Generated and shifted of Ion beams By Electrostatic Lenses (*Einzel lens*)

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Abstract:

In this paper, the path of the extracted and focused ions by the electrostatic lense having three electrodes of the same size and shape have been studied. However, the first and third electrodes had a different potential from the second electrode and the distance between any three electrodes was (d).The beams of the charged particles were controlled by using electrostatic fields which are used for accelerating and focusing. This paper focuses also on the effect of electrodes potentials on ion beam focusing. It is found that the best focusing was achieved when the values of the potential of the first and third electrode are equal to half of the value of the second electrode. Concerning transmiting and acumulating the ions beams, the study shows that these beams stayed fixed and steady when their paths were doubled, without any change in extracted beam density. This method is called Plasma Portation.

Key words: Electrostatic Lenses, Einzel lens, Plasma Potation, Ion beam focusing.

Introduction:

Electrostatic lenses are utilized in many aspects of life like the extraction, focusing, deceleration and acceleration of electron and ion beams. It has an immense value in designing the low energy electrostatic accelerators such as the accelerators of Cockcroft Walton and Van de Graff. Over many years, electrostatic lenses theories were advanced. For instance, ion optics with rotational symmetric electrostatic lenses was investigated by Hinterberger [1]. Later, the calculation of electron optical properties was reviewed by Hawkes and Sise et al [2,3]. Moreover, cylindrical multi-element electrostatic lenses were designed and fabricated by Sinno et al. [4].

The field and its profile are the dominant factor of the electrostatic lens. Due to the entrance angle of charged particle beam with the interaction of the relevant potential, the component of velocity gives the successive variance in the velocity component of the ion beam, which resulted in the convergence (bundle from) or divergence. The three element lens or the einzel lens was used to maintain the solid geometry of the beam. This effect was achieved by maintaining the same entrance and exit potential with a different mid electrode, which preferred to be U_2 /U_1

=2-5, to allow the bundle behavior formation of charged particle beams .
The operation idea of electrostatic lenses depends on the variation of the electric field between the two surfaces of the lens due to varying the applied potential. So, this lens will work to focus the charged particles which passes through it[5,6]. The electron is effected by the electrostatic field directly, by a force proportional with the value of the field and depends on its direction. Practically, the electrostatic field is described in term of potential distribution. Then, the effective force of the electron will be vertical on the surface of the lens. The electron velocity which accelerated will be a function of that potential, as in the fallowing equation [7,8,9] ;

$$\upsilon = \sqrt{2eV/m} \qquad \ldots (1)$$

Where V is the electric potential applied a surfaces of the lens.
e is the electron charge .
m is the electron mass .

Fig (1) shows that the three coaxial electrodes (apertures or cylinders), where these three coaxial electrodes form the unipotential lens. The outer electrodes were at a common potential U_1, and the center electrode at a different, lower or higher potential than U_1 (known as U_2). If the outer electrodes are of the same shape and are located at the same distance from the center electrode, the field of the lens is symmetric relative to the mid-plane of the lens. Such a unipotential lens is called a symmetric lens. The unipotential lens is converging and diverging regions ($U''_0 > 0$ and $U''_0 < 0$). In this case the unipotential lens is always positive. The optical parameters of a unipotential lens greatly depend on the potential ratio U_2 / U_1 of the center and outer electrodes. The greater ratio differs from unity, the stronger is the lens. with $U_2/U_1 = 1$ the optical power of a unipotential lens is equal to zero since the equipotential regions lie at both sides of the unipotential lens, the focal lengths in the object and image spaces are equal to each other [10,11,12].

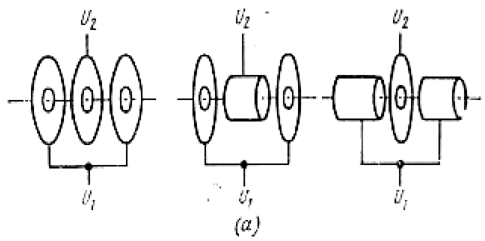

Fig (1) Unipotential lens

Theory

The theory of limited differences (Liebmann method) has been used in this paper to solve Poisson’s equations. The basic idea of this method is the secondary divisions of the space including the field, considering the limited squares or limited grids.
There are many famous methods to solve this problem such as the Five and Nine- Points Formulas. The first method (Five- Points Formula) connects the potential of any point to the nearest four points. While the second method (Nine-Point Formula) uses the four points as well as other four points behind the first four points along the longitudinal and diametric axes. Poisson’s equation was used to solve the symmetric axial problems which given by spherical coordinates [13,14].

