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The Effect of the Iron Arm's Relative Position to the Pole piece Tip Position on the Objective Snorkel Lens Type

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ABSTRACT

The bipolar region is one of the most important factors in determining the effectiveness of a magnetic lens. Regarding the focus and optical qualities of the display devices, the optimal position of the polepiece and the most significant aspect of the magnetic electron lenses were the iron shrouds, where the magnetic field increases smoothly and uniformly with the highest possible value and has just one peak. The goal of this study is to determine the position of the shroud tip relative to the axial axis (Z), where the tip of the polepiece is located at (Z = 0 mm). In practice, it has been seen that the optical properties of electron lenses have improved when the position of the polepiece iron shroud tip is separated by a distance of 180 mm. By extending the distance between the iron shroud and the polepiece face in the opposite direction of the coil, by removing or reducing magnetic flux leakage, it is possible to increase its performance. The axial magnetic field will then rise within the lens in a direction that prevents it from being lost. In this work, the FEMM and MELOP programs were used to investigate the lens' performance, axial magnetic field, and focal optical characteristics.

Keywords: MELOP Program, FEMM Program, Snorkel lens design, Magnetic electron lens.

INTRODUCTION

The electron lens is the most important component of an electron microscope. The three types of electromagnetic lenses are electrostatic lenses, permanent magnetic lenses, and magnetic lenses. The electromagnetic lens is one of the most widely used types of electron lenses due to its ease of operation, accuracy, simplicity in manufacturing, and low cost, in focusing all the charged particles of the emitted beam from a single point in the body plane to a single blurry point (Kadhem *et al*., 2018). Magnetic lenses are devices that produce a strong field within a small space, the differences between which are attributed to the design and nature of the windings, yokes, and rails used to create the field, except for the distance between the poles, the flux in a well-designed lens remains within the region of the coupler or coil, and the gap, generally represented by the distance (S), and bore diameter (D) as they are characteristic of these lenses (Hawkes, 2017).

The development of magnetic lens geometry has been extensively studied, to emphasize the importance of each magnetic lens parameter from a practical and theoretical point of view. Mulvey and Yin(1988) studied the consequences of the air gap on the bore diameter ratio (S/D), Al-Khashab and Abbas (1997), Clever and JRA (1980) investigate the improvement of the polar shape of symmetric bipolar lenses, while Wenxiong (Wenxiong, 1988) examines bipolar lenses. It was discovered that objective lens pillars have a significant effect in reducing spherical and chromatic aberrations (Al-Obaidy,1996). Al-Khashab and Ahmed (2004) studied several approaches to the geometry of the polar segment of the magnetic projector lens and its effect on the magnetic field lines and optical properties of double and single poles. Alamir (2004) studied the chromatic aberration of magnetic lenses. (Al Abdullah and Khashab, 2006) choosing the appropriate coil geometry that improves the performance of a monopolar magnetic lens with a theoretical computational study to improve the performance symmetry. The contributions of (Al Khashab and Hijazi, 2010) have improved the design of magnetic and electrostatic lenses with low aberration coefficients. Modern and advanced electron technology has contributed to the emergence of many improvements in the design of lenses to obtain optical performance and high accuracy in optical properties and lens flux density (Al-Jumayli, 2010) Battat and Al Rubaye, 2012 presented a theoretical study using the electromagnetic lens installation process afterward. Ahmed (2014) studied two types of electronic lenses (compact lenses) to get the best lens fitting. Hijazi and Hussain conducted a detailed study of dual lenses (Hujazie and Hussain., 2014) as well as, and El-Shahat was interested in the optical properties of monopolar magnetic lenses of different shapes (El-Shahat *et al.*, 2016), followed by Abbas and Sahi who studied the objective properties of the asymmetric double pole (Abbas *et al.*, 2017). The lens was shown by a Numan, such as air gap length, magnetic flux density, spherical aberration, etc. (Numan, 2018).

