Focusing Effects of The Triplet Quadrupole lens on Charge Particle Beam

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Abstract

This research includes a study of the main parameters effecting on the charged particle ion beam passing through the triplet quadrupole lenses ,which used as focusing element. And the research included a study of the effect of changing the first free region ,the lenses distance and quadrupole lens length on the properties of the charge particle beam in horizontal and vertical plane.

Key words: This research studies the transport of charged particles beam through the triplet quadrupole lenses

Introduction

Electrostatic triplet quadrupole lens uses for focusing charged particles beam by using either a magnetic or an electrostatic field. It plays an important role in the formation and control of electron or ion beam and has applications in several different fields such as electron microscopy cathode ray tubes, ion accelerators and electron impact studies. There are numerous types of lenses like; magnetic lens and electrostatic lens .There are many electrostatic lenses classified according to its shape of their electrodes ,such as cylinders, planes containing circular holes and grid [**1**].

The action of electrostatic field can be use as a bending of ion path .The total effect of electrostatic lens depends on the strength extent of electrostatic field and on the speed of the ions of the passed beam.

In this research was used electrostatic lens (Electrostatic Quadrupole lens (EQL)) constant of four parallel electrodes as shown in fig (1) [**2**].

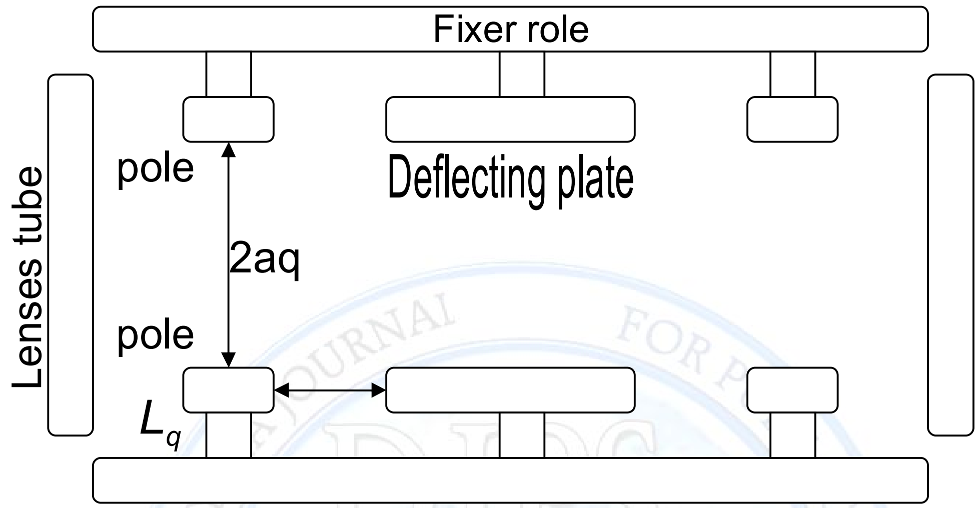


Figure (1): Triplet quadrupole lens [2].

It has four planes of symmetry intersecting along the Z- axis with an angle (w) between them .The lens, centered at Z=0, extends in the positive and negative Z-direction the aperture of the lens ($2a_q$) is defined by the diameter of the hypothetical circle tangential to the four electrodes as shown in fig (2) [**3**].