$$\frac{1}{r}\frac{\partial V}{\partial r} + \frac{\partial^2 V}{\partial r^2} + \frac{\partial^2 V}{\partial z^2} = \frac{-n_{i,j}e}{\epsilon_0} \quad \ldots (2)$$

By using the Five-Point equation, which is a method of FDM theories, the result will be:

$$V_{i,j} = \frac{1}{4}(V_{i+1,j} + V_{i-1,j} + V_{i,j+1} + V_{i,j-1}) + \frac{h}{8r_0}(V_{i+1,j} - V_{i-1,j}) - \frac{h^2 n_{i,j} e}{4\epsilon_0} \ldots (3)$$

Equation (3) represents the analytic equation which is derived from

Poisson's equation. The potential for each point of the limited area inside the lens was calculated

If we considering $n_{ij}e = \rho = 0$, i.e. there are no free charged particles, then eqn. (3) will reduced to

$$V_{i,j} = \frac{1}{4}(V_{i+1,j} + V_{i-1,j} + V_{i,j+1} + V_{i,j-1}) \ldots (4)$$

In this research, the Successive –Over–Relaxation Method has been used to calculate the potential inside system in order in the use of Poisson's equation.

When Laplace equation is used, the result will be:

$A_l = V_{i,j}$

$$B_p = \frac{1}{4}(V_{i+1,j} + V_{i-1,j} + V_{i,j+1} + V_{i,j-1}) + \frac{h}{8r_0}(V_{i+1,j} - V_{i-1,j}) - \frac{h^2 n_{i,j} e}{4\in_0} \ldots (5)$$

$V_{i,j} = A_p + w(B_p – A_p)$

When Poisson's equation is used, the result will be:

$A_p = V_{i,j}$

$$B_L = \frac{1}{4}(V_{i+1,j} + V_{i-1,j} + V_{i,j+1} + V_{i,j-1}) \ldots (6)$$

$V_{i,j} = A_L + w(B_L – A_L)$

w: acceleration factor $1 < w < 2$

Theoretical Model

A program in visual basic was written to solve Poisson equations and to calculate the potentials and ions by using the finite difference method.

Results and Discussion:

It is found that the ionic beam in the electrostatic lenses was created by the acceleration of ions according to potential difference, which is applied on the space between the creation pole and acceleration pole. [15]

The figures (2,3,4,5) show the potential distribution for various voltages ratios between the electrodes, and the path of extracted and focused ions. The electrostatic lenses had three electrodes similar in size and shape. The first and third electrodes were at the same potential in comparison to the second electrode. The distance between the first electrode and each of the other electrodes is (d). The figures also illustrate the potential distribution pattern, and the effect of the second electrode on others. It is clearly seen that the increase in potentials of the first and third electrodes with respect to the second electrode leads to a change in the shape of equipotential lines especially near the first and third electrodes. In addition, the plots above show the ionic paths at different locations inside the three electrodes of the lens, and show also that the ion path is normal to the equipotential lines.

Figure (6) shows that, the ions beams are trundling at a distance of 50% for away from the focusing point. This clarifies that the lens has playing an important role in focusing the external ion beam and in a long distance plasma portation without any distortion in ionic beam.

When the voltage polarities are reversed, it is seen from the figures (7,8,9,10) describe that the potential distribution pattern changed and the effect of the second electrode on the first and third electrodes was also changed. It is clearly seen that the increase in potentials of the second electrode with respect to the first and third electrodes leads to a change in the shape of equipotential lines especially near the second electrode.

In the decelerating field, the electron with its initial velocity moves to an opposite direction to force acting on it, and this means it moves to the points of more negative potential; thus, the electron kinetic energy decrease because the electron itself does work against the field. Therefore, electron gives energy to the decelerating field. It is clear from above that the electric field might accelerate or decelerate electron, in consequence the field is called accelerating or decelerating. Thus, if an electron enters an electric field with a specific angle between its initial velocity vector and the direction of field lines, its path deviates. The path of electron in the uniform field is parabolic not straight.

Conclusions:

In the present work, it is found that the greatest focusing ratio is achieved when the potential of the second electrode equal to twice of the potential for 1st and 3rd, and the ideal plasma portation is achieved without any distortion of the ion beam.

