Theoretical Study of Effect of Magnetic Mass Analyzer and Electrostatic Quadruple Lens on Beam Plasma

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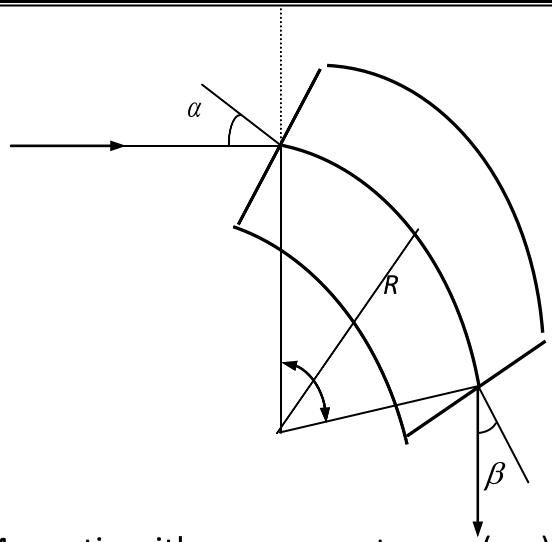
Abstract:

The research includes a study of the main parameters effect on plasma beam passing through the magnetic mass analyzer and the triplet quadrupole lenses where changing the parameter (entrance angle *α*, exit angle *β*, the distance between the lenses LD and quadruple lens length *lq*), which used as focusing or defocusing elements on the plasma beam in horizontal and vertical plane.

A computer program (Mustansiriyah transport ion beam) written in Fortran language to study these parameters, the results indicated that good focusing properties for both horizontal and vertical plane.

Introduction

A plasma beam is a group of particles that have about the same kinetic energy and move in about the same direction. A beam has a limited extent in the direction transverse to the average motion. The axis of charge particle beam could be represented by central trajectory and the axis may by curve if the beam passes through a transverse electric or magnetic field. The beam transport system has been containing a magnetic analyzer and electrostatic quadruple lens. Magnetic represented the classic type of mass analyzer, and many designs have been performed and still in use for magnetic sector instruments. The bent of the charged particles by the magnetic field leads to cleaning the beam from natural particles, then, focusing charged particles [1]. In design and manufacture of deflecting magnetic, some parameters must be regarded. Firstly, the entrance and exit edges (*α*, *β*),which are act as focusing regions that are resulted by a non-homogenous magnetic field .These regions are called a fringing field, as shown in figure (1). Secondly, the magnetic field distributions vacuum gap which are inside magnetic mass analyzer [2].



Figure(1): Magnetic with nonzero entrance (α) and exit (β) angles [3].

The triple consists of three single lenses of alternating polarity, are almost invariable symmetrical. That means the two outer elements are equal in length, strength and equally separated from the central element. So it may be derived from a double by dividing one of the elements into parts and placing the other element between them. The type of triplet depends on the arrangement of the singlet or doublet lenses forming it [4, 5] as shown in figure (2).