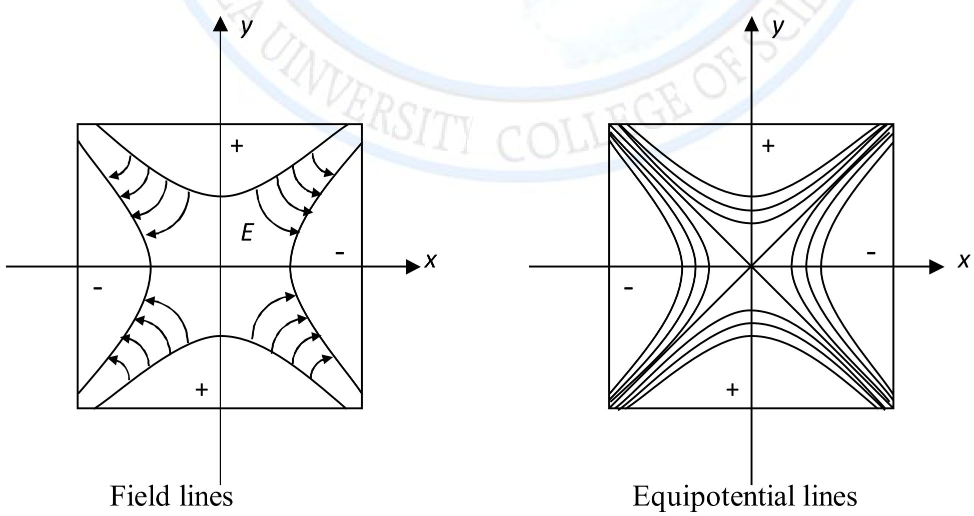


Figure (2): Electrostatic quadrupole field [3].

Mathematical Treatment

The optical system contains, source, first drift space (S1) , quadrupole region ,second drift space (S2) and target where Drift space regions are limited between two elements a long beam transport line and there is no force effect on the charged particle as shown in figure (3) [**4,5**].

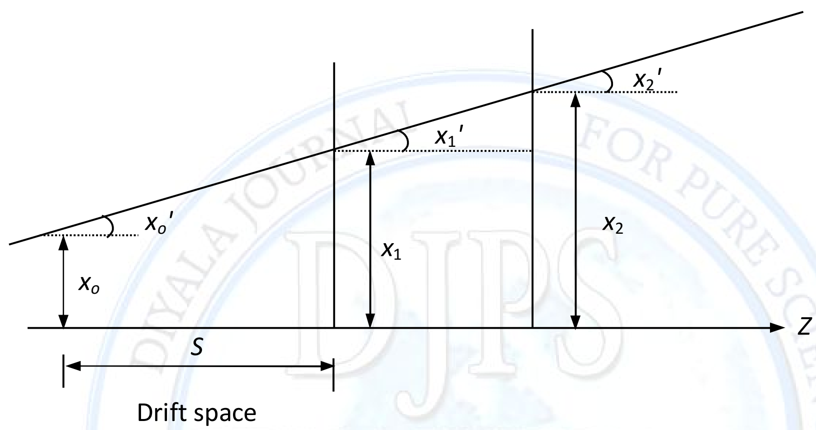


Figure (3): Particle path in the drift space region [4].

From the above figure (2) we note the particle path in the drift space region where the particle position and divergence (x_o, x_o') is transferred through drift space length (S)and causing new position and divergence (x_1, x_1') where

$$x_1 = x_o + x_o' S \quad (1)$$

And

$$x_1' = x_o' \quad (2)$$

And in the matrix form:

$$\begin{bmatrix} x_1 \\ x_1' \end{bmatrix} = \begin{bmatrix} 1 & S \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_o \\ x_o' \end{bmatrix} \quad (3)$$

And

$$\begin{bmatrix} y_1 \\ y_1' \end{bmatrix} = \begin{bmatrix} 1 & S \\ 0 & 1 \end{bmatrix} \begin{bmatrix} y_o \\ y_o' \end{bmatrix} \quad (4)$$

So the sigma matrix can be introduced by using equation.

$$\sigma x(out) = R_x \sigma x(in) R_x^T \quad (5)$$

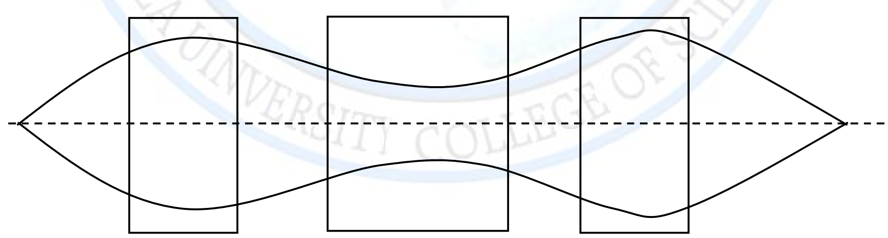
In term of $\sigma x(in)$ matrix element.

