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Design of the Objective Magnetic and Electrostatic Lenses for Low Beam Energies

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ABSTRACT

The design of the objective magnetic and electrostatic lenses with low aberration coefficients at low beam energies is of a considerable interest in various fields of electron spectroscopy. The present research work is concerned with intensive studies and calculations on both types of electron lenses (magnetic and electrostatic) in order to obtain the preferable design of a compound lens. An asymmetrical magnetic electron lens has been designed in conical shape geometry.

The study is concerned with a set of asymmetrical two-coaxial overlapping cylinder electrostatic lenses, having different geometries for the outer electrode and length of the electrode gap, respectively. It was found that the geometrical shape of the outer electrode and the length of electrode gap have a clear effect on the electron optical properties of such lenses. It was noticed that the best optical properties occurred when the length of electrode gap (g) equals 5 mm.

The results obtained for the objective magnetic lens and the electrostatic lens for the preferable design were compared with the results of the recent published papers. An improvement in the optical properties obtained by the proposed design was noticed to be improved compared to the published results.

Keywords: Magnetic Lens, Electrostatic Lens, High Performance Objective Lens, Low Beam Energies, High Resolution.

1. INTRODUCTION

A conventional electron microscope, which places great demands on the design and construction of electron lenses, has made a steady progress over years. However, high quality lenses have been developed to produce good quality images. In order to obtain an optimum design, it is necessary to reduce the aberration of the focusing lenses. Lens is still mostly based on trial and error of different electrode geometries and pole piece shape and coil dimensions until an acceptable result is achieved.

The objective lens is considered to be the most critical component in the microscope. Its main objective is for resolving power of the instrument. The reason for this is that it is the only lens in the microscope that contributes significantly to the spherical aberration for the optical system, being the only lens in which the electrons are reasonably steeply inclined to the axis. Due to the same reason, it makes a much larger contribution to the axial chromatic aberration.

The present work tackles the influence of two main kinds of electron lenses (magnetic and electrostatic) on achieving an improved design suitable as an objective lens for low- voltage scanning electron microscope. The magnetic electron lens is an axially symmetric magnetic field which has a focusing effect on an electron beam. An optimum design of a magnetic electron lens with low aberration coefficients is of considerable interest in various fields of electron optics. Intensive studies have been carried out to optimize the geometrical structure and the dimensions of the magnetic electron lenses. The shape and the position of the lens coil were studied by Al-Khashab (Al-Khashab, 1983) and later by Al-Nakeshli and Juma (Al-Nakeshli and Juma, 1985). The optimization of the pole piece shape was studied for asymmetrical single pole piece lens by Al-Khashab and

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Abbas (Al-Khashab and Abbas, 1991).

The resolution of the traditional SEMs During the 1970s at low-voltages (~1kV) was poor. The need for the high resolution and low voltage SEMs is more demanding. Due to these reasons the design of the objective lens, for the low-voltage SEM,in particular becomes more important, since the beginning of the 1980s.

We have designed in the present work and evaluated an asymmetrical magnetic electron lens. It has a conical shape geometry especially was made for low-voltage applications. The specimen for this type of lenses is placed beneath the objective lens in the field-free region. This type of lenses operates at low excitation values.

The electrostatic lenses are widely used to control the beams of charged particles with various energies and control the direction in several fields, especially in the electron spectroscopy. Two-element electrostatic lenses have been used in the low energy electron spectrometers in order to increase the sensitivity and resolution of the image (Kuyatt and Simpson,1967). Coaxial-cylinder electrostatic lenses are mainly used for accelerating or decelerating the electron or the ion beams. Firestein and Vine gave in 1963 useful design criteria for overlapping two cylindrical lenses (Firestein and Vine, 1963). This configuration gives the least spherical aberration in which the cylinder at the high potential has the smallest diameter (Mulvey and Wallington, 1973). More accurate calculation for the electrostatic lens composed of two cylinders of equal diameter was given by Read (Read et al., 1971). The calculation obtained by Read for the double aperture electrostatic lens (Read, 1969) provided the focal properties with wide variety of the lens geometries and voltages, too. Details of the properties for several types of two-element coaxial cylinder electrostatic lenses were found in many references such as (Szilagyi, 1987 ; Hawkes and Kasper, 1996).

It is well known that a simple two-electrode electrostatic lens requires the specification of four geometric parameters (two electrodes thickness, spacing between electrodes, and aperture size). For the above reasons, the production of the universal curves for the electrostatic lenses is not of similar manner as for the magnetic lenses (Lencovà, 1995). The final design would usually be based on trial and error; different electrode shapes and voltages are tried until acceptable results are achieved.

The principal aim of this work is to achieve an improved design for the electron lenses (magnetic and electrostatic) suitable for an objective lens.The first part of the present paper has tackled the influence of the working distance on the electron optical properties of the magnetic lens. The second part of the work is carried out to investigate the effect of the outer electrode geometry and the length of the inner electrode on the performance of the electrostatic lens. In the light of these developments, the paper consider some of those magnetic and electrostatic lenses that appear to have interesting possibilities for present and future analytical equipments.

2. LENS DESIGN CONSIDERATIONS

A- The Magnetic Electron Lens Design Considerations

The asymmetrical magnetic lens denoted by (M1) has a conical shape geometry energized by a coil of area equals (860) mm^2. A numerical calculation method for the electron optical properties was first developed by (Munro, 1975), is based on a differential form in which the whole area is divided into finite elements. The total number of the fine meshes was chosen to be equal to (26x52) meshes in lens design.

