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Study the Optical Properties of Ion Beam from Plasma Source for Quadruple Magnet

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دراسة الخصائص البصرية للشعاع الأيوني من مصدر بلازما عبر المغناطيس الرباعي الاقطاب

بشرى جوده حسين

كلية التربية للعلوم الصرفة – ابن الهيثم / جامعة بغداد / بغداد، العراق

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ABSTRACT

Background:

The present research includes a study length effect of quadrupole magnet on the properties of charged particles beam passing through it, the work included theoretical analysis using matrix expounding because it is optimum way to be the representative of beam along any optical system.

Materials and Methods:

we used a Matlab program to study the effect of effective length (Lmm) on the basic parameters of quadruple magnet lens. The values of effective length are from (500 mm to 1000 mm) , to determine focal length and the lens power. The results indicated that increasing the effective length led to a decrease in the horizontal and vertical focal length of the system, but for the power lens, the opposite behavior would be occurred.

Results:

The effective length (L) and the focusing factor (k), whose product gives us the reversed focal length of the magnetic lens, are the main parameters that govern the behavior of a charged particle beam passing a set of quadruple magnets. Any alteration in the value of any one of them so provides a new perspective.

Conclusion:

Two measures that are used to characterize lenses are the focal lengths and the lens power. Shorter focal lengths are associated with stronger lenses. The reciprocal of focal length is lens power. It characterizes different optical systems in terms of particle movement and the smallest possible focusing point.

Keywords: Effective length, Ion beam, magnet quadrupole, optical properties and magnetic lenses

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1. INTRODUCTION

Beam transmission systems are those that provide the beam steering and focusing . these systems consist of a series of electromagnetic devices through which a beam passes [1]. There are many different types of electromagnetic devices such as magnets, which it used to direct the beam along a predetermined path, and magnetic fields are used that deflect beam as determined by the balance of the centrifugal force and the Lorentz force. [2, 3]. A quadrupole magnet is main part of a beam transmission system . It acts as a focus element on one axis and defocus element on the other axis.

The mechanism for directing and focusing the particles is provided by beam transmission systems and particle accelerators. For any application, a beam is expected to move along a desired beam transmission line, in close alignment with the design specified path. The basic components of are a series of electromagnetic components through which a beam is transmitted[1]. Most focusers for beam installations are actually designed to focus the particles, thus achieving focused beam on a point with a very small cross section of the beam [2,3]. There are many devices for focusing the beam such as alternating progressive focusing, edges focusing for magnet sectors , quadruple and sextuple lenses, solenoidal magnet and other devices. [4-6]. Two fascinating areas of plasma physics that are used to everyday applications as well as scientific study and technology developments are charged particle beam production and plasma confinement. The ultimate development of fusion reactors, which is almost ready to provide fusion energy as a sustainable energy source, is perhaps one of the most significant confinement topics. Various electrostatic and magnetic devices are needed to direct an ion beam in an accelerator system and charged particle transport system, all the way from the ion source to the experimental equipment. Electrostatic or magnetic lenses are needed to retain the diverging ion beam inside the evacuated beam tube. This is because the ion beam emerges from the ion source. As a result, the lenses aid to transfer as many ions from the ion source to the experimental equipment as possible by preventing the ion beam from striking and being stopped by the beam tube walls [7].

2. THEORETICAL PART

2.1. Ion Beam System

Ion sources produce pure ion beams. Typically, ions are produced in a plasma contained in a confined volume, and ions are extracted using a grid system, which confines the electrons and accelerates the ions[8].

The plasma extraction electrode, which is the front plate of the ion source and the electrode drawer, generates electric field required to accelerate the charged particles, and ion beam source forms ion optical system as figure (1). The intensity of the beam is based on a rough estimate of the flow of beam that strike the aperture of the extraction electrode and then release the plasma. The shape of the surface area is concave and depends on the plasma density and the electric field of the plasma surface[3,9]. The drift area is the same like the free area optical optics. As with a divergent or parallel beam remaining that way, the beam in this region maintain their direction of motion [10]. These lenses deflect beam at an angle proportional to the distance of beam from the center of the lens, which is their feature a particle of beams that are parallel can be focusing to a spot with use of such a lens focusing devices are necessary to maintain the beam

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coherence and providing the beam features at precise locations throughout the beam transmission line [11].

