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Investigation of the Acceleration and Deceleration Performance of the New Geometrical Shapes of the Three Electrode Electrostatic Lenses

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ABSTRACT

Electrostatic lenses are established using billed electrodes with cylinder bores which are exactly organized on a line of symmetry. In this paper, four designs of three-element cylindrical electrostatic lenses in the acceleration and deceleration mode with different geometrical shapes were created to prove how the operational characteristics of the lenses are affected by the electrode geometry according to potentials, the electron beam diameter in the image plane, kinetic energy, velocity, and acceleration before and after the electron beam passes through each of the four lenses. The best lens is chosen from the four lenses based on its optical performance. It has been found that the lens with the concave outer electrode surface has the best optical performance as an accelerating lens, and the lens with the concave inner electrode surface has the best optical performance as a decelerating lens. It was discovered that the geometry of the electrodes plays a major role in minimizing the beam electron diameter at the image plane and in accelerating and decelerating the electron beam. The calculations are carried out by using the SIMION8.0 and SL Tools Programs package.

Keywords: Electrostatic lenses design; Charged, particle optics, SIMION8.0

INTRODUCTION

One of the key objectives of electrostatic lens design is to maintain lens variables over a broad range of final-to-initial potential ratios. "Zoom" lenses are lenses that are used in this manner (Sise *et al.*, 2005). A set of axially arranged electrodes is placed on each of them to create an electrostatic lens. A different electrical voltage causes an axially symmetric electrostatic field with imaging properties to be generated (Lencova, 1997). Because the electrostatic field intensity component perpendicular to the optic axis is directed toward this axis in the case of such an accelerating lens, the field at the entrance side of the lens is focused. Defocusing is happening in the lens's field just on the outer side. As a result, this field acts as a lens that could focus and defocus charged beams. For a decelerating lens, the field at the entrance side serves as both a defocusing and a focusing lens, and the field at the outer side serves as a focusing lens. In both instances, it should be noted that the radial coordinates of trajectories are larger in the focusing than in the defocusing portion of the field (Yavor, 2009). Electrostatic lenses are widely used in a variety of fields to control charged particle beams of various energies and directions, particularly in electron spectroscopy (Sise *et al.*, 2007), (Al-Hialey, 2013). Low-energy electrostatic accelerators like the Cockcroft–Walton and Van de Graaff accelerators rely heavily on electrostatic lenses (Hinterberger, 2006). Particle accelerators, ion implantation, and mass spectrometers all use this type of lens. In a spectrum of uses, including atomic ion implantation studies, ion/surface scattering investigations, surface-induced dissociation (SID), "soft landing" of polyatomic ions for surface modification, sector or hybrid instruments designed to study low-energy ion/surface interactions, simple deceleration lenses (Ginzel *et al.*, 2010), (O'Connor *et al.*, 1991) are used.

Many research papers have been published on focused ion beam systems, where they outperform electrostatic lenses. The goal is to pack as many particles as possible into as small a space as possible. The optical features of electrostatic lenses are defined by the voltage ratios. Devices made up of a series of accelerating electrodes with cylindrical symmetry and lens-like properties could be used to focus charged particles in an electrostatic field, modeled the focus point characteristics of three-electrode zoom lenses for varying diameters and voltage percentages (Heddle, 1971). Ions can be successfully decelerated to energy levels below the trapping potential of a standard ion trap using a novel deceleration method that combines an electrostatic lens and an ion trap technique (Chen *et al.*, 2020).

A three-electrode lens known as an Einzel lens has its outside electrodes retained simultaneously voltage. The beam focusing is accomplished by varying the potential of the central electrode. Solitary (uni-potential outer electrodes) lenses are needed when a beam needs to be centered without wasting energy (Adams and Read, 1972). Due to their versatility and the quick advancement of modern instrumentation, Einzel lenses are being used more and more in many fields of science and technology (Al-Ani, 2007), (Syms *et al.*, 2003). By applying various voltages to the two outer electrodes, it is possible to eliminate the symmetry while maintaining a usable lens (Kim *et al.*, 2005).