The schematic diagram of the cross-section of the lens (M1) is shown in Fig. 1a.The taper angles are selected such that inner pole piece angle (G_1= 65^o) and the outer pole piece angle (G_2= 47^o), as shown in Fig.1b. The air gap between the pole piece is equal ($S=S_2-S_1$= -21 mm). If $S<0$, it means that the lens is an axial gap lens as given by Tsuno (Tsuno et al., 1995). The shape of the pole pieces and the coil geometry were studied by Frosien (Frosien, 1989).The axial magnetic flux density distribution for the lens (M1) was computed by the aid of a program called AMAG (Lencova',1986). The program was modified by (Al-Khashab and Ahmad, 2005). The values of the axial field profile calculated at low excitations [(NI = 500 to 5000) A-t] are illustrated in Fig. 2. It may be noticed that the axial magnetic flux density distribution (B_Z) did not change and had nearly symmetrical shape since D_1 = D_2 and the maximum value of the axial magnetic flux density B_{max} equals to (0.035 Tesla). It is found that the half-width (H.W.) is constant and equals to (9 mm) at all the ranges of excitations.

Furthermore, the research work has been carried out on computing the paraxial ray trajectory R(z) for the electron beam through a purely magnetic lens that enters the lens field parallel to the optical axis at different accelerating voltages (V_r) chosen from (4-10) kV. Fig.3 shows the calculated values of trajectory R (z) together with the magnetic flux density distribution at different accelerating voltages (V_r) as a function of Z. It may be noted that, as (V_r) increases, the focal length (f_M) of the magnetic lens increases, too. The choice of a favorable lens design in an electron microscope depends on its objective focal properties (Mulvey, 1982). The important electron optical properties of an objective lens are the objective focal length f_M, spherical and chromatic aberration coefficients (C_s and C_c) respectively. The working distance (W.D.) is also an important factor, too. Figure 4 illustrates the variation of the relative spherical coefficient (C_s/f_M) and the chromatic aberration coefficients (C_c/f_M) for the magnetic lens M1 (in this work- solid line) along with the excitation parameter compared to those published by Frosien (dotted line). It is noticed that (C_s/f_M) decreases with increasing $NI/V_r^{1/2}$.However, the rate of the values reduces considerably as it exceeds around (14 A-t/$V^{1/2}$). However, on other hand, the variation of (C_c/f_M) with $NI/V_r^{1/2}$ is very small and it becomes nearly independent of the excitation factor. Fig.4 represents the general behavior that is valid for most of the conventional lens designs. The results obtained by lens M1 nearly coincide with those obtained by (Frosien et al., 1989).

Table 1 shows the values of the objective focal properties of the magnetic lens (M1) for zero magnification conditions at NI= 500 A-t as computed by M21. It is clear from the data in table 1 that as the excitation parameter ($NI/V_r^{1/2}$) decreases, all objective focal properties including its working distance increase, accordingly.

The calculated values of the spot diameter (d_p) for the electron probe of the magnetic lens in terms of the final beam voltage V_r at different working distances [(W.D.= 0,4,&12)mm] are shown in Fig.5.The calculation of (d_p) is obtained by using the following relations:

$$d_p = \sqrt{d_c^2 + d_\lambda^2} \quad \text{where} \quad \frac{d_C}{2} = C_C \, \frac{\Delta V}{V_r} \, \alpha$$

and $$d_\lambda = \frac{0.6\,\lambda}{\alpha}$$

for (α=0.016 rad) and (ΔV =1.5 V), respectively. Where, d_c, d_λ are the diameter of least confusion of chromatic aberration and diffraction discs, ΔV is the electron source voltage spread, V_r is relativistically-corrected accelerating voltage, α is angle of convergence of the electron beam and λ is the electron wavelength. It is worth mentioning that the results of this lens are in a good agreement with those published by (Frosien, 1989).

B- The Electrostatic Lens Design Considerations

The investigation of the asymmetrical electrostatic lenses has been carried out throughout two main stages: In the first stage, a set of the asymmetrical two-coaxial electrostatic lenses are designed with an identical length of the inner electrode while different outer electrodes geometry is used to find the preferred design.In the second stage, the effect of the length of the electrode gap on the electron optical properties has been studied for the asymmetrical two-coaxial electrostatic lens which possesses preferred design of an outer electrode geometry that had been already obtained from the first stage.

In order to examine the effect of the outer electrode geometry on the two-coaxial cylinder electrostatic lens designed, the inner (smaller diameter) cylinder which represents the first electrode (I) was chosen of a constant length (L=5mm) and voltage (V_I=8000 Volt), respectively. However the outer (larger diameter) cylinder representing the second electrode (II) was chosen with different shapes and accelerated at different voltages [(V_{II}=100-1000)V]. These lenses are denoted by (E1-E4). Fig.6 shows the geometrical structure and dimensions of the lenses. We notice from the above figure that, the outer electrode shape of E1 was parallel to the optical axis, while in the other suggested lenses, the electrode has become oblique to the optical axis which is just like a conical shape. The calculation of the properties of any electrostatic lens system requires knowing of the axial potential distribution V_z along the whole optical axis. The values of V_z for the electrostatic lenses are computed by the aid of program E11 (Munro, 1975),which is a finite element program for computing scalar potential distributions in electrostatic lenses. The total number of the fine meshes were chosen to be constant for all the lenses (E1-E4) and equal to (17 × 19). Fig. 7 represents the V_z plotted as a function of z for the above lenses. It should be mentioned that, the lens will be locally convergent if the curve of V_z versus z concaves upward and divergent if the curve concaves downward (Grivet, 1972). Therefore, the region from (Z=-3 to 3)mm, which is shown in the previous figure, is called a divergent region. In this region the longitudinal component of the electric field (E_z) accelerates the electrons (making the electrons move faster). Thus, the diverging power diminishes as the divergent action lasts for a shorter time. While the region from (Z=6 to 12) mm is called a convergent region. The longitudinal component (E_z) retards the electrons (making the electrons move more slowly), and hence, the convergent power increases. Thus, the convergent effect always exceeds the divergent effect and the whole lens becomes convergent.

