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Effect of Magnetic Lens on the Efficiency of Magnetic Deflection System

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Abstract

The effect of operation condition of the magnetic lens on the efficiency of the magnetic deflection system, which is consist of the magnetic lens and magnetic deflector was investigated. The relation between the value of the applied magnetic field on the magnetic lens and the properties of the out electron beam was studied. For a more accurate understanding to the relation for both of electron beam dimensions and the kinetic energy distribution were calculated for different values of applied magnetic field of lens. The results showed that the increasing of the magnetic field of the magnetic lens by 0.02 T led to enhancement in the dimensions of the electron beam at image plan by 20% for Δy and 66% for Δz, in comparison between the applied magnetic field of B = 0.015 T and B = 0.035 T. Also the results clearly show the importance of adding a magnetic lens to the magnetic deflector to form on integrated and effective magnetic deflection system, where the beam dimensions were reduced by 40% for Δy and 70% for Δz, where comparing the presence of a magnetic lens with magnetic field of 0.035 T. The addition of magnetic lens to the magnetic deflector maintained a stable distribution of kinetic energy of electron beam, where the distribution was stable in the presence and absence of the lens. Also despite the change of the applied magnetic field on the lens to improve the beam dimensions. The kinetic energy distribution remained stable for all cases of change, and the loss of kinetic energy is very small and can be neglected. The results showed that the effect of the systems behavior in the presence of the lens is not affected by the characteristics of the electron beam, the characteristic of the electron beam source were changed by taking different initial angles, but the systems behavior and efficiency remained the same.

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1. Introduction

The manipulation of charged particles—electrons, protons, ions—through electric and magnetic fields is a primary focus of charged-particle dynamics, or charged-particle optics. What charged-particle optics is concerned with is the ability to analyze how electromagnetic fields will deflect charged particles. This is a key principle in many fields, including engineering, the physical sciences, and the life sciences, and any technology based on these principles. Millions of high-tech devices use this processing, including: particle accelerators, storage rings, electron microscopes (including the SEM and the TEM), mass spectrometers, magnetrons, nuclear fusion reactors, and medical diagnostic instruments (specifically, radiation diagnostic tools) [1-5]. Magnetic deflection of electrons is the basis for producing visible images in display devices such as cathode-ray tubes, all electron beam instruments, early televisions and some medical imaging devices. In these cases, the electrons must be positioned, and then deflected to create visible images (it is the modulation of intensity during the scanning, where the visibility comes). The issue with the deflection schemes, however, is that they cause defocusing and distortion in many cases; it compromises the clarity of the image [6]. Depending on the arrangement of an electron optical lens system, as well as how the shape and position of a sample, the magnetic field will change the path of the beam and accordingly where electrons are interacting on that target material [7]. electron lenses are capable of addressing several grand challenges of modern accelerator and beam physics [8]. Although both electrostatic and magnetic forces can theoretically be used to produce electron optical lenses, magnetic lenses are the obvious choice for working with fast electrons while the two are completely equivalent from an optical perspective. Photo-electron microscopes and detectors are examples of lower energy applications for electrostatic lenses, whereas cathode ray tubes, particle accelerators, and electron microscopes (SEMs and TEMs) are only a few of the many uses for magnetic lenses [9]. Thus, magnetic lenses are designed with axial symmetry with the primary function of beam focusing. A magnetic system has a finite capacity for focusing by concentrating magnetic flux; the denser, the more capacity for output voltage and performance [10-11]. A prominent role is played by axially symmetric magnetic lenses, particularly in the focusing and imaging of charge particle. One technique for examining lens performance is by utilizing the angle of the beam's trajectory, which provides a measure of how much the magnetic field has acted to deflect from the intended nominal axis [12-14]. Certainly, magnetic fields will change the azimuthal direction of electrons without affecting them in the longitudinal direction (speed, kinetic energy) [13]. Common magnetic lens configurations have pole pieces now positioned on a plane perpendicular to the lens axis. Designers generally used pole pieces to limit distortion in an outer fringe field. An intermediate perforated disk between conductors was one idea to minimize fringe field when making a hole for the beam to pass through the pole pieces [15]. There are many lens design aspects affecting lens performance: geometry of the conductors, level of excitation, level of acceleration voltage, operating mode for the beam, and the object to be studied. Common lens configurations will include iron core and iron free coils, and therefore be classified as unipolar, bipolar, and iron free lenses. Unipolar lenses are now seen as an important new development in the field [14-16]. The present work aims to design magnetic deflection system consist of magnetic lens and magnetic deflector, and study the value of improvement in system efficiency that this addition brings about. The effect of the operation condition of the magnetic lens of the behavior and efficiency of the system was studied. To ensure the stability and efficiency of the system behavior in the presence of the lens some of electron beam properties were changed by changing the initial angle of the beam.