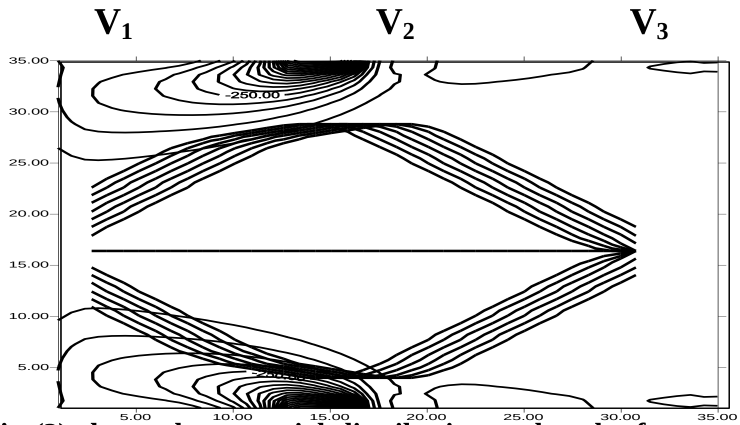

Fig (2) shows the potential distribution and path of extracted and focused ions by the electrostatic lens having three electrodes of the same size and shape V_1=V_3 = -100 , V_2 = -1000

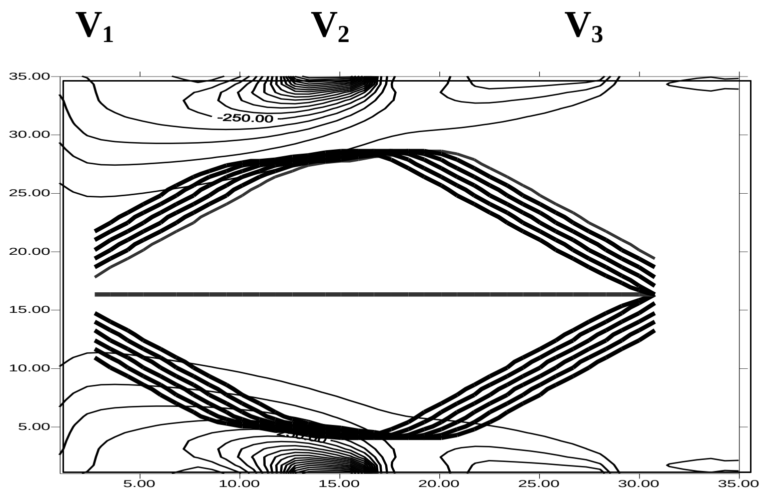

Fig (3) shows the potential distribution and path of extracted and focused ions by the electrostatic lens having three electrodes of the same size and shape V_1=V_3 = -200 , V_2 = -1000

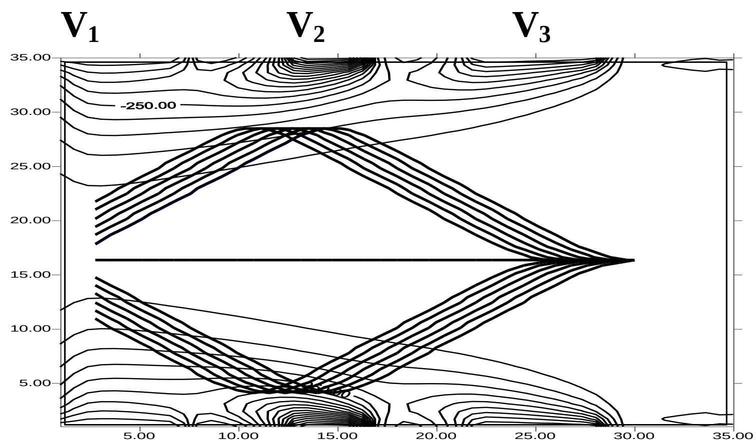

Fig (4) shows the potential distribution and path of extracted and focused ions by the electrostatic lense having three electrodes of the same size and shape V_1=V_3 = -500, V_2 = -1000

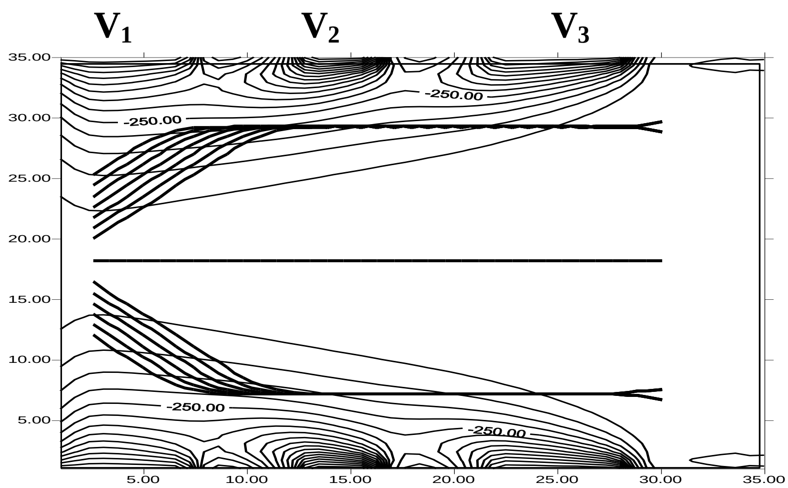

Fig (5)shows the potential distribution and path of extracted and focused ions by the electrostatic lens having three electrodes of the same size and shape V_1=V_3 = -700 , V_2 = -1000