There have been a number of prior studies on the properties of electrostatic lenses. It is appropriate to take into account especially, such zoom lenses (lenses whose maximum aperture can be changed without losing concentration). The results are completely reliant on the controlling voltage percentages, electrode length and gap ratios, and other factors. (Nezhad *et al.*, 2019). Impact of multiple electrodes on the effectiveness of immersed electrostatic lenses in optics (Sise *et al.*, 2009). Three electrostatic lens systems' zoom-lens characteristics as a function of lens voltages and diameters were investigated by designers (Sise *et al.*, 2005). The SIMION application has been used to create lens systems made up of cylindrical electrodes spaced 0.1 of lens diameter (Sise *et al.*, 2005).

In this research, the four different geometries of the cylindrical electrode electrostatic lenses' have been proposed as new designs for the demonstration of the lens's performance in the acceleration and deceleration modes to optimize the beam electron properties.

Design of the three-cylinder electrostatic lens systems:

A system of electrostatic lenses can be challenging to design. The number of design factors, including electrode thickness, radius, gaps between electrodes, and voltage, is especially high when there are many lens electrodes involved, quickly rises (Al-Khashab and Al-Shamma, 2010), (Nezhad *et al.*, 2018). In this research work, four different electrostatic lenses of three-electrode have been designed, illustrated in Fig. (1), each having identical electrode symmetry. The first lens, denoted (m1), has a flat inner and outer surface; the second lens, denoted (m2), has a concave inner and flat outer surface; the third lens, denoted (m3), has a flat inner and concave outer surface; and the last lens, denoted (m4), has a concave inner and convex outer surface. All of these lenses in acceleration mode have the same electrode potential. The first electrode potential denoted V_1, near the object position, is equal to 1 Volt. The second electrode potential denoted V_2, at the center of the lens, is equal to 3 Volts. The third electrode potential, denoted V_3, near the image position, is equal to 2 Volts, and the same lenses in deceleration mode have electrode potentials of (2, 3, and 1.5 Volts) respectively. Each lens has an inner diameter (40 mm), an outer lens diameter of (60 mm), a lens length (140 mm) and a gap width between the two successive electrodes equal (10 mm). In this study, we propose four designs of three-element cylindrical electrostatic lenses with an electrode length to diameter ratio (A/D) of (1) and various geometrical shapes. The calculated lens parameters have been accomplished at a wide range of V_3/V_1 and V_2/V_1 values under the conditions of ($V_3/V_1 > 1$) for the accelerating and ($V_3/V_1 < 1$) for the decelerating modes (Hujazie, 2010).

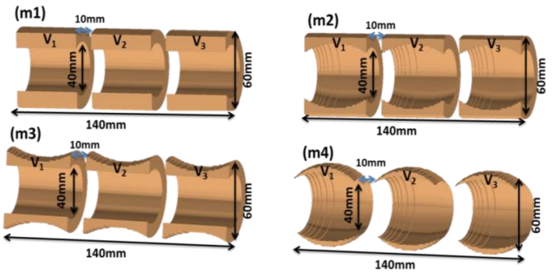

Fig. 1: Three-diminution illustration and the geometrical parameters of the four electrostatic lenses of three electrodes, denoted by (m1, m2, m3, and m4).

The calculations

The SIMION program was used to perform all the calculations, including the impact of the suggested electrode geometry on the performance of the four electrostatic three-electrode lenses; the beam trajectory, the electron beam diameter in the image plane, the kinetic energy, the velocity, and the acceleration before and after the electron beam passes through each of the four lenses in the mode of acceleration and deceleration, which has been assessed.

RESULTS AND DISCUSSIONS

For each of the four lenses, the axial potential in acceleration and deceleration modes at constant voltages (1, 3, and 2 Volts) and (2, 3, and 1.5 Volts) respectively was calculated. There were slight differences between the potential curves while the lens (m3) acquired the highest peaks in acceleration mode and the lens (m2) in deceleration mode, as shown in Fig. (2).

The results of the kinetic energy, the velocity, and the acceleration as the function of optical axis in acceleration and deceleration mode for each lens, depending on whether the kinetic energy, the acceleration, and the velocity of charged particles are increased or decreased inside the lens relative to this energy in the surrounding field-free space, enisle lenses are made reference to as accelerating or decelerating.