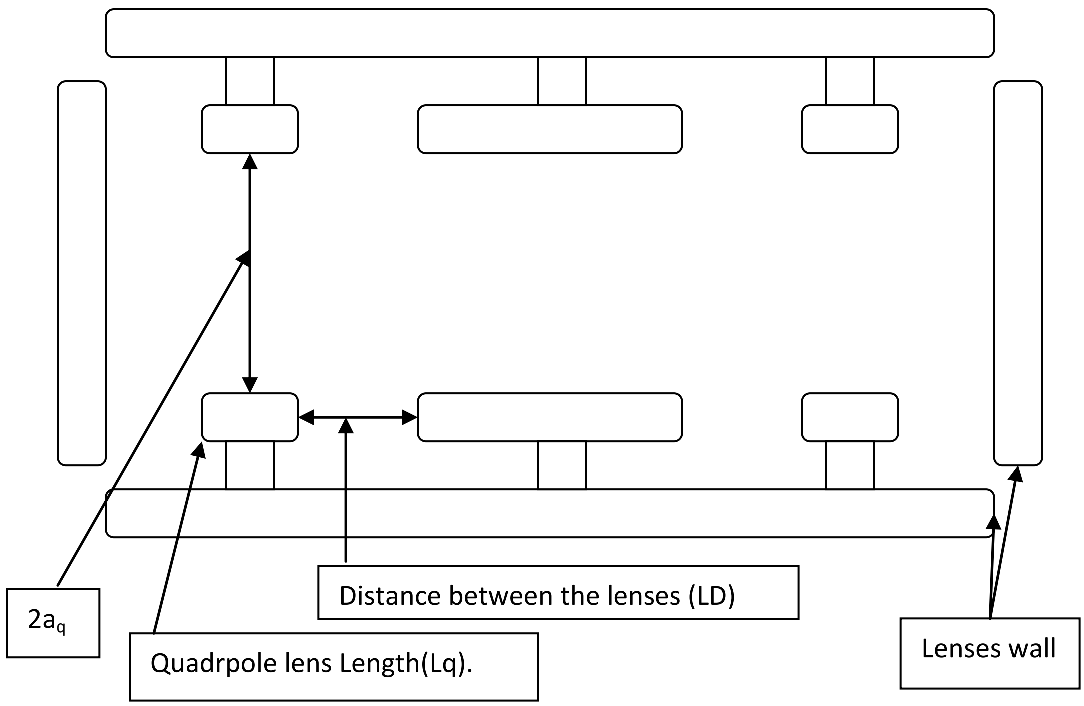


Figure (2): Triplet quadruple lens [3].

Mathematical treatment:

We represent a bundle of ray by a linear phase space matrix, σ-matrix, and for each region the relation between σ-matrix in two locations of the beam line is [2]:

$$\sigma(out) = R\ \sigma(in)\, R^{T} \qquad (1)$$

Where R : the 4×4 linear matrix, in the case of mid plane symmetry which leads no coupling in (x)and (y) plane.

After analyzing the motion of ion passing through the magnetic and electrostatic quadruple lenses the total R_x -matrix of the magnetic region is as follows:

$R_x = R_x$ (exit edge). R_x (inside the magnetic). R_x (entrance edge)

So that [6].

$$R_x = \begin{bmatrix} 1 & 0 \\ \dfrac{\tan\beta}{R} & 1 \end{bmatrix} \begin{bmatrix} \cos k_x l & \dfrac{1}{k_x}\sin k_x l \\ -k_x \sin k_x l & \cos k_x l \end{bmatrix} \begin{bmatrix} 1 & 0 \\ \dfrac{\tan\alpha}{R} & 1 \end{bmatrix} \qquad (2)$$

While total R_y -matrix of the magnetic region is [6]:

$R_y = R_y$ (exit edge). R_y (inside the magnetic). R_y (entrance edge)

$$R_y = \begin{bmatrix} 1 & 0 \\ -\dfrac{\tan(\beta-\psi)}{R} & 1 \end{bmatrix} \begin{bmatrix} \cos k_y l & \dfrac{1}{k_y}\sin k_y l \\ -k_y \sin k_y l & \cos k_y l \end{bmatrix} \begin{bmatrix} 1 & 0 \\ -\dfrac{\tan(\alpha-\psi)}{R} & 1 \end{bmatrix} \qquad (3)$$

Where (R) is the radius of the central trajectory inside the magnetic.(l) is the ion beam path inside the magnetic,($R_x = \dfrac{(1-n)^{\frac{1}{2}}}{R}$), ($k_y = \dfrac{\sqrt{n}}{R}$) ,(n) is the field index, and (ψ) is the fringing field effect angle[6].

Sigma matrix for the quadruple triplet lens in x-plane [7]:

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

$$+ 4\sigma x_{22}(in)\left(2L_q + s\right)^2\left(1+\theta^2\left(1+\frac{s}{L_q}\right)\right)^2$$

(4)

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

$$\left.\left(1+\theta^2\left(1+\frac{s}{L_q}\right)\right)\ \right)+2\sigma x_{22}(in)(2L_q+s)\left(1+\theta^2\left(1+\frac{s}{L_q}\right)\right)$$

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

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

In the same manner sigma matrix for the quadruple triplet lens in *y*-plane $\sigma y_{21}(out)$ can be found.

Where Lq : is effective length of lens, θ =*wt*=$w\frac{L_q}{\dot{z}}$ and (s) represents the relative length in (*z*) direction [7].

Results and Discussion:

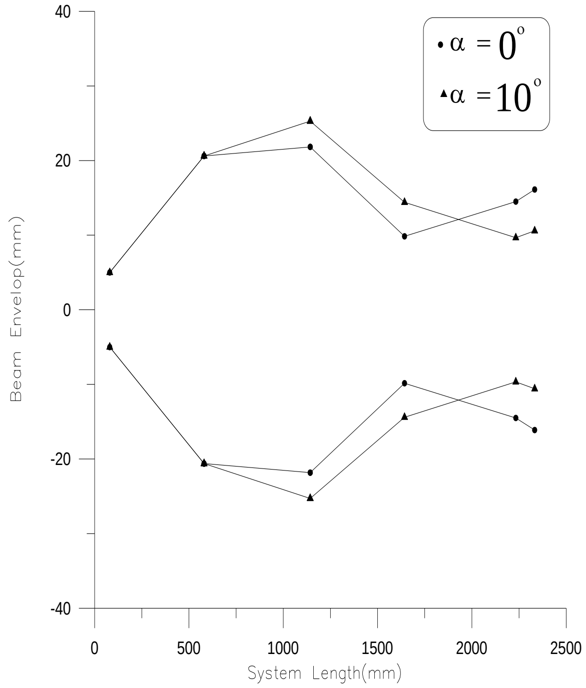
In this study, we consider a design at beam line system consisting of magnetic and quadruple setting the bending magnetic first and the electrostatic quadruple lens second and changing the parameter of these devices. Also we study the action of the system focusing or defocusing by using the beam line system, these parameters change as:

1. Entrance angle α=0º,10º
2. Exit angle β=0º,10º
3. Distance lens(LD)=20mm,100mm
4. Quadruple lens length(Lq)=100mm,150mm

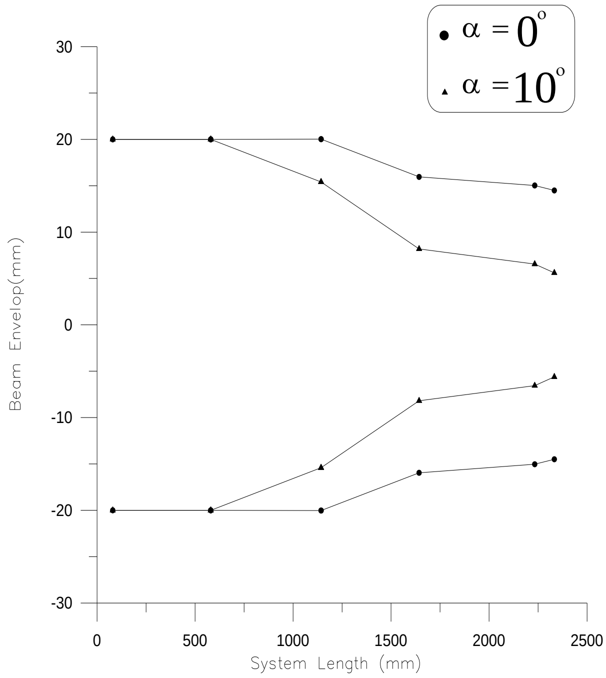
The schematic diagram of the system in this case represent as follows:

source	First drift space(S1)	Bending Magnetic	Second drift space (S2)	Quadruple region	Third drift Space(S3)	Target

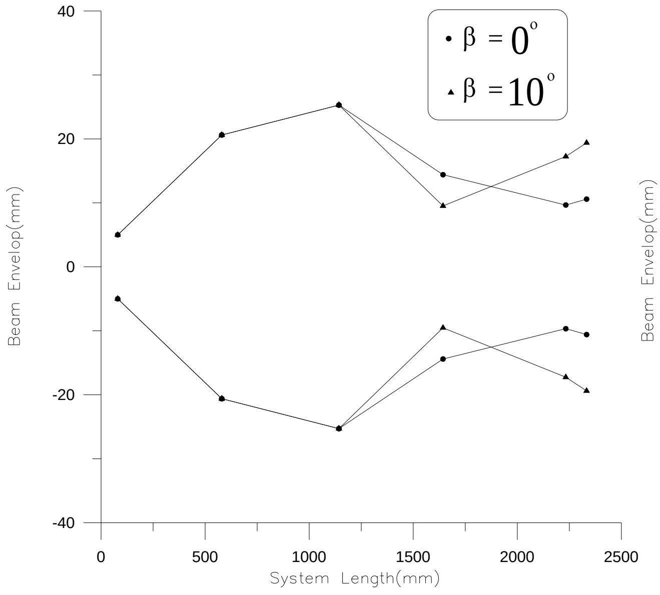
In case of horizontal plane, the entrance angle acts as divergence lens and exit angle acts as convergence lens as indicated in figures (1), (3)while in the vertical plane, the entrance angle acts as convergence lens and exit angle acts as divergence lens as indicated in figures (2), (4).