The basic designs of asymmetrical objective lenses that are used in SEM as objective lenses: the first is called a pinhole lens or conical lens, in which the specimen is outside the lens and its magnetic field, and the second contains samples small enough (only several mm) to fit inside the lens called the submersible lens, while the third is the breathing tube of the lens, where the sample is outside the lens but within its magnetic field (Goldstein *et al*., 2003).

The monopolar lens (the recessed lens) was first proposed by Mulvey and Newman in 1973 in a low-voltage SEM, this lens combines the best qualities of pinhole and dip lenses, its magnetic field extends beyond the lens, and reaches the sample(Mulvey and Newman, 1973). Extensive research has been carried out to improve the geometry of magnetic electron lenses with the geometrical dimensions suitable for symmetric dipole lenses (Clever and JRA , 1980) and asymmetric dipole lenses (Wenxiong, 1988).

The best electromagnetic lenses have the largest axial magnetic field value and the narrowest frequency ranges (Hawkes, 1972). As a consequence, stronger magnetic lenses always provide shorter resolution distances, as stated by Al-Obaidi (2020), as well as concluded by Abd Alghane and Ahmad(2021).

High-quality lenses were improved and developed by reducing aberrations and increasing the focus of the lens. In 1982 Mulvey played a role in the improvements of the electron microscope and generated changes in the structures of the single lenses and the shape of the iron shroud represents a real challenge that leads to controlling the amperage (Mulvey,1982). As a result, the iron shroud's purpose is to reduce magnetic flux leakage at the same time, the lens' stray field is reduced and concentrates the magnetic force in a gap near the surface of the pole. This topic was followed up by Al-Khashab and Abbas (1991) for improving the shape of the pole then this challenge was applied and described by Al- Abdullah (1997), The design of two images for the geometry of asymmetric magnetic objective lenses was studied by Al-Khashab and Al-Shamma (2019), these two images are known as the pinhole lens and the countersunk lens. In the asymmetric magnetic lens, the base electrode structure and the geometry of the iron arm are improved, and electron microscope lenses with extremely high resolving powers can be developed using a condensed objective lens. Where Al-Khashab and Al-Khalidi were carried out due to their significance in establishing the optical properties of the magnetic lens (Al-Khashab and Al-Khalidi, 2018). Electronic lens design cannot be completed without relying on an electronic calculator. Under the carnival of electronic development, it became possible to know and calculate the magnetic or electric field of any proposed lens, as well as the possibility of finding its optical properties with extreme accuracy, and determine the properties of the lens and its operation, all of this is done before it is manufactured.

The finite Element Method (FEM) is a numerical technique used in many engineering and physical fields as well as broad scientific fields that require the solution of complex differential equations (Mulvey, 1984).

Snorkel lenses are known to be weak lenses and do not withstand high currents or irritations, but it is possible to improve their performance and eliminate or reduce the effect of magnetic flux leakage by increasing the distance of the iron arm from the electrode face. In this case, the magnetic flux will rush in a direction inside the lens and thus prevent it from getting lost.

In this research work, the research is to find the optimal relative value of the position of the tip of the iron shroud on the axial axis of the magnetic lens.

Design Consideration

The research aims to find the best location of the tip of the iron shroud relative to the optical axis of the diving magnetic lens as the location of the pole tip is seen at (Z = 0 mm). The lens is designed as shown in Fig. (1), the coil has (N = 1043 turns of 20 AWG to withstand I = 4 A) surrounded by an iron circle representing a snorkel-type lens with the dimensions as shown in the figure, a method been used Finite Elements (FEM) in the design of lenses, where the axial magnetic field distribution is calculated, which was used to calculate the properties of magnetic lenses that are used for electron focus beams (Lencová and Zláma, 2008).

The task of the FEMM program is to calculate the axial magnetic field distribution of a magnetic lens, where the axial magnetic field is calculated for some excitation (NI) values.