It is important to calculate the trajectory ray R(z) of the electron inside the lenses, in order to investigate the performance of the above lenses. The values of R(z) were computed using the program E21(Munro,1975) which is a program for computing the optical properties of electrostatic lenses by solving the paraxial ray equation while using the fourth order-Runge Kutta formula (Lencovà and Lenc, 1994). Fig. 8 shows the trajectories of the electrons inside the electrostatic lenses (E1-E4) at constant voltages (V_I=8000V) and (V_{II}=100 V). It can be seen from the figure that, the electrons traveling parallel to the optical axis (for zero magnification condition) and entering into the lens system from the left side will be affected by the electrical field (formed by the large voltage difference between the two cylinders), they received an impulse towards the wall of the cylinder (i.e. deflected to the larger radii on the entrance side). As they pass through the field, they will be decelerated (retarded) by decreasing the positive field. Finally, they will again receive an impulse towards the axis of cylinder. Since the axial velocity v_z is low at the exit side, this results in focusing the electron beam (Sampson, 1996). It is clear from Fig.8 that the trajectory of the electrons inside the lens E4 has acquired a minimum value of the position of the image plane (Z_i=11 mm). This gives the minimum value of the working distance which, in turn, gives an acceptable performance for this type of lens in comparison with the other lenses.

The plot of the equipotential lines for the previous mentioned (retarding or decelerating) electrostatic lenses (E1-E4) is important for investigating the effect of the outer electrode geometry. The equipotential lines were calculated by using program E31.This program was introduced by Munro 1975 (Munro, 1975), modified to be run on the personal computer by the present author in 2006, University of Mosul (Abd-Hujazie, 2006). Fig. 9 shows the plot of the equipotential lines for the previous lenses at constant voltages for (V_I = 8000 V) and (V_{II} = 100 V). It is noticed that, the equipotential lines are more converging as in the case of lens E4 compared to those in the other lenses. Therefore, the focusing spot of the electrons is displacing away from the specimen position as we go from E1 to E4.. This behavior is important for producing the way to obtain low voltage reaching the specimen surface. This is one of the important parameters in order to protect the specimen from damage. In order to compare the performance of the electrostatic lenses, a systematic search has been carried out on the effect of the outer electrode geometry for the electron optical properties. The data of the axial potential distributions were used to calculate the electron optical properties for the above lenses by means of program E21.

Table 2 summarizes the electron optical properties (C_s, C_c, f_E) and the positions of the image plane (Z_i) by varying the immersion ratio (V_I/V_{II}) that determines the power of the electrostatic lens between (8-80) for each electrostatic lenses (E1-E4). It observed from the data in the table that, when the immersion ratio (V_I/V_{II}) increases (by lowering the voltage (V_{II}) of the outer electrode (II)) the focal length (f_E) for each lens decreases and the position of the image plane (Z_i) becomes closer to the inner electrode (I). This means that, the ability for the lenses to converge the electrons beam increases as f_E decreases. That is because the convergent power is inversely proportional to f_E and consequently decrease the working distance which decreases the values of C_s and C_c. The results in Table 2 indicate that lens E4 has relatively lower electron optical properties compared to the other lenses. Therefore, lens E4 can be regarded as the best design within the set of the lenses (E1-E4). In order to demonstrate the influence of the length of the electrode gap (g) on the performance of the electrostatic lens (E4), the length of the gap (g) was chosen to be equals to 5, 3 and 1 mm, respectively.

Based on varying the electrode gap (g) another new set of the asymmetrical electrostatic lenses are taken into consideration for which they have different length of the electrode gap (g). These lenses are denoted by E41, E42 & E43 as shown in Fig. 10. The preferred outer electrode geometry in the asymmetrical two-coaxial cylinder electrostatic lenses in this research work has been effectively achieved in the case of lens E4, as obtained from the previous stage (see Table 2). Fig. 11 shows the axial potential distribution for the lenses. It shows that the half-width (H.W.) of the potential distribution decreases as the length of the electrode gap (g) increases (i.e. when the inner electrode (I) becomes far from the specimen). Other trials for the gap dimensions were performed and yielded the fact that the design lens E41 produces the best electron optical properties. It is important to calculate the trajectories of the electrons inside the electrostatic lenses (E41, E42 & E43) in order to compare the performance of these lenses. The trajectories ray R(z) of the above asymmetrical electrostatic lenses are calculated using a subroutine (RAY FE) present in the main program E21. Fig. 12 shows the trajectories ray R(z) for the electrons inside the above lenses as a function of (Z) calculated at constant voltages (V_I = 8000 V) and (V_{II} = 100 V). It is noticed from this figure that, as the length of the electrode gap (g) increases the trajectories ray R(z), increases moves back to intercept with the axis at a point (Z_i) far away from the specimen position. In other words, when the electrode gap (g) increases, the working distance (W.D.) decreases. It is noticed that there is a linear relation between both of them as shown in Table 3. This is in turns will give better results in spherical and chromatic aberration coefficients.

A systematic investigation has been carried out on the effect of the length of the electrode gap (g) on the electron optical properties in order to obtain the performance of the asymmetrical electrostatic lenses (E41, E42 and E43). The electron optical properties of these lenses were calculated by using E21. Table 4 gives a comparison between the electron optical properties (C_s, C_c and f_E) of the lenses at constant voltages (V_I = 8000 V) and (V_{II} = 100 V). It is important to point out that there is a progressive development in the electron optical properties for these lenses. Moreover, Table 4 shows that lens E41 has relatively lower electron optical properties values in comparison with those of the other lenses. Thus, lens E41 can be regarded as the best or preferable one in this set of lenses. Each type of the previous preferable magnetic and electrostatic lenses are suggested to be used as a compound lens model for future works.

3. CONCLUSIONS

The first conclusion from the previous analysis is that, asymmetrical magnetic lenses (axial gap lenses) that are having different shapes and areas of energizing coil posses no significant effect on the objective focal properties, especially at low excitation energy,since the shape of the axial magnetic flux density distribution and its half-width did not vary. One of the advantages of using this type of lenses is that, it possesses a relatively low chromatic aberration coefficient, which stays almost constant over a wide range of working distance.