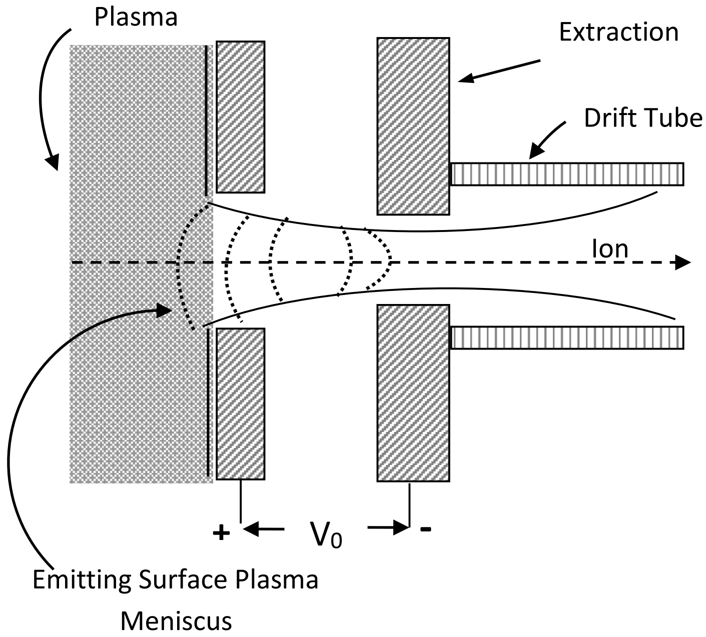


Figure 1: Schematic of a plasma ion source

2.2. Quadruple Magnet

The element that has two north poles and two souths is quadruple magnet. All of them are symmetrically grouped around the magnet's center. Across the main axis, there is no magnetic field [6]. The beam focusing by use of these lenses magnet. The beam passing through the center of the quadrupole magnet is not affected by any force, because all the field lines cancel each other out at that point. Particle beams that are farther off axis become more sharply focused because the field becomes stronger farther we are from the quadruple's center. It is evident that the particle beam is simultaneously defocusing in the horizontal direction and focusing in the vertical direction [9]. As a result, two distinct quadruple types must be utilized. One is similar to figure (1) [6]. The particle beam will be defocused in the vertical plane and focused in the horizontal plane due to this rotational variant. A sequence of quadrupoles can result in net focusing in both planes when set up properly [1,10]. It is common to refer to quadrupoles that focus in the horizontal plane as focusing quadrupoles (QF) and quadrupoles that focus in the vertical plane as defocusing quadrupoles (QD) [12]

In many disciplines, lenses magnet are frequently used to control beams of different energy and directions. A circularly form coil act like the simplest lens magnet, allowing the beam to flow cross its axis [1,13]. Quadrupole magnet as shown in Figure 2[14]. The beam passing across it experiences no force because each of lines field in the center cancel each other out [15-17].

The axis of orbital $w_j = (x_j, \acute{x}_j)$ changed in vector $w_f = (x_f, \acute{x}_f)$ by lens magnet quadruple. The components of w_f are linear combination of the component parts of w_j. This process can be expressed using the matrix notation $w_f = (A_f, w_j)$ if A_f is [1]:

$$A_f = \begin{vmatrix} \cos(L\sqrt{k}) & \sin(L\sqrt{k}/\sqrt{k}) \\ -\sqrt{k}\,\sin(L\sqrt{k}) & \cos(L\sqrt{k}) \end{vmatrix} \quad (1)$$