2. Materials and Methods

Magnetic deflection system consists of magnetic deflector and magnetic lens was designed to bend electron beam at a 90° angle, where the magnetic lens was added to the deflector to produce the deflection system to focus the beam of electrons. As shown in Figure 1 which display the electron beam basing through magnetic deflector and magnetic lens until hit the screen (image plane), the virtual laboratory in SIMION 8.1 charge particle optics was used to construct the magnetic deflection system. Table 1 provided the system's geometrical dimensions. A number of parameters, such as the size of the electron source and the distance between the electron source and the deflector, are defined by the divergence (or collimation) of the beam of fast electrons propagating inside the deflector. The influence coefficients of the magnetic lens, and its effect on the electron beam, where the effect on the dimensions of electron beam and kinetic energy distribution.

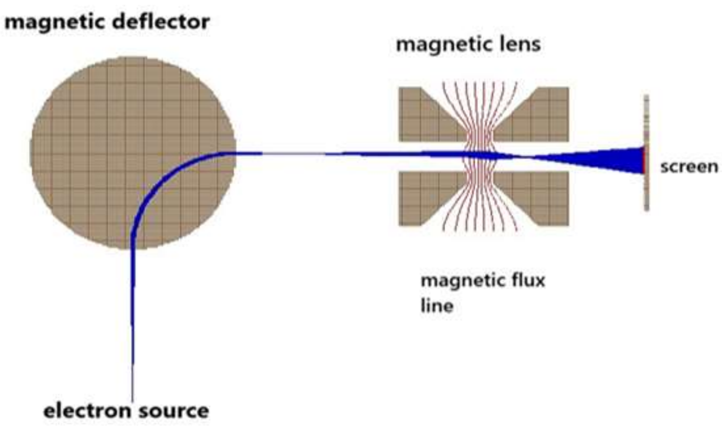

Figure 1: Electron beam passing through the magnetic deflection system.

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Table 1: Geometrical parameters of the deflection system

Distance between the deflector and the magnetic lens	210 mm
Distance between the lens and the screen	120 mm
Distance between the electron source and the deflector	130 mm
Kinetic energy	50 eV

3. Result and discussion

The effect of adding magnetic lens to the magnetic deflector to produce the deflection system was studied, and the effect of the applied magnetic field of the lens on the properties of electron beam was investigated, and the result were shown in figure 2. This figure appears that adding a magnetic lens greatly improves the properties of the electron beam, as the dimensions of the electron beam decreases very clearly, and this improvement increases as the value of magnetic field applied to the lens increases. The figure shows that at fixed kinetic energy 50 KeV and fixed initial angle of electron beam 0.6 ̊, the focusing of lines increase with increasing of the applied magnetic field of magnetic lens and the effect of magnetic lens caused strong focusing on electron beam.

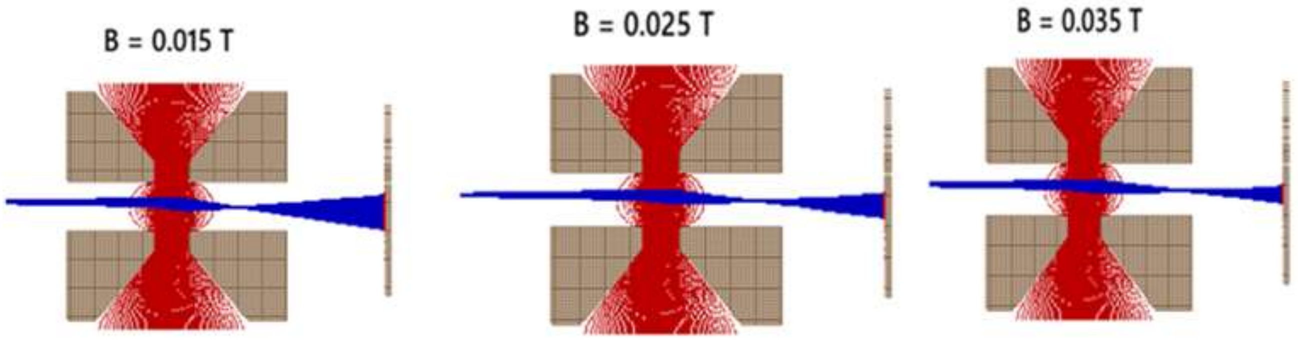

Figure 2: Magnetic lens at different values of the magnetic field at fixed kinetic energy 50 KeV and initial angle 0.6 ̊.