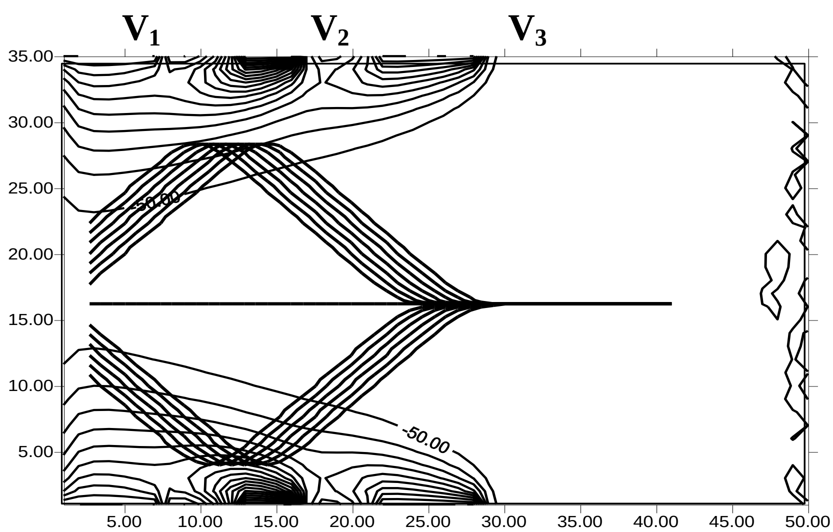

Fig (6) shows the ions beams are trundling at a distance V_1=V_3 = - 500, V_2 = - 1000

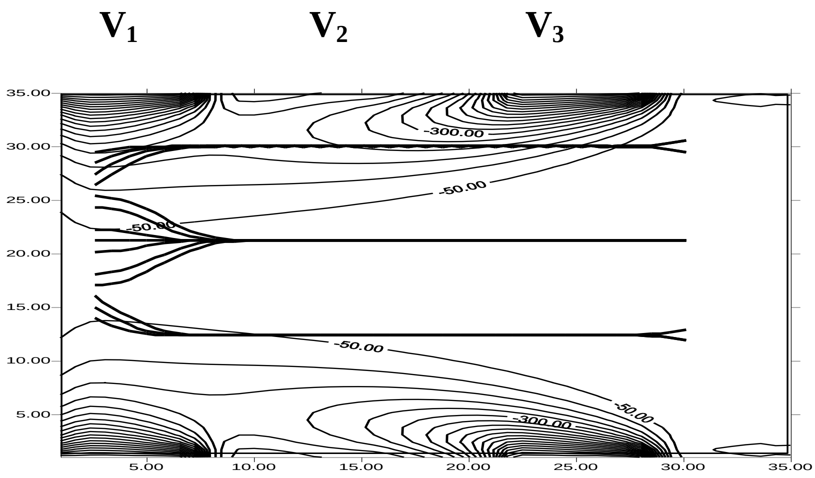

Fig (7) shows the potential distribution and path of extracted and focused ions by the electrostatic lens having three electrodes of the same size and shape when the voltage polarities are reversed $V_1=V_3 = -1000$, $V_2 = -100$

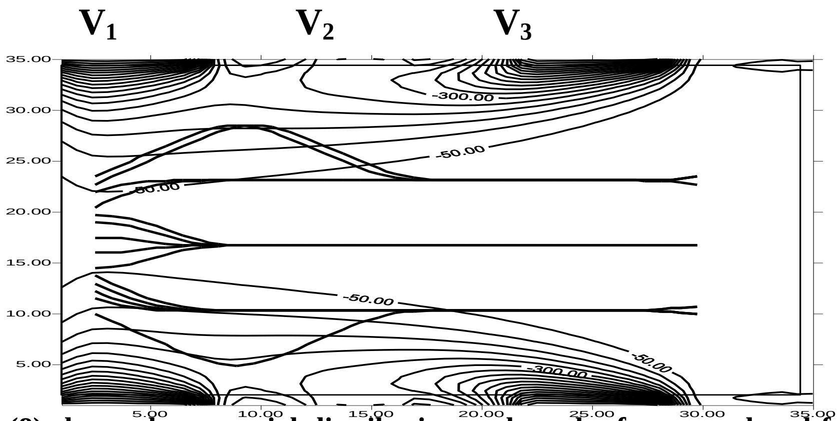

Fig (8) shows the potential distribution and path of extracted and focused ions by the electrostatic lens having three electrodes of the same size and shape when the voltage polarities are reversed $V_1=V_3 = -1000$, $V_2 = -300$