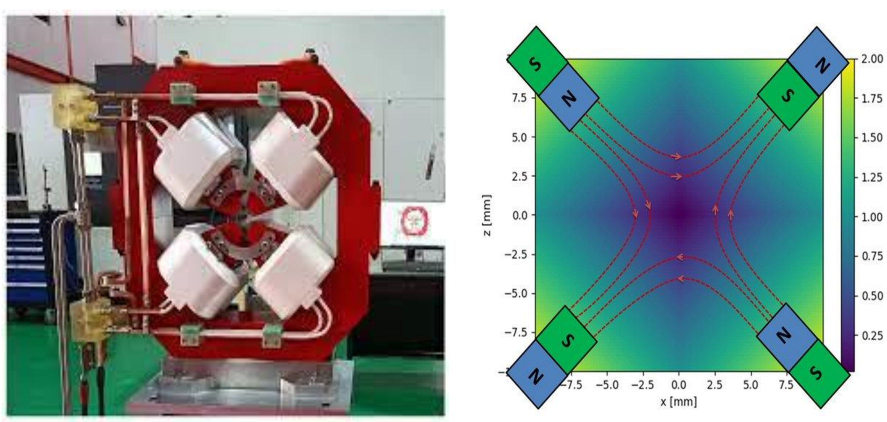
When the poles are rotate (90°), it causes the lens to defocus in the opposite direction, then:

$$A_D = \begin{vmatrix} \cosh(L\sqrt{k}) & \sinh(L\sqrt{k})/\sqrt{k} \\ \sqrt{K}\,\sinh(L\sqrt{k}) & \cosh(L\sqrt{k}) \end{vmatrix} \quad (2)$$

The specification (L) represents the effective length and (k) is the focusing power factor make a small value of (kL) and preserving the first Taylor series term of the sin and cosine results in the thin lens, in this case, the matrix becomes [16,18]:

$$A_q = \begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix} \quad (3)$$

where ($1/f = kL$) is the value of P (power of lens) and f is the focal length.



(a) (b)

Figure 2: (a) magnetic quadruple (b) description of a quadruple magnet Field [14]

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3. RESULT AND DISCUSSION

The effective length (L) and the focusing factor (k), whose product gives us the reversed focal length of the magnetic lens, are the main parameters that govern the behavior of a charge particle beam passing a set of quadruple magnets. While the two factors (focal length and power of lens) are calculated after both the effective length and the focusing factor are calculated. Any alteration in the value of any one of them so provides a new perspective. The effect of quadruple magnet lenses functioning as focusing or defocusing objects in both planes was calculated using a computer program created especially for this work (see table 1).

Table 1: Different values of effective length (L mm) with power of lens (p mm^{-1}) and focal length(F mm)

L_{eff} mm	F_x mm	F_y mm	P_x mm^{-1}	P_y mm^{-1}
500	0.62	2.28	1.86	0.43
525	0.53	1.96	1.97	0.50
550	0.48	1.77	2.20	0.58
575	0.45	1.65	2.38	0.61
600	0.41	1.59	2.52	0.64
625	0.39	1.41	2.69	0.70
650	0.33	1.27	2.78	0.73
675	0.30	1.13	2.86	0.76
700	0.27	1.08	2.99	0.80
725	0.26	0.96	3.11	0.83
750	0.24	0.94	3.28	0.87
775	0.21	0.93	3.36	0.91
800	0.19	0.91	3.49	0.94
825	0.18	0.87	3.57	0.99
850	0.16	0.85	3.62	1.08
875	0.15	0.82	3.91	1.19
900	0.14	0.80	4.12	1.22
925	0.12	0.78	4.50	1.29
950	0.10	0.75	5.01	1.32
975	0.09	0.71	5.42	1.36
1000	0.07	0.68	6.08	1.38

The stronger lenses are shown by decreasing focal lengths, whereas higher (L values) yield higher focus, indicating that the quadruple magnet is a narrow lens with good focusing capabilities [1]. We see a decrease in the lens's focal length values for both axes as the effective length grows, as shown in Figure (3).