One of the main objectives of this study was finding the impact of altering the lens' magnetic field on the electron beams characteristics. This effect appears on the dimensions of beam, where increasing magnetic field of lens leads to increase the concentration of charge particle as shown in figure 3. One can notice from figure 3, that when the applied magnetic field of the magnetic lens increases leads to an increases the concentration of electron beam, where at high value of magnetic field of magnetic lens B = 0.035 T, give small dimensions of electron beam at the image plane. The applied magnetic field and the dimensions are shown in table 2. From table 2, the results appear that adding the magnetic lens to the deflector significantly improves the systems properties, which is clearly evident in the beam dimensions when comparing the presence and absence of the lens. Comparing the presence of the lens with magnetic field of B= 0.035 T and its absence shows a significant improvement in the beam dimensions, with improvement value reaching 40% for y-direction and 70% for z-direction. Also, the increasing of the applied magnetic field by 0.02 T resulting reduction in the dimensions of beam by 20% for y-direction and 66% for z-direction as evident when comparing the two cases of the applied magnetic field of 0.015 T and 0.035 T.

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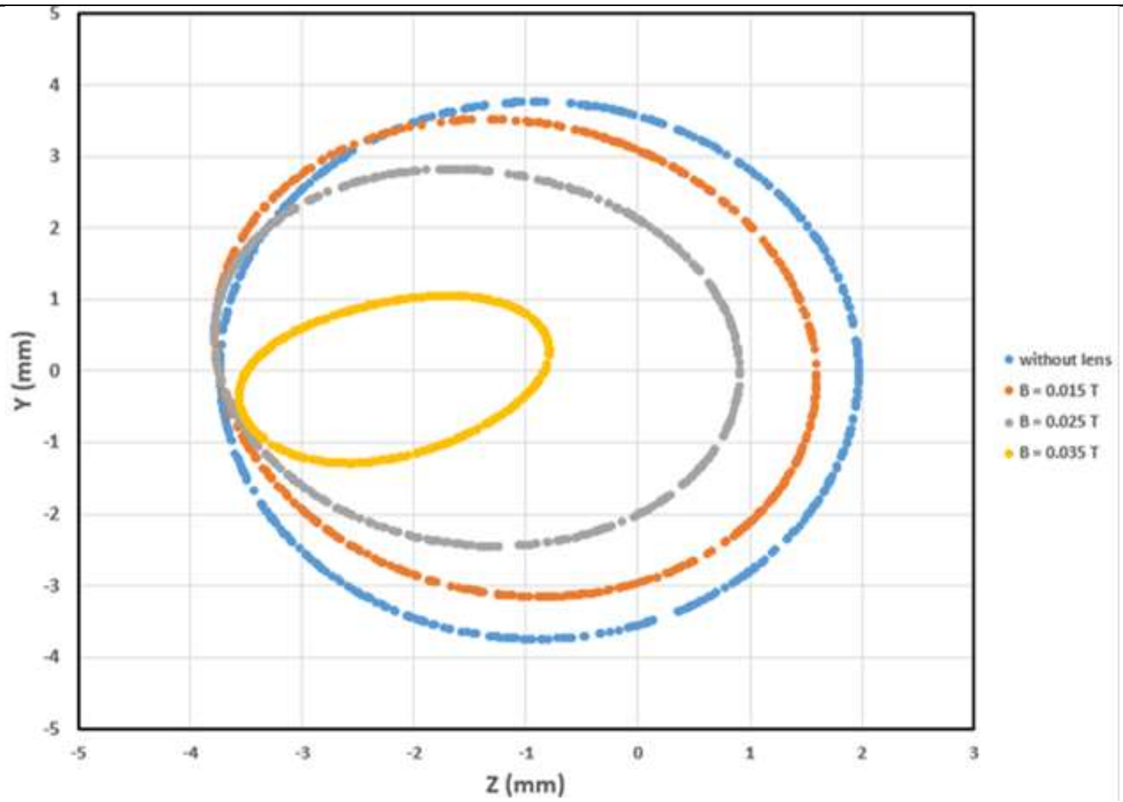


Figure 3: Comparison between the aberration figures of electron beam shape at different value of magnetic field of magnetic lens at kinetic energy 50KeV and α = 0.6 ̊.

Table 2: Values of magnetic field applied to magnetic lens and its effect on electron beam width

B (T)	ΔY (mm)	ΔZ (mm)
Without lens	7.2	8.5
0.015	5.4	7.7
0.025	4.7	6.5
0.035	4.3	2.6

To determine the effect of adding lens to the deflector on the kinetic energy distribution of the electron beam, the kinetic energy distribution of the beam was calculated before and after adding lens. Several values of the applied magnetic field to the lens B=0.015, 0.025 and 0.035 T were taken and the results shown in figure 4 were compared. The comparison shows that the kinetic energy distribution of the electron beam was not affected by this addition and remained stable without any loss in energy. Also, the increase in the field did not affected the energy distribution and loss in it was almost about zero except for a very limited number of some abnormal electrons.
To confirm prove that the properties of the deflection system which was designed are intrinsic and constant regardless of the nature of the electron beam and are not affected by changes in the beam properties. The calculations were repeated for three electrons beam whose properties were changed, where three different angles were taken into account α = 0.2 ̊, 0.4 ̊ and 0.6 ̊ and the shape of the electron beam in the image plane was founds as shown in figure 5. By comparing the resulting in figure 5 between the dimensions of the electron beam without and with the lens, one can find that its presence played an important role in improving those dimensions and reduced them in both y-direction and z-direction, which generated a more coherent and focused beam. This behavior is constant and stable for all angles value that were taken into consideration and for which calculations were made. The results confirm and prove that the behavior obtained for the system are not affected by the properties of the electron beam.