The second conclusion is related to the asymmetrical two-coaxial overlapping cylinder electrostatic lenses, the geometrical shape of the outer electrode and the length of the electrode gap of an asymmetrical two-coaxial cylinder electrostatic lenses have a great influence effect on the axial potential distribution and on the electron optical properties of such lenses. The best electron optical properties occur when the length of the electrode gap is equal to (5 mm) and the outer electrode has a conical shape in the form of the cup instead of the parallel shape.

Table1. The objective focal properties of the magnetic lens (M1) for zero magnification conditions at NI = 500 A-t.

Excitation Parameter $NI/V_r^{1/2}$	Image Plane Z_i(mm)	Principal Plane Z_p (mm)	Focal Length f_M(mm)	Spherical Aberration C_s (mm)	Chromatic Aberration C_c (mm)
7.94	**0.34**	**- 17.42**	**17.76**	**32.28**	**14.91**
6.48	**7.64**	**- 16.95**	**24.59**	**76.02**	**21.61**
5.61	**14.80**	**- 16.72**	**31.52**	**149.7**	**28.48**
5.02	**21.90**	**- 16.59**	**38.49**	**261.28**	**35.42**

Table 2. The electron optical properties of the electrostatic lenses for zero magnification conditions, at constant voltages (V_I = 8000 V) and [(V_{II} = 1000-100) Volt] are given with respect to the voltage of the outer electrode V_{II} and immersion ratio (V_I/V_{II}).

Voltage of the outer electrode V_{II} (Volt)	Lens E1				Lens E2				Lens E3				Lens E4			
	C_s (mm)	C_c (mm)	f_E (mm)	Z_i (mm)	C_s (mm)	C_c (mm)	f_E (mm)	Z_i (mm)	C_s (mm)	C_c (mm)	f_E (mm)	Z_i (mm)	C_s (mm)	C_c (mm)	f_E (mm)	Z_i (mm)
1000	3687	48.4	36.5	53.7	45.6	9.6	8.9	19.7	15.1	6.19	5.0	13.9	13.3	6.06	4.6	12.6
500	7938	35.5	30.7	47.6	27.3	5.9	6.8	17.8	7.1	3.32	3.7	12.8	6.3	3.18	3.4	11.8
200	25392	19.3	21.1	36.7	19.1	2.9	4.5	15.6	2.4	1.30	2.4	11.97	3.5	1.86	2.7	11.4
100	57520	11.9	15.1	29.7	19.7	1.7	3.2	14.4	0.97	0.56	1.71	11.7	0.84	0.41	1.6	11.03

Table 3. The variation of the length electrode gap (g) as a function of the position of the image plane Z_i for the electrostatic lenses.

Lens	g (mm)	Z_i (mm)
E41	5	10.04
E42	3	11.03
E43	1	11.97

Table 4. Comparison between the values of C_s, C_c and f_E for the lenses at constant voltages (V_I=8000V) and (V_{II} = 100).

Lens	C_s (mm)	C_c (mm)	f_E (mm)
E41	0.77	0.35	1.74
E42	0.84	0.41	1.59
E43	1.09	0.6	1.64

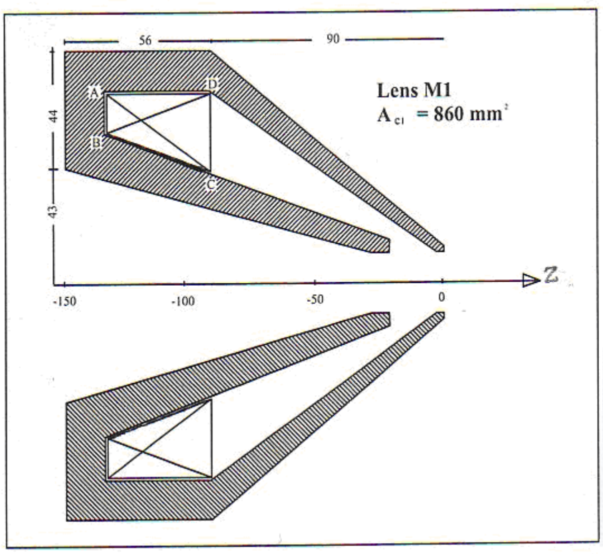

Fig. 1a. The schematic diagram of the asymmetrical magnetic lens M1 energized by co il of 860 mm^2 area.

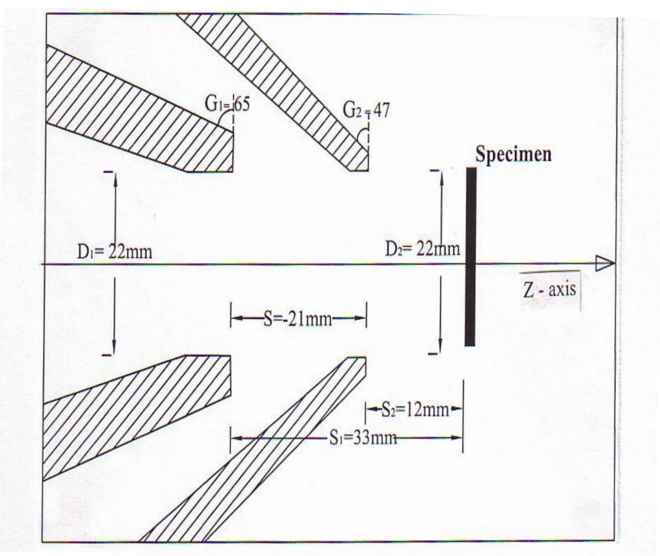

Fig. 1b. The schematic diagram of shape parameters of the magnified polepiece region for the lenses shown in Figure (1a).