$$\sigma x(out) = \begin{bmatrix} \sigma x_{11}(in) + 2S\sigma x_{12}(in) + S^2\sigma x_{22}(in) & \sigma x_{12}(in) + S\sigma x_{22}(in) \\ \sigma x_{12}(in) + S\sigma x_{22}(in) & \sigma x_{22}(in) \end{bmatrix}$$

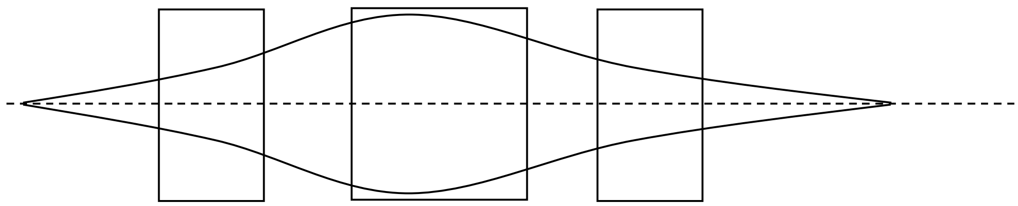
(6)

The axis quadrupole lens is z-axis a long the four fold symmetry axis of the lens .In the positive poles there are focusing on the ion passing through the lens and defocusing in the negative poles[**6**].

The major action of triplet quadrupole lenses is focusing the ion beam .The triplet quadrupole lens consists of three quadrupole parts[**7**].



a: Focusing-defocusing-focusing plane.



b: Defocusing-focusing-defocusing plane.

Figure (3): Beam envelope in triplet [7].

For small θ the R-matrix in triplet becomes :

$$R = \begin{bmatrix} 1 & 2\left(2L_q + s\right)\left(1 \pm \theta^2\left(1 + \frac{s}{L_q}\right)\right) \\ -2\left(\frac{\theta^4}{L_q}\right)\left(\frac{2}{3} + \frac{s}{L_q}\right) & 1 \end{bmatrix} \quad (7)$$

Where L_q: is effective length of lens.

$$\theta = \frac{Lq}{aq}\sqrt{\frac{Va}{U}} \quad (8)$$

Where $V\alpha$: pole voltage, α_q:distance between the pole tip and lens axis and U :particle potential. Sigma matrix for the quadrupole triplet lens in x-plane:

$$\left.\begin{aligned}
\sigma x_{11}(out) &= \sigma x_{11}(in) + 4\sigma x_{12}(in)\left(2L_q + s\right)\left(1+\theta^2\left(1+\frac{s}{L_q}\right)\right) \\
&\quad + 4\sigma x_{22}(in)\left(2L_q + s\right)^2\left(1+\theta^2\left(1+\frac{s}{L_q}\right)\right)^2 \\
\sigma x_{12}(out) &= -2\sigma x_{11}(in)\left(\frac{\theta^4}{L_q}\right)\left(\frac{2}{3}+\frac{s}{L_q}\right) + \sigma x_{12}(in)\left(1 - 4\frac{\theta^4}{L_q}\left(\frac{2}{3}+\frac{s}{L_q}\right)\left(2L_q + s\right)\right. \\
&\quad \left.\left(1+\theta^2\left(1+\frac{s}{L_q}\right)\right)\right) + 2\sigma x_{22}(in)\left(2L_q + s\right)\left(1+\theta^2\left(1+\frac{s}{L_q}\right)\right) \\
\sigma x_{21}(out) &= \sigma x_{12}(out) \\
\sigma x_{22}(out) &= 4\sigma x_{11}(in)\left(\frac{\theta^4}{L_q}\left(\frac{2}{3}+\frac{s}{L_q}\right)\right)^2 - 4\sigma x_{21}(in)\left(\frac{\theta^4}{L_q}\right)\left(\frac{2}{3}+\frac{s}{L_q}\right) + \sigma x_{22}(in)
\end{aligned}\right\} \quad (9)$$