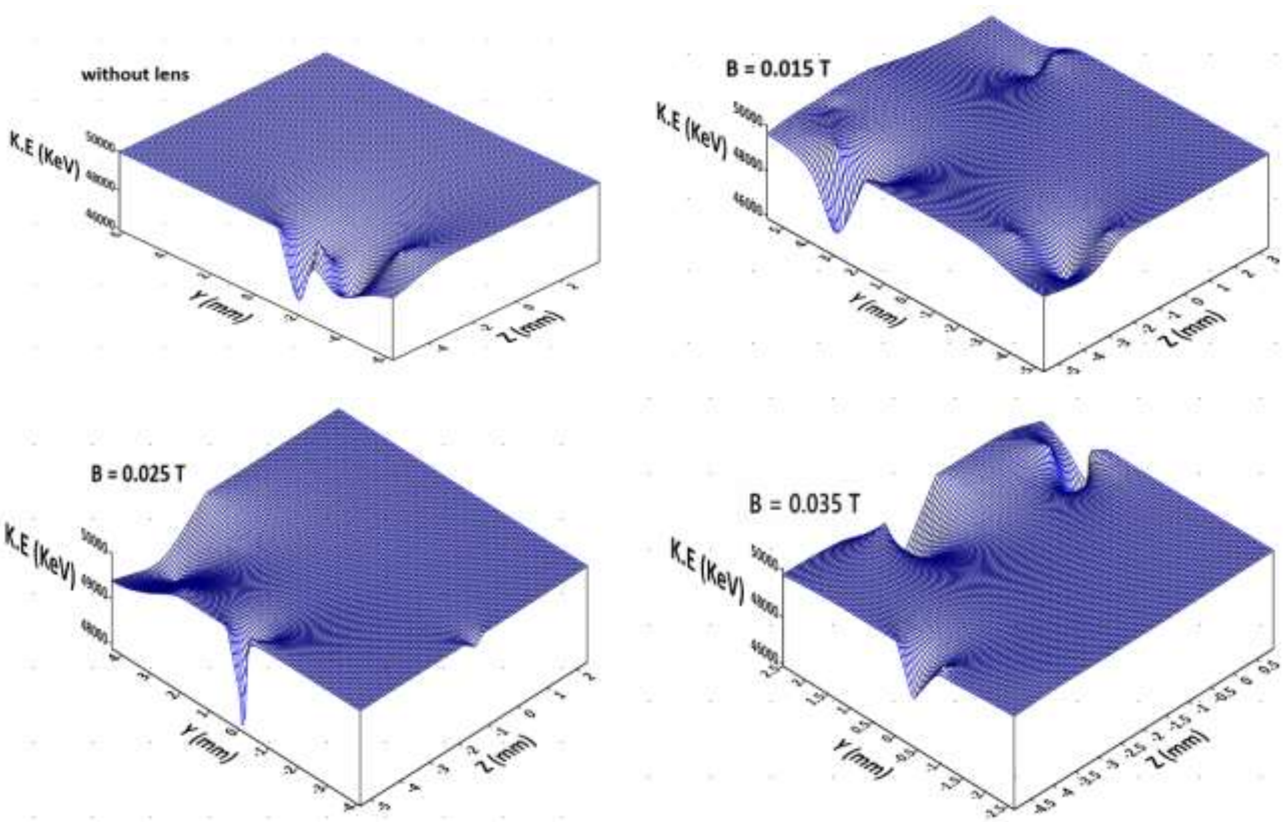
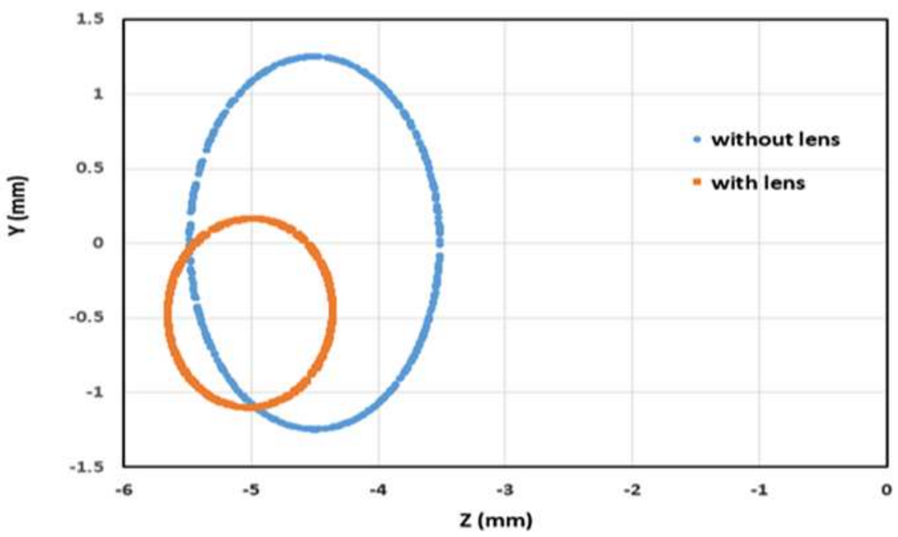