The comparison of the kinetic energy, the acceleration, and the velocity of the charged particles at the cross-over point has been computed relative to the main axis in acceleration mode for each of the four proposed lenses shown in Fig. (3), respectively. The result indicated that the charged particles kinetic energy, acceleration, and velocity increased as they moved through the four specially designed lenses. It has been demonstrated that the concave lens on the electrode's outer face (m3) performed the best as an acceleration lens.

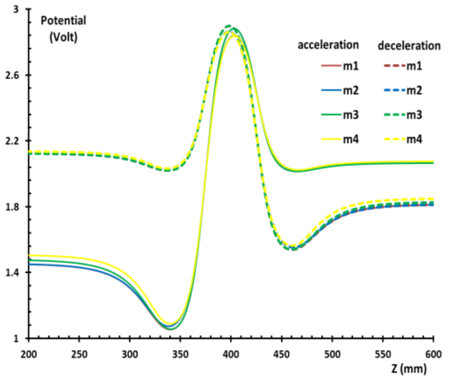

Fig.(2): The axial potential distribution of four electrostatic lenses (m1, m2, m3, and m4) in acceleration and deceleration

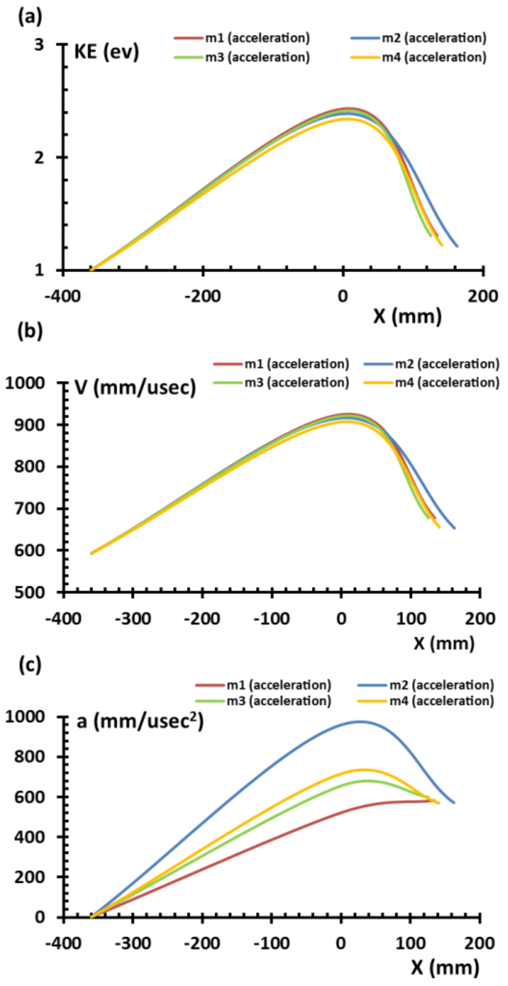

Fig. 3: Comparison of (a) the kinetic energy, (b) the velocity, and (c) the acceleration of the charged particles at the cross over point relative to the main axis in the acceleration mode of the electrostatic lenses (m1, m2, m3 and m4).

Similarly, Fig. (4) shows the comparison of the kinetic energy, the velocity, and the acceleration of the charged particles at the cross-over point relative to the main axis in the deceleration mode for each of the four proposed lens. The result indicated that the kinetic energy, velocity, and acceleration of the charged particles decreased as they moved through the four specially designed lenses. It has been demonstrated that the concave lens on the electrode inner face (m2) performed the best as a decelerator lens.