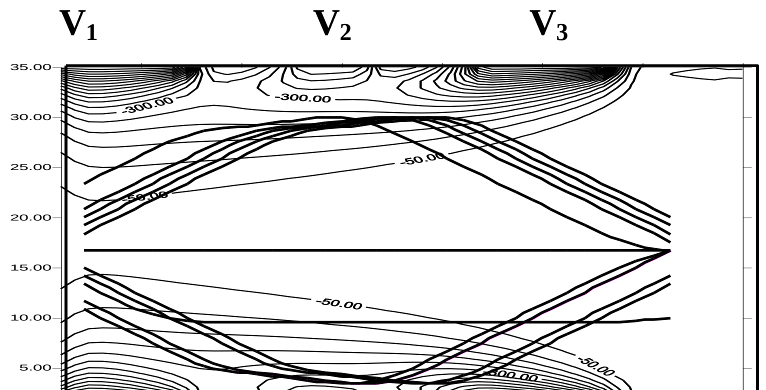

Fig (9)shows the potential distribution and path of extracted and focused ions by the electrostatic lens having three electrodes of the same size and shape when the voltage polarities are reversed $V_1=V_3 = -1000$, $V_2 = -500$

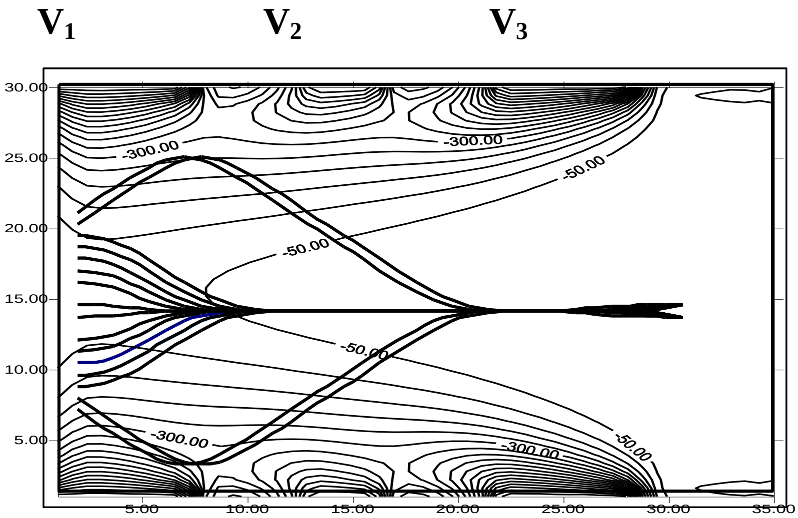

Fig (10) shows the potential distribution and path of extracted and focused ions by the electrostatic lens having three electrodes of the same size and shape when the voltage polarities are reversed $V_1=V_3 = -1000$, $V_2 = -700$

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توليد وأنحراف الحزم الايونية بأستعمال العدسات الكهروستاتيكية الثلاثية الاقطاب

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الخلاصـة :

تم في هذا البحث دراسة مسار الايونات المستخرجه والمبئرة بوساطة عدسة كهروستاتيكية (einzel lens) مكونة من ثلاث اقطاب متشابهة في الحجم والشكل ولكن لكل من القطبين الاول والثالث جهد مختلف عن القطب الثاني ويبعد كل قطب مسافة مقدارها d عن القطب الاخر .اذ يتم السيطرة على حزم الجسيمات المشحونة باستعمال المجالات الكهروستاتيكيه فقط لغرض تعجيلها أو تبئيرها .اذ اشتمل البحث على دراسة تأثير جهد الاقطاب على تبئير مسارات الايونات ولوحظ انه افضل حالة تبئير لمسارات الايونات عندما يكون جهد القطب الاول والثالث نصف جهد القطب الثاني .

أظهرت الدراسة الحالية بالنسبة الى نقل وتجميع الحزم الأيونية، أن هذه الحزم تبقى ثابتة ومستقرة عند مضاعفة مسار هذه الحزم مع الحفاظ على كثافة الحزمة المستخرجة وهذا مايعرف بأسلوب نقل البلازما (Plasma Portation).

الكلمات المفتاحية: العدسات الكهروستاتيكية ذات ثلاثة اقطاب، نقل البلازما، تبئير الحزم الايونية