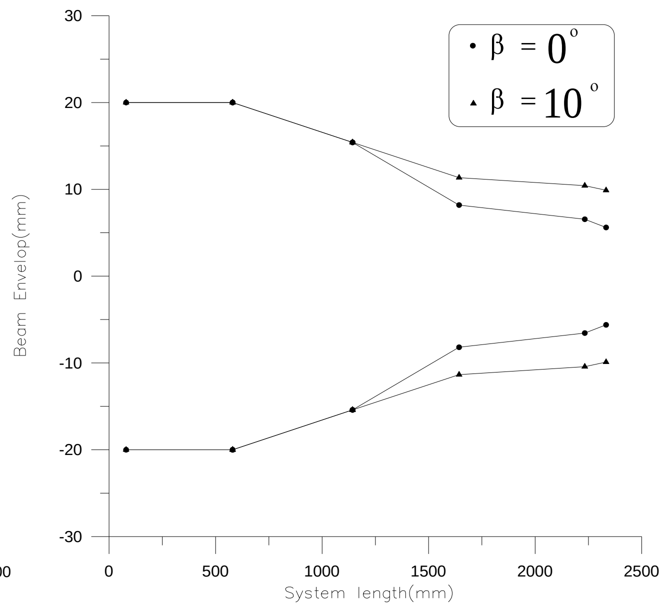
Figure(1):illustrates effect of entrance angle when exit angle=10,LD=20 and *Lq*=100mm in horizontal plane.



Figure(2):illustrates effect of entranceangle when exit angle=10,LD=20 and *Lq*=100mm in vertical plane.



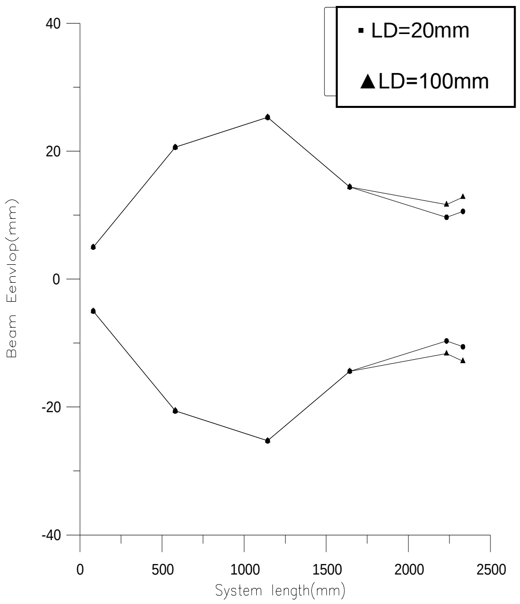
Figure(3):illustrates effect of exit anglewhen(entrance angle=10, LD=20mm and *Lq*=100mm in horizotal plane.



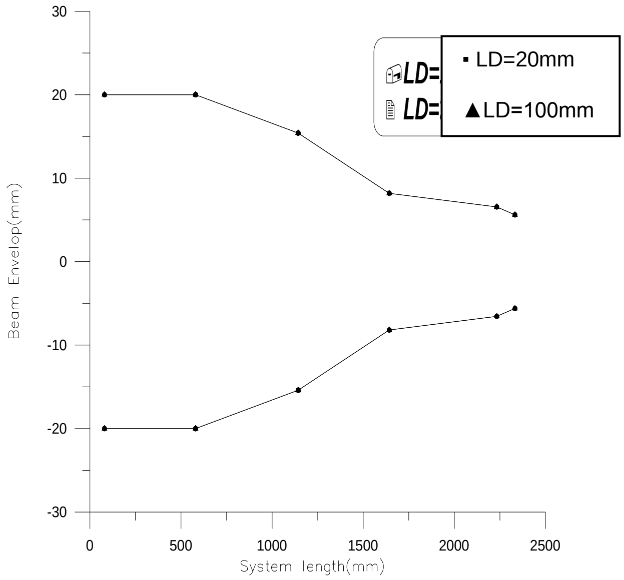
Figure(4):illustrates effect of exit anglewhen(entrance angle=10, LD=20mm and *Lq*=100mm in vertical plane.

For the increasing of distance between lenses LD it can be shown the defocusing (diverge) action of system in horizontal plane as shown in Figure (5) and there is no effect of LD on this action with constant beam envelope at the target as shown in figure (6) in the vertical plane because the initial angular divergence is small a value where initial angular divergence is the angle of the ray makes in the vertical plane with respect to the central trajectory.