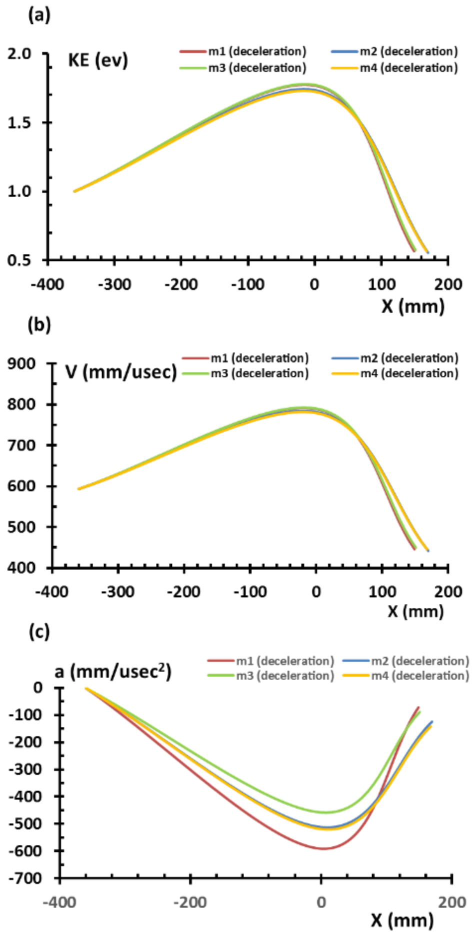

Fig. 4: Comparison of (a) the kinetic energy, (b) the velocity, and (c) the acceleration of the charged particles at the cross over point relative to the main axis in the deceleration mode of the electrostatic lenses (m1, m2, m3 and m4).

The focus point size was calculated (using a built-in user program written in lua script named "Surface Plot") relative to both voltage percentages,$(V_A = \frac{V_2}{V_1})$ and $(V_B = \frac{V_3}{V_1})$ in acceleration mode for each of the four proposed lenses, as shown in Fig. (5). In this plot, the minima on the surface plot indicate where the lens is correctly focused. The beam diameter at the image plane (Δr) is indicated here. The plots provide a general idea of the location of the surface minima but do not give exact coordinates. Therefore, for just this kind of calculation, optimization is required. The "Surface Plot" program uses the simplex optimization method in order to find the best voltages for a particular optical condition. Because it is based on a conjugational gradient algorithm, this approach converges quickly and streamlines the optimization process. To precisely identify locations, the program employs an optimization routine and (Monte-Carlo) technique method (Sise *et al.*, 2009). The result demonstrated that the lens (m3) has a minimum focus point size in the image plane.

Similar calculations were made to determine the beam diameter for the same four lenses in the deceleration pattern. The results showed that the lens (m2) stands out from all the other lenses by having a minimum focus point in the image plane, as shown in Fig. (6).

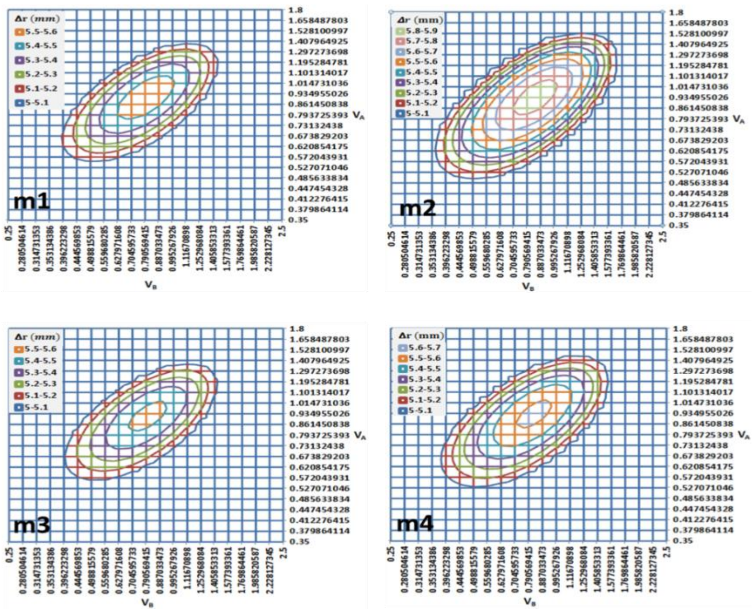

Fig. 5: A two-dimensional surface plot of the beam diameter relative to both voltage percentages (V_A) and (V_B) of the electrostatic lenses (m1, m2, m3 and m4) in the acceleration mode.