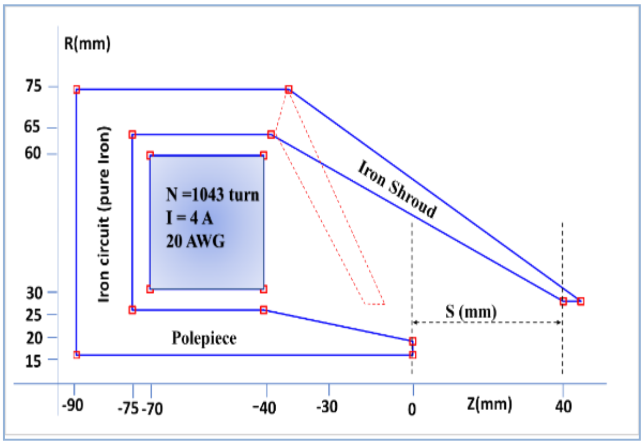

Fig. 1: The design of snorkel lens with its geometrical parameters

RESULT AND DISCUSSIONS

In this study, a Snorkel lens was designed, this type of lenses considered a weak lens, that does not withstand high currents or irritations, but it is possible to overcome its drawbacks by improving its performance and eliminating or reducing the effect of magnetic flux leakage by focusing on the pole area that determines the effectiveness of the lens by increasing the distance of the iron arm from the electrode face. In this case, the magnetic flux will rush in a direction inside the lens and thus prevent it from getting lost. Where the position of the tip of the pole was determined at (Z = 0 mm), while the iron-shroud tip position has been taken from Z= -30 to 200 mm in the optical axis (Z-axis), an improvement in optical properties was observed at 180 mm, the position of the tip of the iron shroud over the location of the magnetic pole, and the axial magnetic field inside the lens increased in a direction that prevents its loss. Thus, we have come to a design that improves the work of this type of lens and helps us to obtain advanced results with possible changes.

The axial Magnetic Field Calculation:

The axial magnetic field distribution (B_z) has been calculated using (FEMM) program (Meeker, 2010) computed at constant (NI = 4172 A-t) and different values of the distance (denoted S) between the iron shroud tip and zero position of the optical axis (Z=0) are equal (S = -30, -20,…….0, 10, 20,……..200) mm as shown in the Fig. (2), this figure shows that the axial field distribution curve has two peaks for each value of S one located at beneath the coil location (Z = -100 to -20 mm it's maximum value named the first peak denoted $B_{1(max)}$, and the other is located inter the polepiece tip and the iron shroud tip named the second peak denoted $B_{2(max)}$, furthermore it has been found that the values of $B_{1(max)}$ drop as the values of S increase, but the values of $B_{2(max)}$ increase as the values of S increase. Fig. (3) shows a comparison between the values of $B_{2(max)}$ and $B_{1(max)}$ with the values of S, this figure shows that the maximum field values of the first peak decrease to its minimum value at S= 180 mm, and the second peak's maximum field value also climbs to its greatest value at S=180 mm. To determine which value of S is the best, the optical properties for each case have been calculated using the program MELOP.