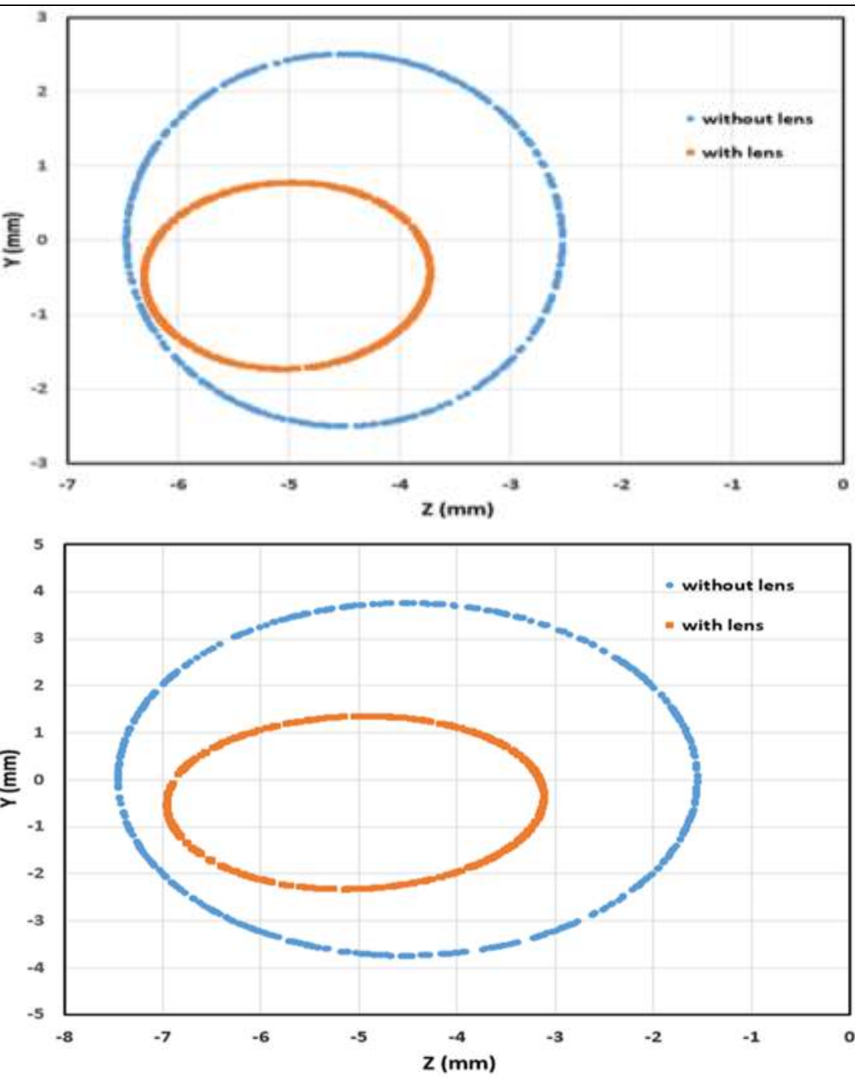