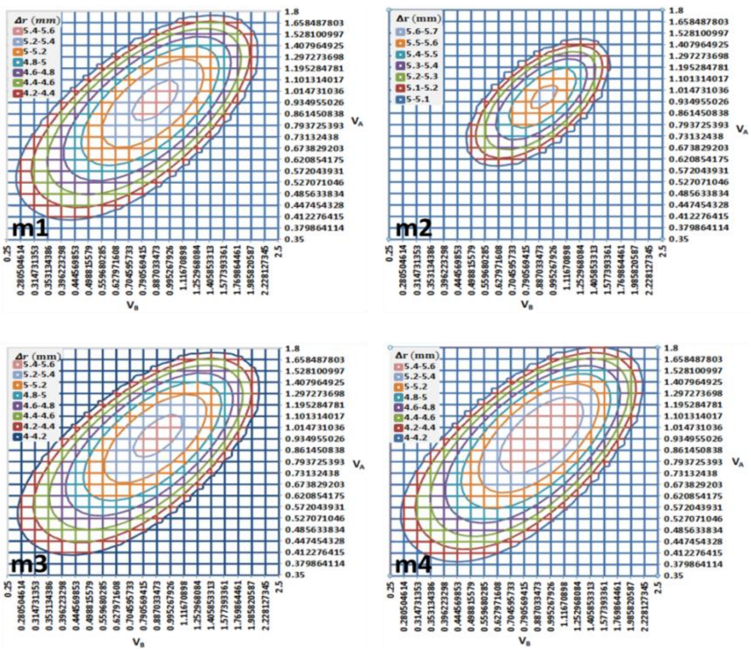

Fig. 6: A two-dimensional surface plot of the beam diameter relative to both voltage percentages (V_A) and (V_B) of the electrostatic lenses (m1, m2, m3 and m4) the deceleration mode.

CONCLUSIONS

It can be challenging to design an electrostatic lens system. The number of design factors, including electrode thickness, radius, gaps between electrodes, and voltage, quickly increases, especially when there are many lens electrodes involved. In order to demonstrate the impact of the electrode geometrical shape on the functionality of the electrostatic lenses, four three-electrode lenses with various electrode geometries in each lens were created. In order to minimize the beam electron diameter at the image plane and to accelerate and decelerate the electron beam, it was observed that the geometry of the electrodes is essential. Likewise, the four lenses' potential field distributions differ slightly from one another.

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التحقيق في أداء التسارع والتباطؤ للأشكال الهندسية الجديدة للعدسات الكهروستاتيكية ثلاثية القطب الكهربائي

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الملخص

يتم تصميم العدسات الكهروستاتيكية باستخدام أقطاب كهربائية ذات فتحات أسطوانية منظمة بدقة على خط من التماثل. في هذا البحث، تم إنشاء أربعة تصاميم لعدسات كهروستاتيكية أسطوانية ثلاثية القطب في وضعي التسارع والتباطؤ بأشكال هندسية مختلفة لإثبات تأثير الخصائص التشغيلية للعدسات بهندسة القطب وفقًا للجهود، وقطر حزمة الإلكترون في مستوى الصورة والطاقة الحركية والسرعة والتسارع قبل وبعد مرور حزمة الإلكترون عبر كل من العدسات الأربع. يتم اختيار أفضل عدسة من بين أربع عدسات بناءً على أدائها البصري. لقد وجد أن العدسة ذات السطح الخارجي المقعر للقطب الكهربائي تتمتع بأفضل أداء بصري كعدسة تسارع، وأن العدسة ذات السطح الكهربائي الداخلي المقعر تتمتع بأفضل أداء بصري كعدسة تباطؤ. تم اكتشاف أن هندسة الأقطاب الكهربائية تلعب دورًا رئيسيًا في تقليل قطر الحزمة الإلكترونية في مستوى الصورة وفي تعجيل وإبطاء حزمة الإلكترون. يتم إجراء الحسابات باستخدام حزمة SIMION8.0 و SL Tools Programs.

الكلمات الدالة: تصميم العدسات الكهروستاتيكية، بصريات الجسيمات المشحونة، برنامج سيميون8.0.