Sigma matrix for the triplet quadrupole lens in *y*-plane:

$$\sigma y_{11}(out) = \sigma y_{11}(in) + 4\sigma y_{12}(in)(2L_q + s)\left(1-\theta^2\left(1+\frac{s}{L_q}\right)\right) + 4\sigma y_{22}(in)(2L_q + s)^2\left(1-\theta^2\left(1+\frac{s}{L_q}\right)\right)^2$$

$$\sigma y_{12}(out) = -2y\sigma_{11}(in)\left(\frac{\theta^4}{L_q}\right)\left(\frac{2}{3}+\frac{s}{L_q}\right) + \sigma y_{12}(in)\left(1-4\frac{\theta^4}{L_q}\left(\frac{2}{3}+\frac{s}{L_q}\right)(2L_q+s)\left(1-\theta^2\left(1+\frac{s}{L_q}\right)\right)\right) + 2\sigma y_{22}(in)(2L_q+s)\left(1-\theta^2\left(1+\frac{s}{L_q}\right)\right)$$

$$\sigma y_{21}(out) = \sigma y_{12}(in)$$

$$\sigma y_{22}(out) = 4\sigma y_{11}(in)\left(\frac{\theta^4}{L_q}\left(\frac{2}{3}+\frac{s}{L_q}\right)\right)^2 - 4\sigma y_{21}(in)\left(\frac{\theta^4}{L_q}\right)\left(\frac{2}{3}+\frac{s}{L_q}\right) + \sigma y_{22}(in) \quad (10$$

Results and Discussion

In this research we use program of Fortran to study the effect of main parameter of quadrupole lens (first free region, the distance between the lenses(LD) and quadrupole lens length(*lq)* on charge particle beam passing through it .The action of electrostatic quadrpole lens as focusing or defocusing elements in horizontal plane or in vertical plane. The value of electrostatic quadrpole lens parameters of change as the follows:

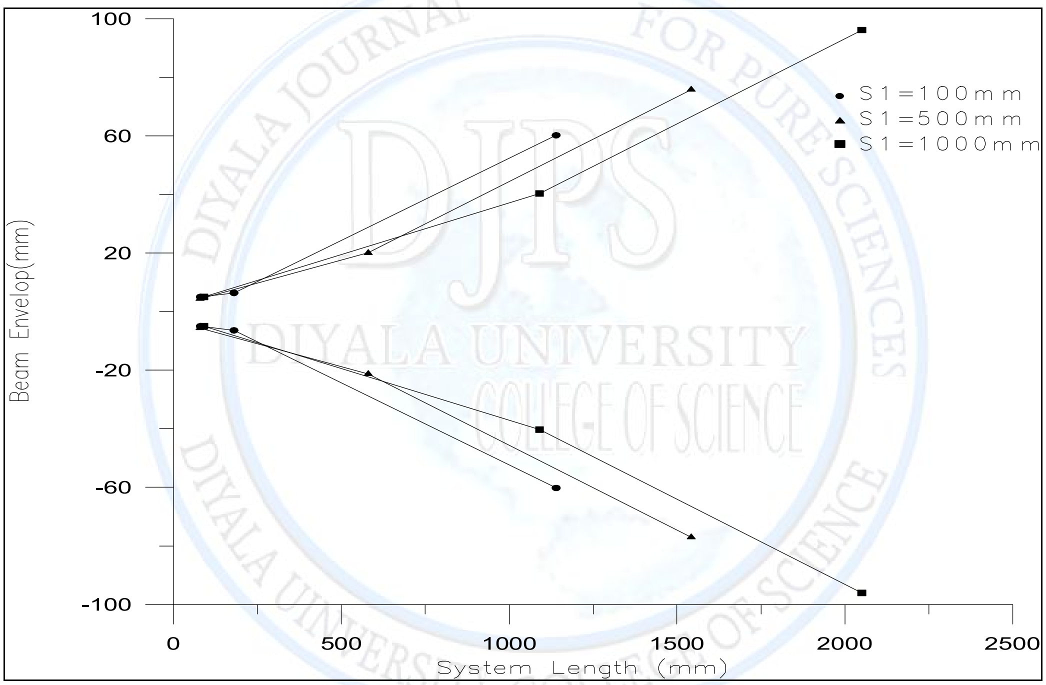
1-First free region (S1=100mm,S2=500mm,S3=1000mm) .