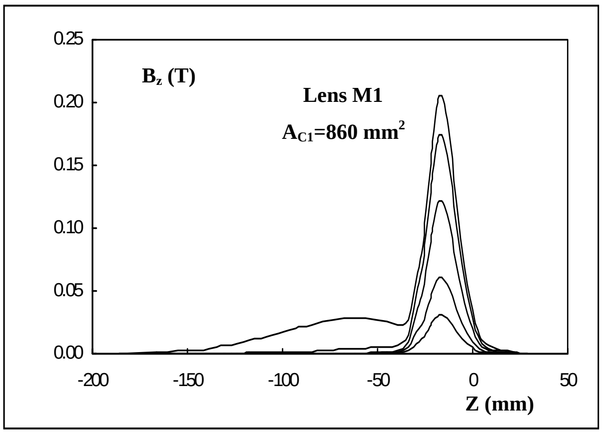

Fig. 2.The axial magnetic flux density distribution (B_z) of the asymmetrical lens (M1) as a function of Z calculated at excitations NI equal to[(500, 1000, 2000, 3000 & 5000) A-t].

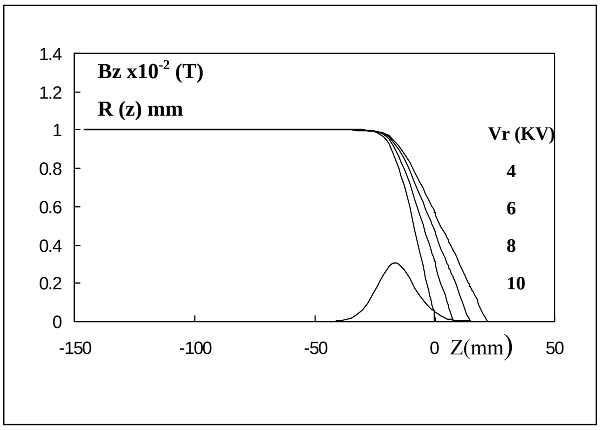

Fig. 3. The paraxial trajectory R(z) of the electron in the magnetic lens M1, and the corresponding axial magnetic flux density distribution B_z at the different values of relativistically-corrected accelerating voltages V_r equal to [(4, 6 , 8 & 10)KV] as a function of distance(Z) calculated at a constant excitation (NI=500 A-t) .

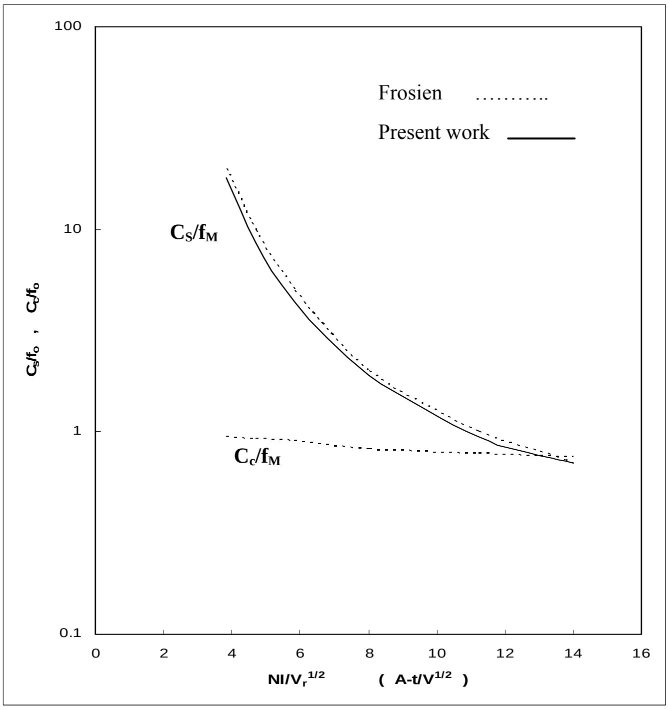

Fig. 4. Variation of the relative spherical and chromatic aberration coefficients (C_s/f_M & C_c/f_M) as a function of the excitation parameter ($NI/V_r^{1/2}$) . Note Frosien's (1989) result has been added for comparison purposes.

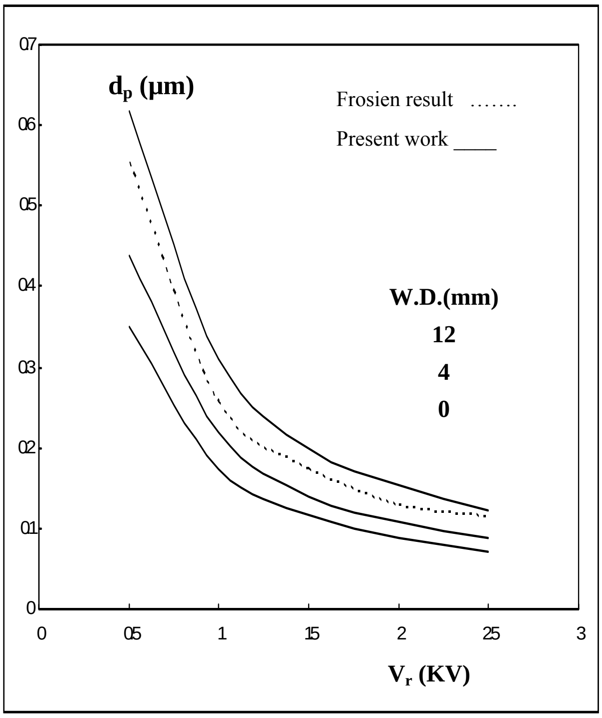

Fig. 5. The spot diameter of probe (d_p) as a function of the relativistically – corrected beam voltage V_r at different working distance [(W.D.=(0, 4 & 12) mm]. Note Frosien's (1989) results have been added for comparison purposes.