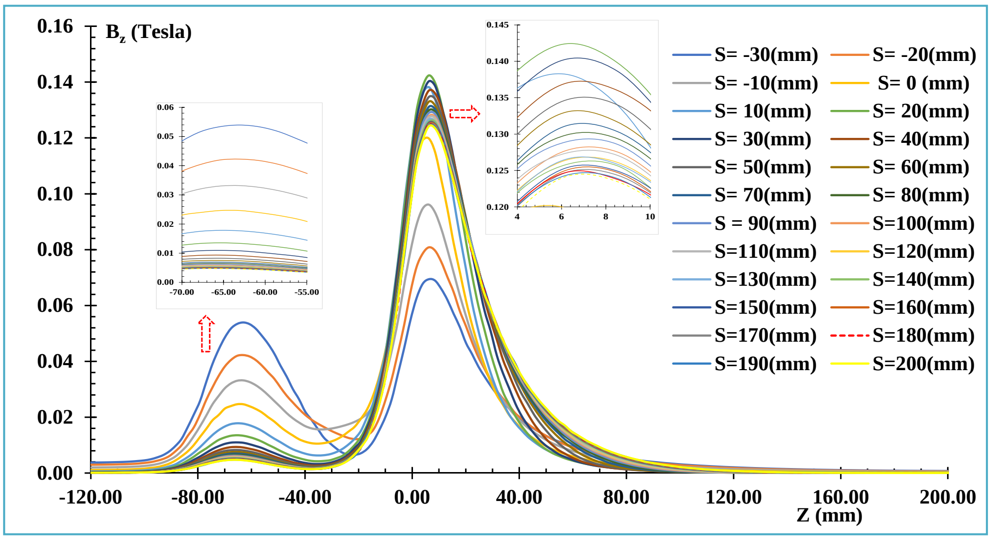

Fig. 2: Comparison of Axial Magnetic field distribution with iron shroud position with respect to the polepiece

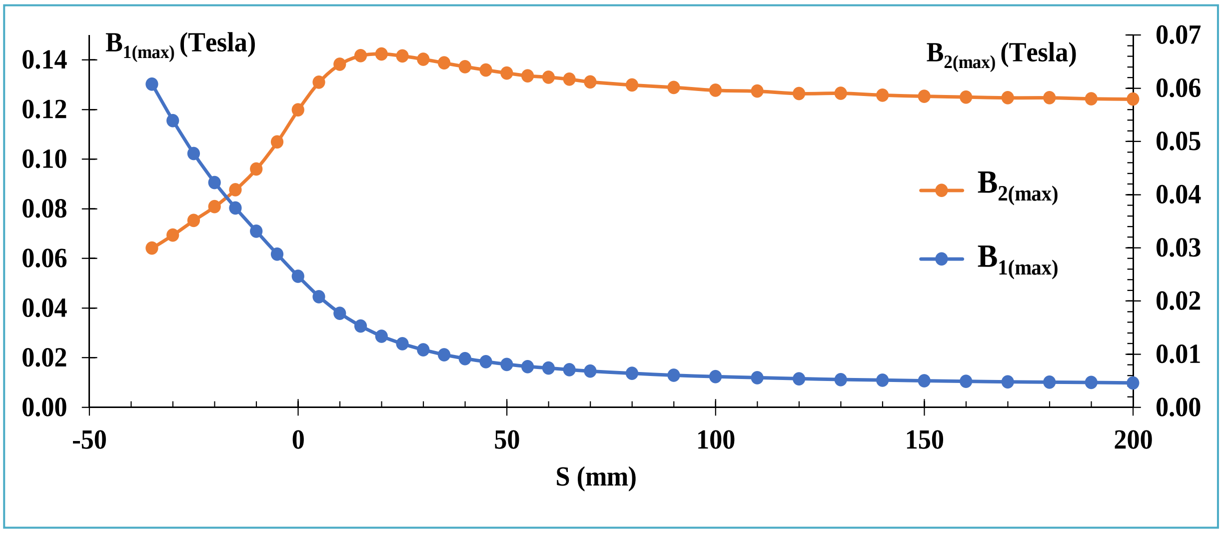

Fig. 3: Comparison between the values of $B_{1(Bmax)}$ for law peak and $B_{2(Bmax)}$ for high beak of the lens at different values of (S), calculated at constant excitation (NI= 4172 A-t).