Figure 4: The kinetic energy distribution of the electron beam for different values of magnetic field for fixed kinetic energy 50 KeV and fixed initial angle of electron beam α = 0.6 ̊



$\alpha = 0.2$



$\alpha = 0.4$

$\alpha = 0.6$

Figure 5: Comparison between the aberration figures of the electron beam shape for different angel under magnetic lens effect at specific kinetic energy 50 Kev and magnetic field 0.025 T.

Table 3 shows the difference and enhancement in the dimensions of the electron beam at the image plane for the difference case, of the initial angles for which the calculations were made, as well as the percentages of improvement for the two dimensions for each case. To determine the stability of the electron beams kinetic energy distribution and its impact on beam properties, this distribution was calculated for the angles and the results were shown in figure 6. The results showed that the kinetic energy loss is very small and approaching zero and negligible. Therefore, the design ensure that it can handle varying initial conditions and improves the electron beams properties while maintaining a stable energy distribution.

Table 3: Values of the initial angel of electron beam and its effect on beam diameter.

Initial angle	Without lens		Percentage of improvement		With lens		Percentage of improvement	
	Δy (mm)	Δz (mm)	Δy (mm)	Δz (mm)	Δy (mm)	Δz (mm)	Δy (mm)	Δz (mm)
0.2°	2.5	3.2	88%	28%	1.35	1.3	18%	50%
0.4°	4.7	4.1	65%	41%	1.6	2.6	11%	46%
0.6°	7.8	5.8	39%	29%	3.4	3.8	52%	31%

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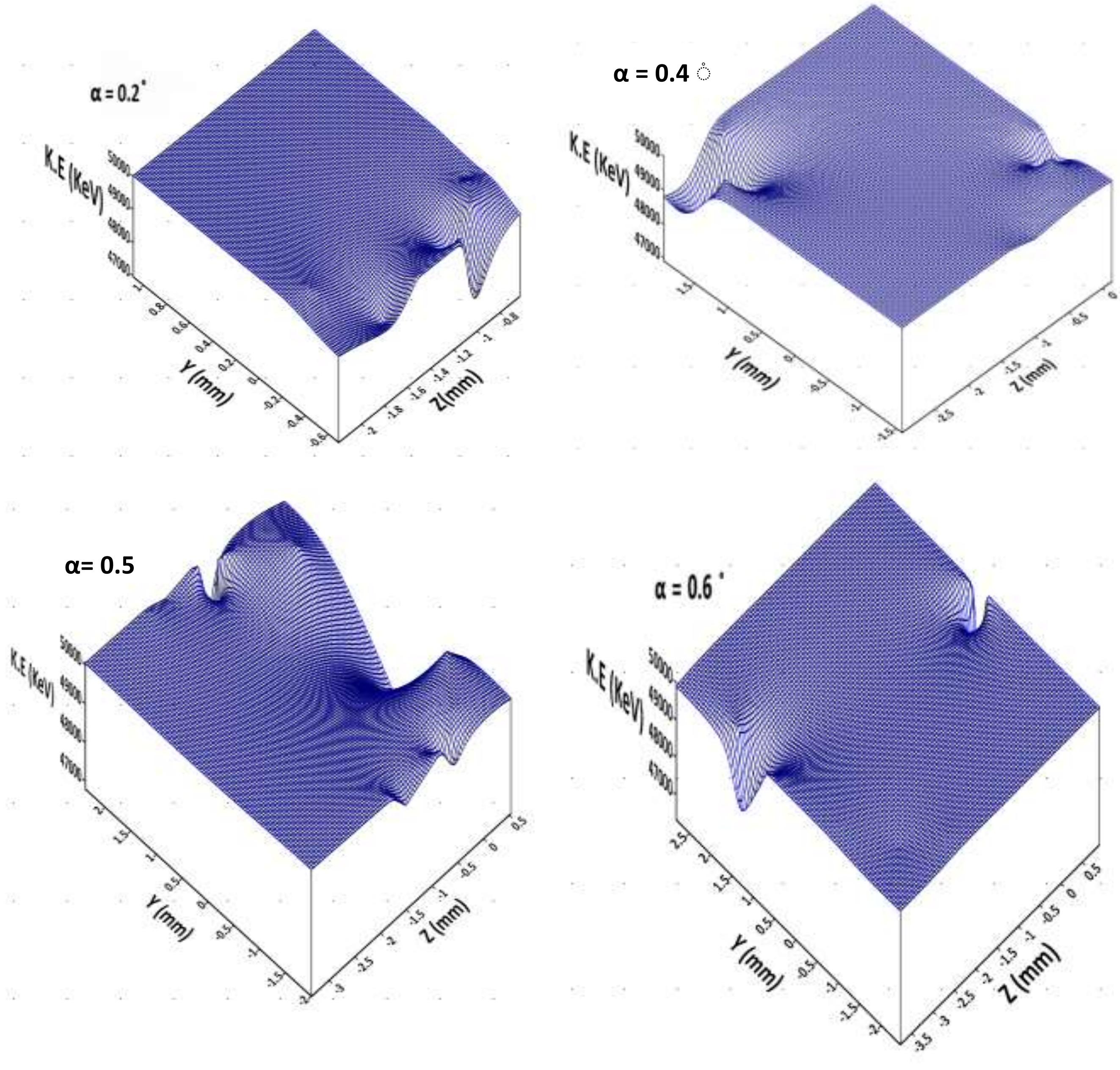

Figure 6: The kinetic energy distribution of the electron beam for different values of initial angle for fixed kinetic energy 50 KeV and fixed magnetic field of lens 0.025T

To understand the relationship between the optical power of magnetic lens and the magnitude of the magnetic field which is applied to it, the optical power was calculated for an electron beam with a kinetic energy of 50 KeV and an initial angle of α = 0.6̊, and the result was show in figure 7. The results in the figure show that the relationship is linear and proportional, where the optical power increasing with the increase in the applied magnetic field to the lens. Because of this linear behavior, it is easy to predicate the optical power simply if the applied field increases. Some values of the focal length and optical power of the lens are shown in table 4 for different values of the applied magnetic field.