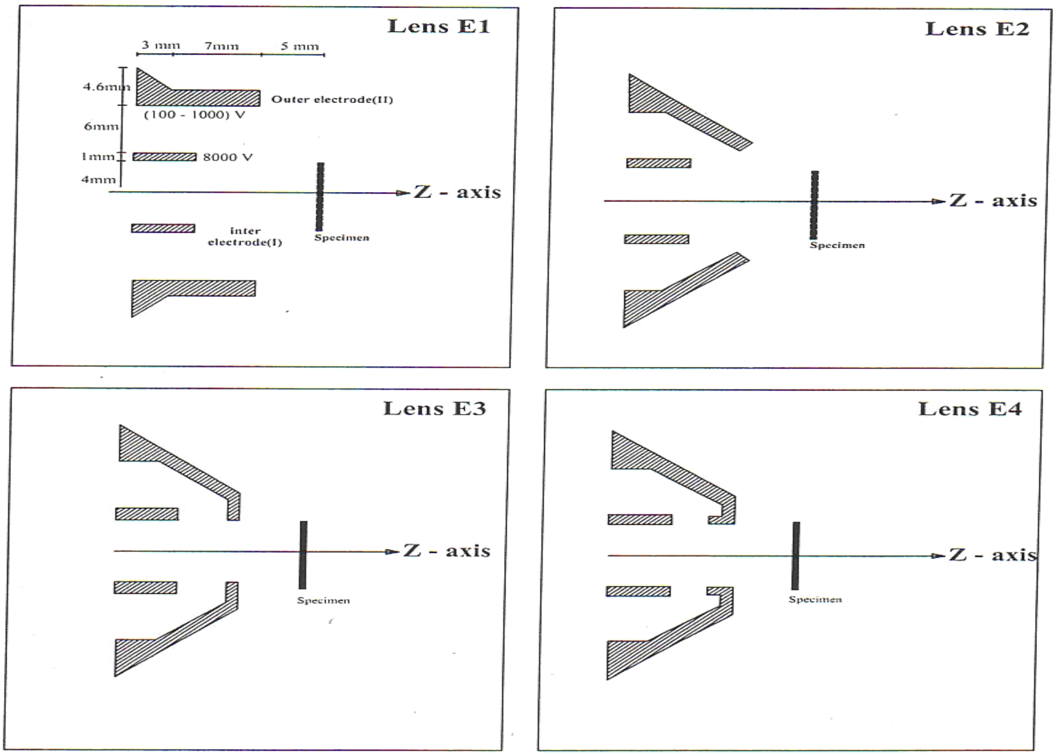

Fig. 6.The cross-section of the asymmetrical two-coaxial cylinders electrostatic lenses having different shapes of the outer electrode (II) shows the voltages of the inner(I) and outer(II) electrodes.

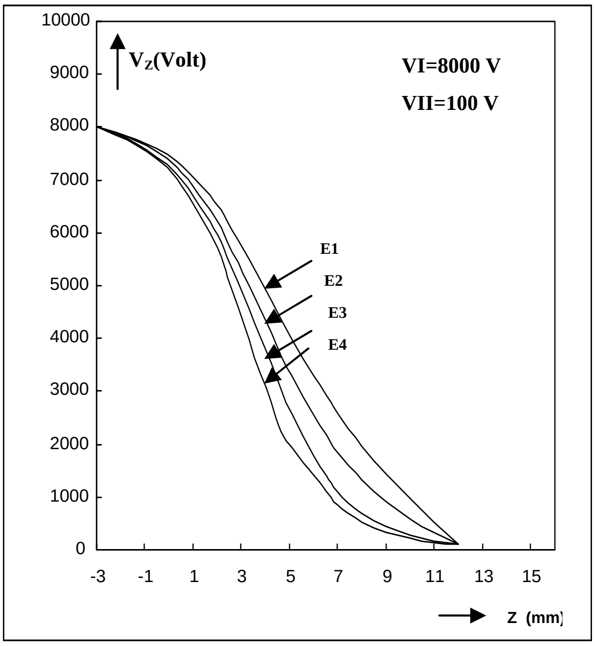

Fig.7. The axial potential distribution of the electrostatic lenses. The length of the electrode (I) is equal to 5 mm.

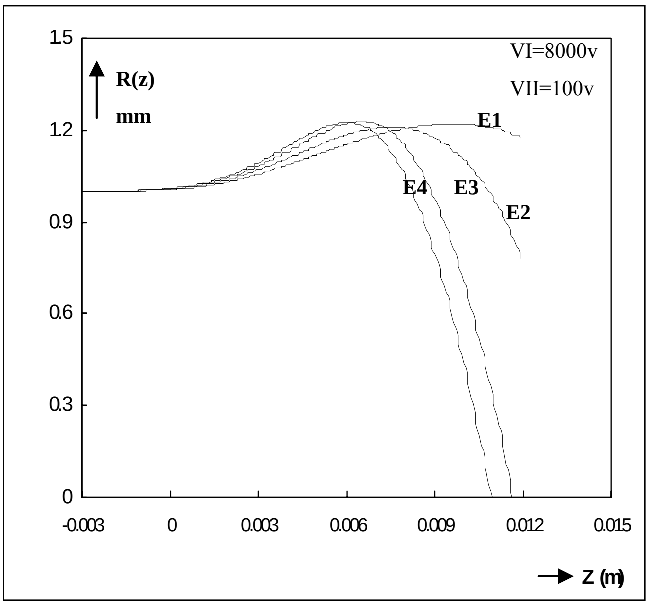

Fig.8. The trajectories of the electron inside the electrostatic lenses. The length of the electrode (I) is equal to 5 mm.

