10] Hussein,S.H. (2012)," A Computer Aided Designing Tools for Electron Liebmann , G. and Grad, E.M. proc. phys. soc. B64, pp. 956 - 971, (1951). https://doi.org/10.1088/0370-1301/64/11/304

[11] Hussein,S.H. (2012)," A Computer Aided Designing Tools for Electron.

[12] R.AL-Salah A. Al-Abdulla and E. Alkattan , "Simple program for computing objective optical properties of magnetic lenses", International Journal of Computer Applications in Technology, vol.66, no.3-4, pp254-259, January.2022. https://doi.org/10.1504/IJCAT.2021.10044336

[13] Lencova and J. Zlamal, (2009)," Electron Optical Design Program " Czech Republic.

[14] Talib M. Abbas, Qutaba Alsahi, (2017), "Design and study of optical properties of symmetrical electromagnetic dipole lenses using (EOD) program", Babylon, Iraq. (In Arabic).

[15] Najwan.H.Numman,(2018) ,"Theoretical study of properties and aberrations in dipole magnetic lenses" ,Almostansiriyah ,Bagdad ,Iraq.

[16] Zena.H.Edan and Talib.M.Abbas ,(2022),"Study computer-aided design of free rotation and distortion dipole electromagnetic lenses" ,Babylon ,Iraq. https://doi.org/10.1016/j.matpr.2021.06.346

[17] Basma F. Abd alghane, Ahmad k. Ahmad, (2021) , "Design of symmetrical magnetic lenses with optimum operational condition", Al-Nahrain ,Iraq. https://doi.org/10.22401/ANJS.24.1.06

[18] Muhammad Al-Jubouri and Mardin Jihad, (2022), "Design and manufacture of the objective magnetic lens used in the scanning electron microscope and the study of its optical properties", Kirkuk, Iraq (in Arabic).

[19] Yaqoub, Yaqoub Aziz and Hassoun, Abbas Muhammad, (1979), Optics, College of Science / University of Baghdad, p. 117.

[20] Goodhew, P. J. (1975), Electron Microcopy and Analysis, Wykeham Science Series.

[21] Yassin, Muhammad Jawad, (1995), a computer study of a non-traditional electronic lens with two opposite magnetic fields, PhD thesis / College of Education / Al-Mustansiriya University.

[22] Szilagyi , M., (1988)Electron and lon Optics. Plenum Press: New York and London. https://doi.org/10.1007/978-1-4613-0923-9

[23] Haine, M.E. and Cosslet, V.E., The electron microscope,Spon Ltd. London, (1961). https://doi.org/10.1063/1.3057288

[24] Loretto, M. H. (2012). Electron beam analysis of materials. Springer Science & Business Media.

[25] Qing, J. (2003), "Maskless, resistless ion beam lithography processes ", Ph. D. Thesis, University of Caifornia , Berkeley.

[26] Kimoto, K., Nakamura, K., Aizawa, S., Isakozawa, S., and Matsui, Y. (2007), "Development of dedicated STEM with high stability", J. https://doi.org/10.1093/jmicro/dfl043

How to Cite

R. Y. J. . AL-Salih, H. E. . Jasim, and H. Y. . Ismaeel, “Study of the Effect of the Geometry of the Inner Pole Arm of a Bipolar Lens”, *Al-Mustansiriyah Journal of Science*, vol. 33, no. 3, pp. 87–93, Sep. 2022.