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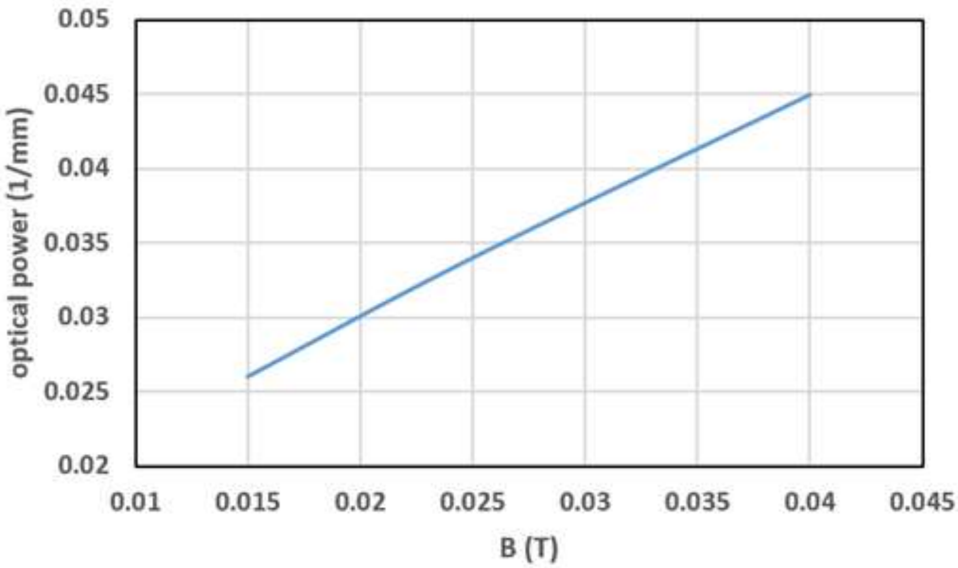

Figure 7: Show the optical power of lens with magnetic field at initial angle 0.6 ͦ.

Table 4: value of optical power with magnetic field of lens

Magnetic field (T)	Focal length (mm)	Optical power (1/mm)
0.015	38.1	0.026
0.025	29.1	0.034
0.035	22.1	0.045

To know the nature of the relationship between the optical power of the lens and the kinetic energy of the electron beam, the power was calculated for different kinetic energies, and the results were presented in figure 8. The results show that the relationship is inversely and non-linear, with optical power decreasing rapidly with increasing of the kinetic energy of the electron beam. This requires increasing the applied magnetic field on the lens in a manner consistent with the value of the kinetic energy in order to maintain the optical power of the lens necessary for the focusing process.

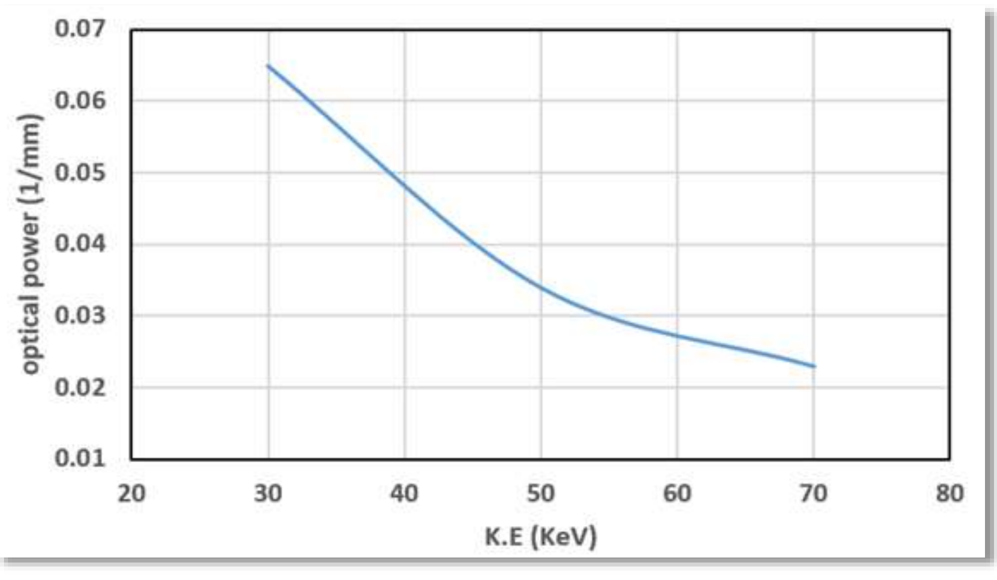

Figure 8: Show optical power of lens with different value of kinetic energy at initial angle 0.6.