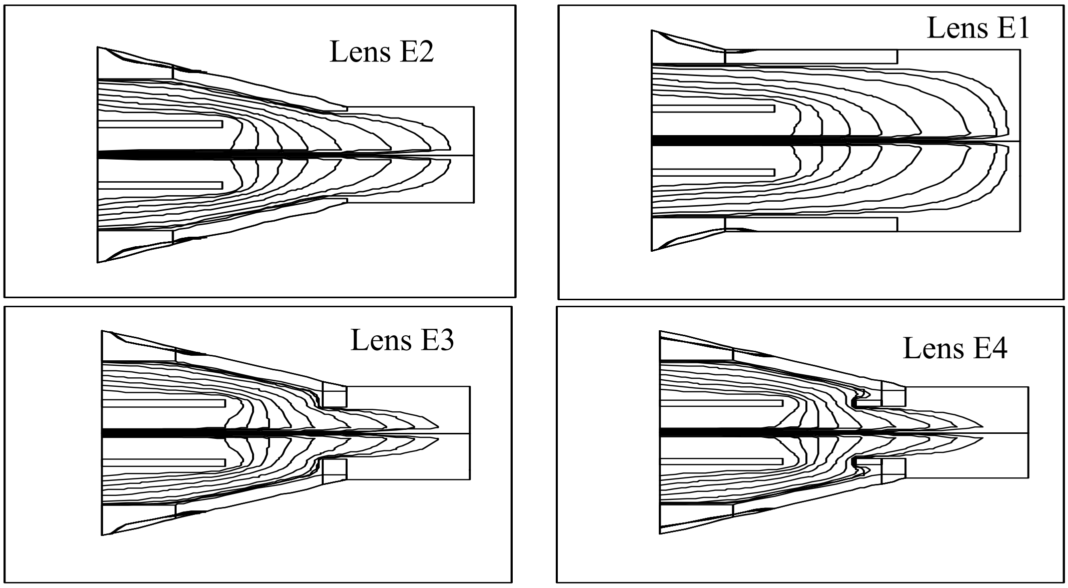

Fig. 9. The equipotential lines of the electrostatic lenses at the constant voltagesV_I-8000 V;V_{II}=100 V) for all lenses .The length of the inner electrode is equal 5mm.

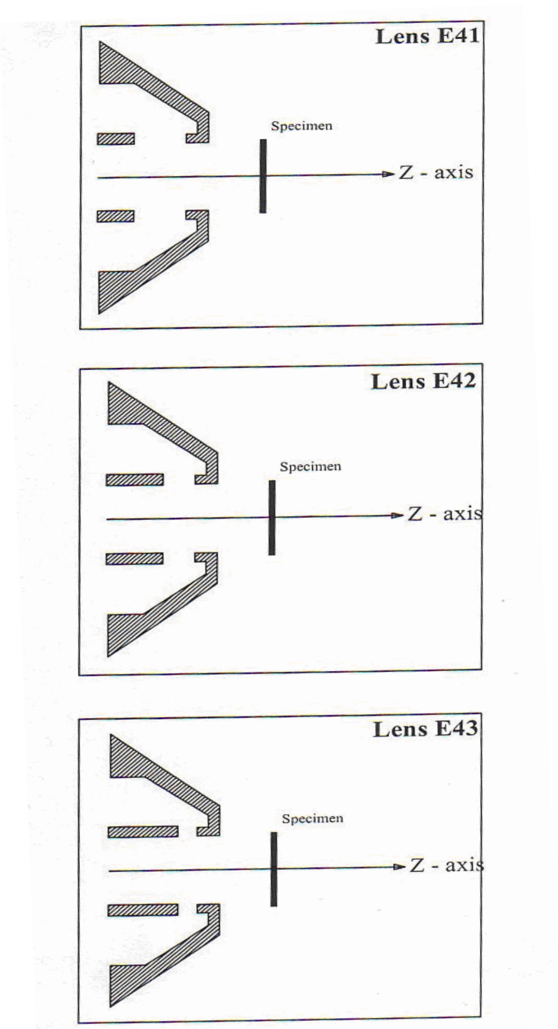

Fig. 10. The cross-section of the asymmetrical two-coaxial cylinder electrostatic lenses having different lengths of the electrode gap (g) .

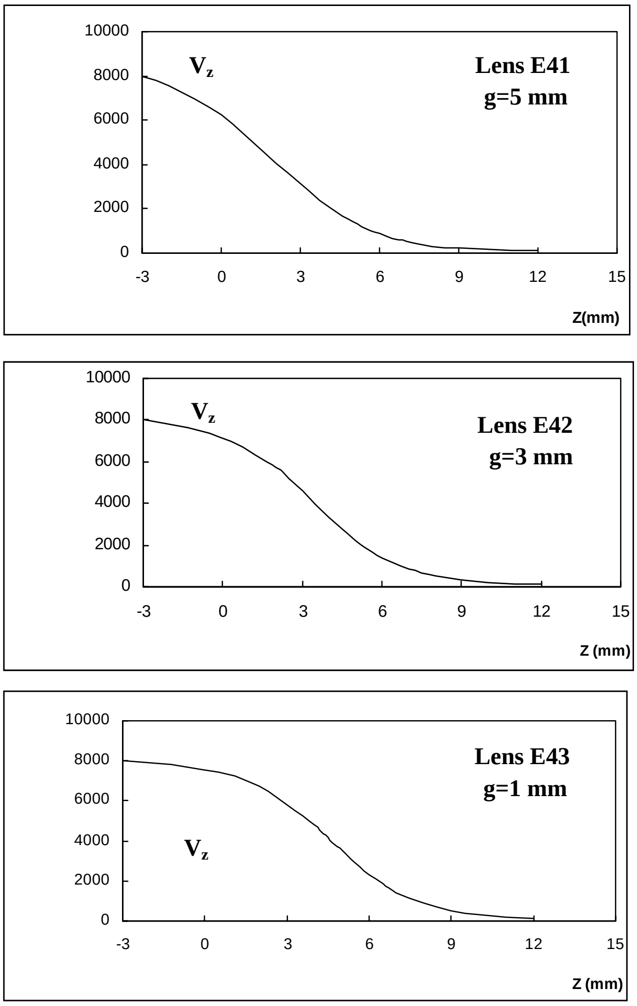

Fig. 11. The axial potential distribution for lenses (E41, E42 and E43) 100 V) for different lengths of the electrode gap (5mm, 3mm & 1mm)at constant voltage of (V_I=8000 V) & (V_{II}=100 V) .