2-Distance lenses (LD=20mm,LD=50mm,LD=70mm).

3- Triplet Quadrupole lens length (*Lq=20* mm, *Lq=100*mm,*Lq=150*mm).

The system continues as the following:

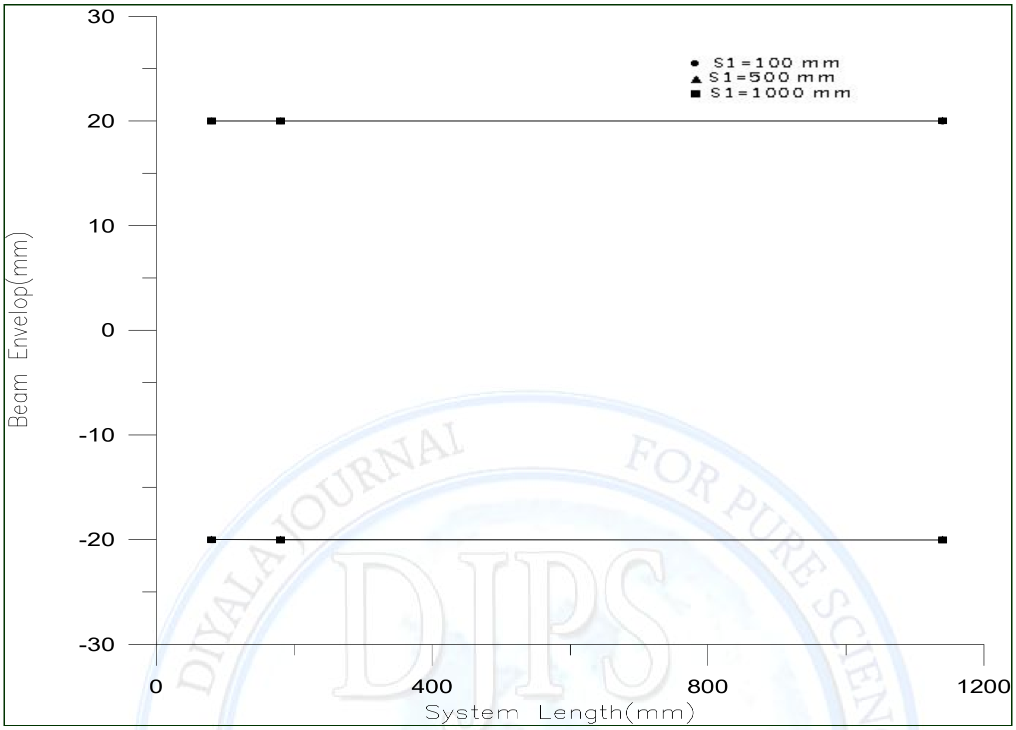
The effect of first drift space (S1) on beam envelope for horizontal plane with constant (LD=20mm,Lq=20mm) shown in figure (5) one can note the focusing action of the first drift space (S1) and this converge increases by decreasing the first drift space (S1) and there is increasing in the system length with increasing the first drift space .