The Optical Properties Calculation:

Aberration coefficients, in charged particle optics, are one of the main crucial factors that determine the efficiency of optical devices for charged particles. Spherical aberration (C_s), chromatic aberration (C_c) coefficients, and the focal length (f_o) are the main determinants of image quality (Read,1969). These coefficients were determined as a function of relativistic ally corrected accelerating voltage V_r for the rang (1 – 100 kV). Fig. (4) compares the focal (C_s), (C_c), and (f_o) as a function of the accelerating voltage calculated at different values of S, (S= -30, -20, …….0, 10, 20, …… .200) mm, this figure shows that the optical focal properties improved as the values of (S) increase, with the best performance at (S = 180mm), where the optical focal properties have the most desirable staple continuous curves.

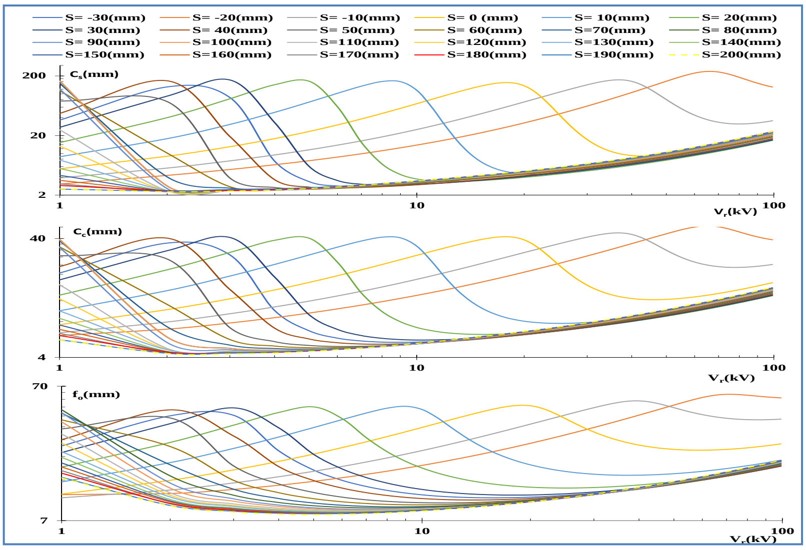

Fig. 4: Comparison of the values of C_s, C_c an f_o as a function of the accelerating voltage calculated at different values of S.

CONCLUSIONS

In this study, it has been found that the increasing value of the distance between the tips of the polepiece and the iron shroud will improve the field profile, where the undesired field leakage at the coil region has been reduced consequently. The optical focal properties values have been enhanced.

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تأثير الموقع النسبي للذراع الحديدي الى موقع وجه القطب في العدسات الشيئية من نوع سنوركل

الملخص

تعد المنطقة ثنائية القطب من العوامل المهمة في تحديد فعالية العدسة المغناطيسية. فيما يتعلق بالصفات البصرية البؤرية لأجهزة العرض، فإن الموضع الأمثل للقطب هو من أهم الجوانب للعدسات الإلكترونية المغناطيسية ذات الاذرع الحديدية، حيث يزداد المجال المغناطيسي بشكل سلس ومنتظم الى اعلى قيمة وله ذروة واحدة. الأستقصاء (الهدف من التحقيق) هو تحديد موضع الذراع بالنسبة للمحور المحوري (Z)، حيث يقع طرف القطب عند (Z = 0 mm). تبين عمليا أن الصفات البصرية للعدسات الإلكترونية قد تحسنت عندما يكون موضع القطب والذراع منفصلين بمسافة 180 mm. مع توسيع المسافة بين الذراع الحديدي ووجه القطب في الاتجاه المعاكس للملف، عن طريق تقليل تسرب الفيض المغناطيسي، من الممكن زيادة أداء العدسة سيرتفع المجال المغناطيسي المحوري داخل العدسة في الاتجاه الذي يمنع من نقصانه. في هذا العمل، تم استخدام برنامج (FEMM) لحسابات المجال المغناطيسي المحوري وبرنامج (MELOP) لحسابات الخصائص البصرية البؤرية.

الكلمات الدالة: برنامج MELOP، برنامج FEMM، تصميم عدسة الغطس، عدسة الإلكترون المغناطيسي.