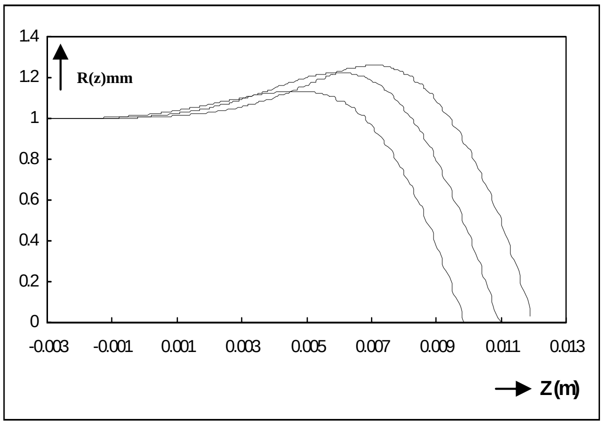

Fig. 12. The trajectories of the electrons inside the electrostatic lenses at a constant voltage (V_I = 8000 V) and (V_{II} = 100 V) .

REFERENCES

Abd-Hujazie, N.S. 2006. *Design of a compound lens (magnetic- electrostatic) for low voltage scanning electron microscope*, ph.D.Thesis, The University of Mosul, Iraq.

Al-Khashab, M.A. 1983. *The electron optical limits of performance of single-pole piece magnetic electron lenses*, Ph.D. Thesis, The University of Aston in Birmingham, UK.

Al-Khashab, M.A. and Abbas, I. K. 1991. Optimized pole piece shape for single pole piece magnetic electron lenses", *Modeling, Simulation and Control*, A. AMSE Press, 35 (3): 1-9.

Al-Khashab, M.A. and Ahmad, A. A. H. 2005. Designing a Doublet Lens of Optimized Pole piece Angle", *Dirasat, Pure Sciences*, 32(2): 182-187.

Al-Nakeshli, I. and Juma, S. 1985. Computation on the electron optical parameters of saturated objective lenses, Electron Microscopy and Analysis, Inst. *Phys.Conf.Ser*. (78): 125-128.

Firestein, F. and Vine, J. 1963. *Br.J.Appl.Phys*., 14: 449-455.

Frosien, J., Plies, E., Anger, K. 1989. Compound magnetic and electrostatic lenses for low-voltage applications, *J. Vac. Sci. Technol*. B7 (6) 1874-1877.

Grivet, P. 1972. Electron optics, Part (1) translated by Hawkes, P. W., Pergamon Press Oxford, 2nd English edition.

Hawkes, P. W. and Kasper, E. 1996. *Principle of Electron Optics*, Academic Press, London.

Kuyatt, C.J. and Simpson, J.A. 1967. Electron Monochromator Design, *Rev.Sci.Instrum*. 38, 103-111.

Lencovà, B. 1986. Program AMAG for computation of vector potential in rotationally symmetric magnetic electron lenses by FEM, *Inst. Sci. Brno, Czechoslovakia*, 1-58.

Lencovà, B. 1995. Computation of electrostatic lenses and multipoles by the first order finite element method", Nuclear Instruments and Methods in Phys. Research Section A, 1-8.

Lencovà, B. and Lenc, M. 1994. Computation of properties of electrostatic lenses, *Optik*, 97(3): 121-126.

Mulvey, T. 1982. Unconventional lens design, in Magnetic Electron Lenses, P. W. Hawkes, Ed., Springer-Verlag,Berlin, 359-420.

Mulvey, T. and Wallington, M. J. 1973, Electron Lenses, In: *Reports on Progress in Physics*, 36 (4): 349-416.

Munro, E. 1975. A set of computer programs for calculating the properties of electron lenses, Cambridge University, Eng., Dept., Report CUED/B-ELECT/TR 45.

Read, F.H. 1969. Accurate calculations of double-aperture electrostatic immersion lenses, *J. Sci. Instrum*., 2:165-169.

Read, F. H. Adams, A. and Soto-Montiel, J. R. 1971. Electrostatic Cylinder Lenses, I: two element lenses, *J. Phys. E: Sci.Instrum*, 4(9): 625-632.

Sampson, A. R. 1996. Scanning electron microscopy, Advanced Research Systems. Section 2. Electron Optics.

Szilagyi, M. 1987. A systematic analysis of two-electrode electrostatic lenses, IEEE-Trans. Electron Device, ED-34, 1848-1858.

Tsuno, K., Handa, N. and Matsumoto, S. 1995. Immersion lenses for low voltage SEM and LEEM, SPIE Charged-Particle Optics, 2522, 243-252.

تصميم العدسات المغناطيسية والكهروستاتيكية الشيئية للحزم ذات الطاقات المتدنية

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ملخـص

إن تصميم العدسات المغناطيسية والكهروستاتيكية الشيئية التي تمتلك معاملات زيوغ قليلة عند الطاقات المتدنية يعتبر من المواضيع التي تحظى باهتمام كبير في مختلف مجالات مطيافية الإلكترون.

يتضمن البحث الحالي دراسات مكثفة وحسابات لكلا النوعين من العدسات الالكترونية (المغناطيسية والكهروستاتيكية) للحصول على أفضل تصميم للعدسة المركبة.

لقد تم تصميم عدسة مغناطيسية لا متناظرة ذات شكل هندسي مخروطي. كما تم إجراء دراسات أخرى تضمنت مجموعة من العدسات الكهروستاتيكية اللامتناظرة مكونة من اسطوانتين متراكبتين ومتحدتين في المحور وذات شكل هندسي متغير لقطبها الداخلي. وجد أن الشكل الهندسي للقطب الخارجي بالإضافة إلى طول قطبها الداخلي لهما تأثير واضح على الخواص البصرية الالكترونية لمثل هذه العدسات.لقد لوحظ أن أفضل خصائص بصرية الكترونية تحققت عند طول فجوة (و) مساويا لـ (5 ملم).

لقد تمت مقارنة الخواص البؤرية للعدسات المغناطيسية والكهروستاتيكية لأفضل تصميم تم اقتراحه في البحث الحالي وتمت مقارنته مع نتائج البحوث المتوافرة حديثا حيث وجد أنها متفقة إلى حد ما.

الكلمات الدالة: العدسة المغناطيسية، العدسة الكهروستاتيكية، العدسة الشيئية ذات الأداء العالي، طاقات الحزمة المنخفضة والتحليل العالي.

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