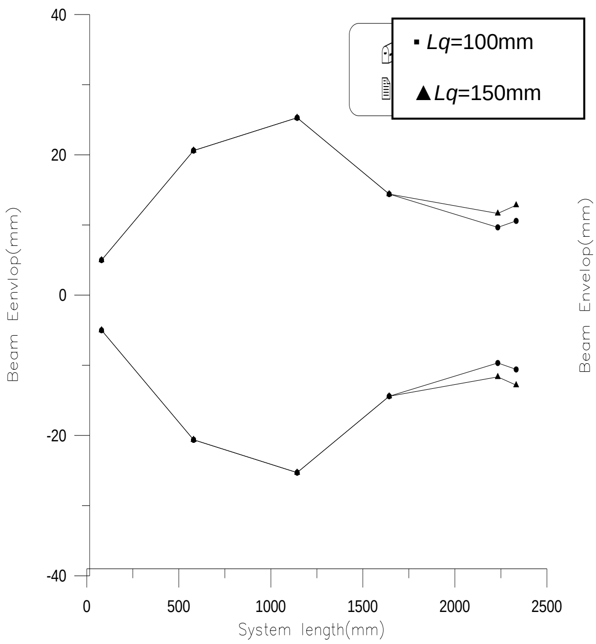
In horizontal plane, the increasing of electrostatic quadruple lens length (Lq) causes defocusing action of the system as shown in figure (7).While In vertical plane, there is no action of quadruple lens length on focusing of quadruple lens but there is an increase in the system length with an increase quadruple lens length as indicate in figure (8) because there is an increase in the length lenses (LD).



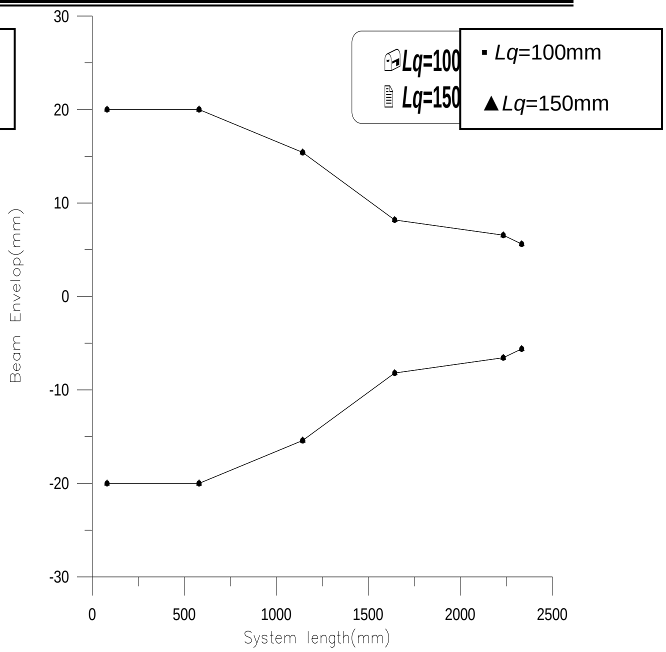
Figure(5):illustrates effect of distance between the lense when α=10,β=10 and *Lq*=100mm for horizontal plane.



Figure(6):illustrates effect of distance between the lenses when α=10,β=10 and *Lq*=100mm forvertical plane.



Figure(7):illustrates effect of quadrupole lens length when α=10,β=10 and *lq*=100mm for horizontal plane.



Figure(8):illustrates effect of quadrupole lens length when α=10,β=10 and*lq*=100mm for vertical plane.

Conclusions:

Form the above results one can conclude that:

The bending magnetic and electrostatic quadruple are important elements in the beam line system.

- The increasing entrance of entrance angle causes decreasing of the beam convergence in horizontal plane and increasing of the beam convergence in vertical plane so that the entrance angle acts as a divergence thin lens in horizontal plane and as a convergence thin lens in vertical plane.
- The exit angle acts as a convergence thin lens in horizontal plane and as a divergence thin lens in vertical plane.
- The increasing of distance between the lenses (LD) and the quadruple lens length (*Lq*) cause decreasing of beam convergence in horizontal plane and there is no change in beam focusing in vertical plane.
- The best design for this research is:

  ($\alpha=0^{0}$,$\beta=10^{\circ}$, LD=20mm and *Lq*=100mm).

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دراسة نظرية لتأثير مغناطيس التحليل الكتلي والعدسات الالكتروستاتيكية الرباعية الثلاثية على حزمة البلازما

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الخلاصة:

تضمن البحث دراسة تأثير العوامل الرئيسية على خواص حزمة البلازما المارة خلال مغناطيس التحليل الكتلي و العدسات الالكتروستاتيكية الثلاثية الرباعية القطب وبتغير كل من(زاوية الدخولα,زاوية الخروجβ والمسافة بين العدسات LD وطول العدسة الرباعية L_q) والتي استخدمت كعناصر تبئير وتشتت على حزمة البلازما في كل من المستويين الأفقي و العمودي.حيث تم بناء برنامج بلغة الفورتران لدراسة هذة العوامل . وقد تم الحصول على خصائص تبئير جيدة.