Figure(5):Effect of first free region with constant LD=20mm,Lq=20mm in horizontal plane.

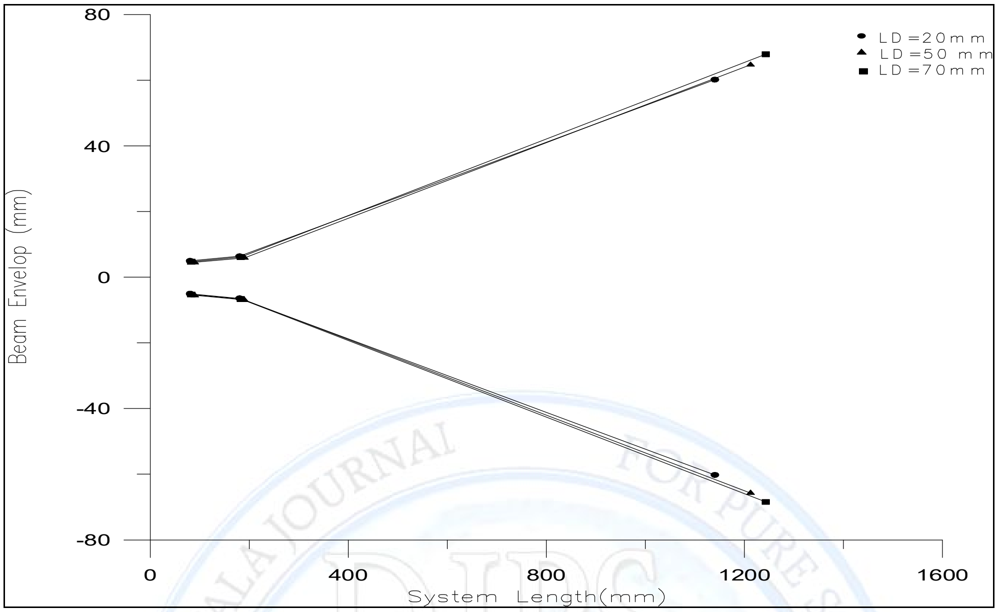
In vertical plane when S1=100mm,S1=500mm,S1=1000mm and constant LD and Lq (20mm,20mm) respectively as figure (6) shows there is no clear action of first drift space (S1) on focusing of quadropule lens

but there is increasing in the system length with increasing the first drift space .



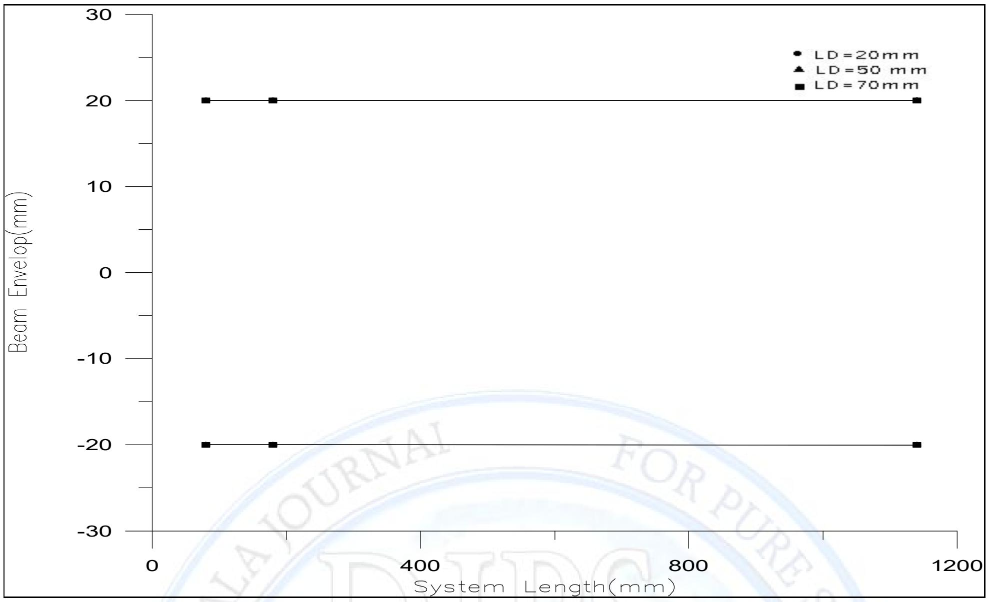
Figure(6): Effect of first free region with constant LD=20mm,Lq=20mm in vertical plane.