Table 5: value of optical power with kinetic energy

K.E. (KeV)	Focal length (mm)	Optical power (1/mm)
30	15.2	0.065
50	29.4	0.034
70	43.3	0.023

4. Conclusions

The complete magnetic deflection system was designed by adding magnetic lens to a magnetic deflector. The impact of this addition and the resulting improvement in system efficiency were studied. The extent to which the systems behavior was affected by the lenses operation conditions, was also investigated to ensure the systems stability and efficiency and its unaffected by changes in electron beam characteristics, the systems efficiency was studied for electron beams of different characteristics. The most important conclusions shown by the results can be summarized as follows:

- An integrated magnetic deflection system can be created that efficiency guarantees both deflecting and focusing properties by adding a magnetic lens to the deflector this addition significantly improves the electron beam characteristic compared to results without lens. The improvement in electron beam dimensions reached by 40% for y-axis and 70% for the z-axis for an applied magnetic field of B= 0.035 T.
- The kinetic energy distribution of the electron beam was unaffected by this addition, and remaining stable with the kinetic energy loss being very small and approaching zero and can be negligible. This means more compact and focused electron beam with greatly improved dimensions, a stable kinetic energy distribution, and no loss.
- The efficiency of the system after addition of the magnetic lens, is constant and its behavior is stable and not affected by changes in the properties of the electron beam.
- The relationship between the optical power of the magnetic lens and magnitude of the applied magnetic field is linear and proportional.
- The relationship between the optical power of the magnetic lens and the kinetic energy of electron beam is inversely nonlinear.

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References

[1] Schröder, A.W.; Tigner, M.; Weise, H.; Zimmermann, F.; "electromagnetic and nuclear interactions". Handbook of accelerator physics and engineering, 3rd ed.; Alexander, W. Ch., Maury, T.; Singapore: World Scientific.; p. 460-6; 1999.

[2] Wong, L.J.; Hong, K.H.; Carbajo, S.; Fallahi, A.; Piot, P.; Soljačić, M.; et al. "Laser-induced linear-field particle acceleration in free space". Sci Rep. 7(1):11159; 2017.

[3] Nassiri, A.; Chase, B.; Craievich, P.; Fabris, A.; Frischholz, H.; Jacob, J.; "History and technology developments of radio frequency (RF) systems for particle accelerators". IEEE Trans Nucl Sci. 63(2):707-50; 2015.

[4] Dattoli, G.; Mezi, L.; Migliorati, M.; "Operational methods for integrodifferential equations and applications to problems in particle accelerator physics". Taiwanese J Math. 186(1):407-13; 2007.

[5] Baumgärtel, C.; Smith, R.T.; Maher, S.; "Accurately predicting electron beam deflections in fringing fields of a solenoid". Sci Rep. 10(1):10903; 2020.

[6] Osseyran, A.; "Computer aided design of magnetic deflection systems". PhD Thesis. Eindhoven: Eindhoven University of Technology; 1986.

[7] Alig, R.C.; Fields, J.R.; "Computer-aided design of electron guns and deflection yokes: A review (Part 2)". J. Soc. Inf. Disp. 8(2):99-113; 2000.

[8] Shiltsev, V.; "Electron lenses: historical overview and outlook". J Instrum. 16(3): P03039; 2021.

[9] Partoens, B.; Verbeeck, J.; "Exploring electron beam shaping in transmission electron microscopy". PhD thesis. Antwerp: University of Antwerp, Faculty of Science; 2015.

[10] Mohammed, M.A.; "A study of Glaser's ball-shaped magnetic lens under the effect of current density". Wasit J Sci Med. 3(1):27-33; 2010.

[11] Ahmed, E.H.; Hasan, A.K.; "Performance and analysis of a designed magnetic lens for

microscopic applications". J Phys Sci. 33(2):125-38; 2022.
[12] Lidberg, G.; Pontén, K.; Millberg, J.; "Design of optical magnetic systems for terahertz lensing". PhD thesis. Uppsala: Uppsala University; 2021.
[13] Bielajew, A.F.; "The effect of strong longitudinal magnetic fields on dose deposition from electron and photon beams". Med Phys. 20(4):1171-9; 1994.
[14] Calvo, M.; Paola, P.; "Theory of a time dependent magnetic field lens". Optik. 113(1):31-4; 2002.
[15] Schott, W.; Springer, K.; Daniel, H.W.; "Calculations and measurements for a magnetic quadrupole lens with a large aperture and a bell-shaped field distribution". Nucl Instrum Methods. 111(3):541-7; 1973.
[16] Janan, M.K.A.; Salih, R.Y.J.; "Design and studying the effect of polepiece shape on the magnetic and optical properties of the unipolar lens". Tikrit J Pure Sci. 27(6): 63-69; 2022.