Figure (7) shows the effect of distance between lenses LD on beam envelope for horizontal plane with constant first free region and quadrapole lens length (S1=100mm, Lq=20mm) respectively. We can note from this figure that there is an increasing in ion beam width with increasing of lenses distance LD so that the lenses distance LD acts as divergence lens.



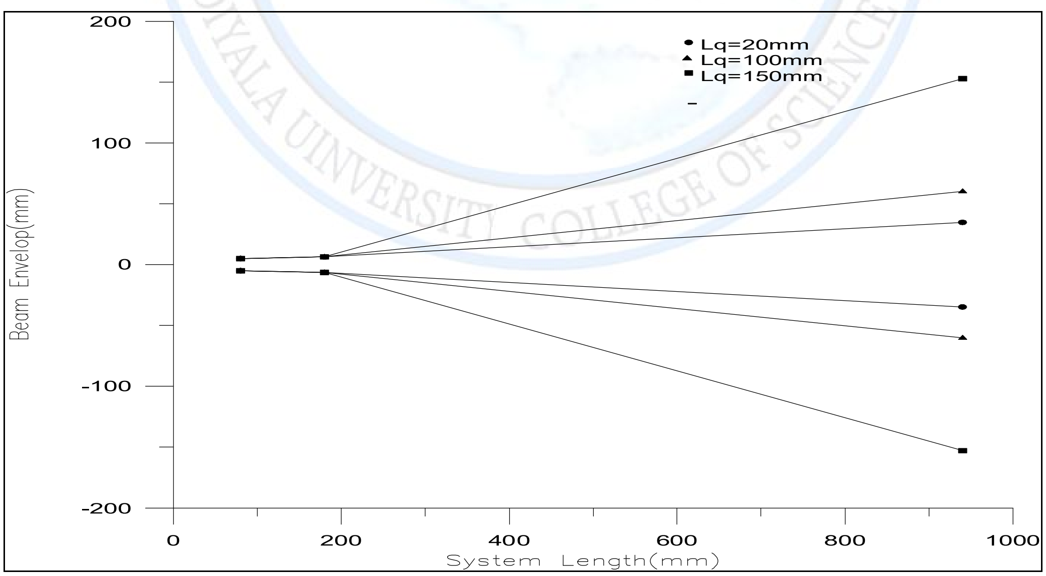
Figure(7):Effect of distance between lenses LD when S1=100mm and Lq=20mm in horizotal plane.

In figure(8) shows there is no clear action of lenses distance on focusing of quadropule lenses with constant (S1=100mm,Lq=20mm) but there is increasing in the system length with increasing distance between lenses.



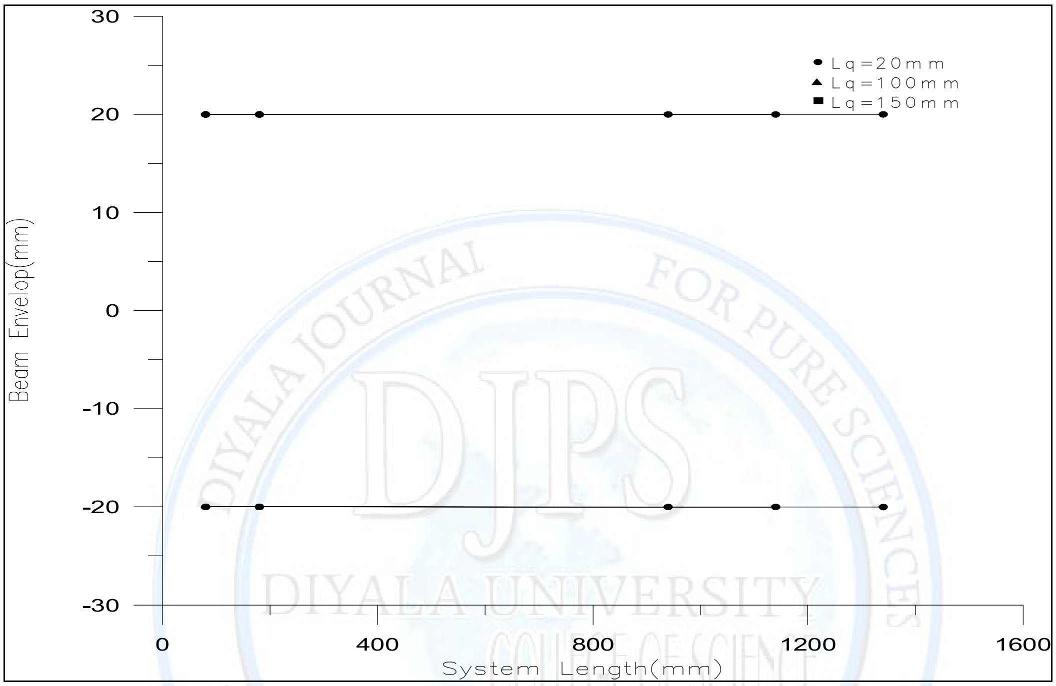
Figure(8):Effect of distance between lenses when S1=100mm and Lq=20mm in vertical plane.

Figure (9) represents the effect of quadrupole lens length Lq on the beam envelope for horizontal plane with constant S1=100mm and LD=20mm in this figure we note there is divergence action with increasing of quadrupole lens length Lq so it acts as divergence lens.



Figure(9):Effect of quadrupole lens length with S1=100mm and L=20mm on beam envelope for horizontal plane.

In vertical plane when Lq=20mm,100mm,150mm as figure (10) shows there is no clear action of quadrupole lens length on focusing of quadropule lens but there is increasing in the system length with increasing quadrupole lens length .



Figure(10):Effect of quadrupole lens length with S1=100mm and L=20mm on beam envelope for vertical plane.

Conclusions

From the results of this research ,it can be concluded the following:

For first free region(S1):

- The ion beam in first free region has diverge always but may be converge action if it came beyond strong focusing element .The increasing of first free region causes increasing of system length .

For triple quadruple lens:

- Increasing in LD obtains defocusing action in horizontal plane but there is no change in beam focusing in vertical plane.

- When increasing of Lq obtains defocusing action in horizontal plane but the increasing Lq does not effect on system action for vertical plane.
- The best design for this research is:
  (S1=100mm,LD=20mm and Lq=20mm)

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تبئير الجسيمات المشحونة باستخدام العدسة الالكتروستاتيكية الثلاثية الرباعية

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الخلاصة

يتضمن البحث الحالي دراسة تأثير العوامل الرئيسية على خواص حزمة الجسيمات المشحونة المارة خلال العدسات الالكتروستاتيكية الثلاثية الرباعية كعنصر تبئير في منظومات نقل الحزمة. و تضمن البحث دراسة تأثير كل من منطقة الانسياق الحرة الأولى ,المسافة بين العدسات وطول العدسات على خواص الجسيمات المشحونة في كل من المستويين الأفقي والعمودي .

الكلمات المفتاحية: هذا البحث يدرس حزمة الجسيمات المشحونة المارة خلال العدسات الالكتروستاتيكية الثلاثية الرباعية