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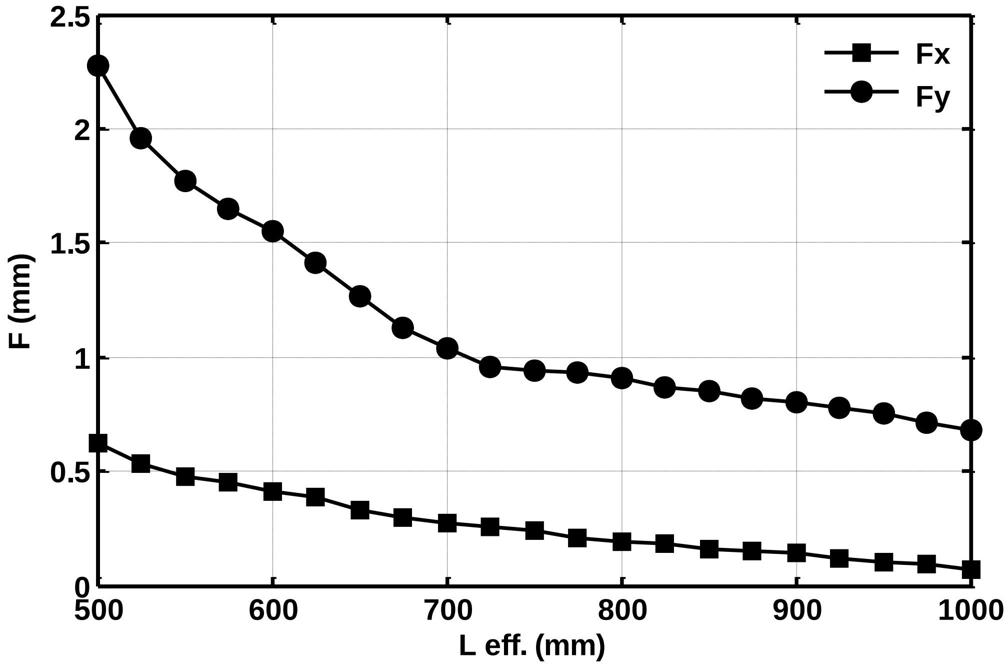

Figure 3: Relationship between the effective length and focal length for both axes horizontal and vertical

While figure (4) express that the power lens increases as effective length increases because the lens power is inversely related to the focal length.

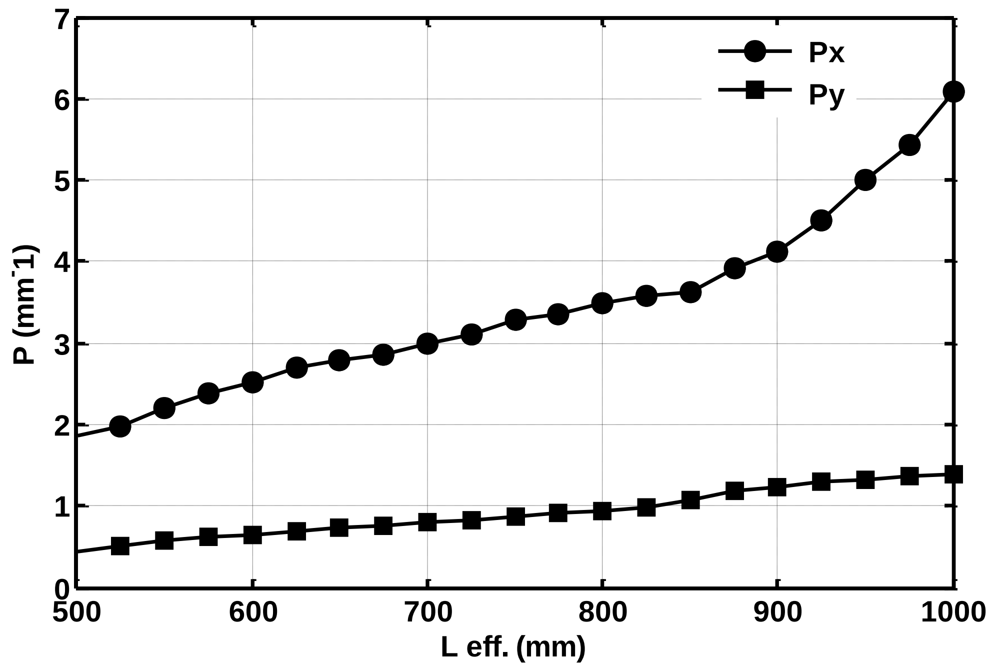

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Figure 4: Relationship between the effective length and power of lens for each of horizontal and vertical axes

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5. CONCLUSIONS

There are many parameters that are used to determine the optical properties of magnetic lenses (such as quadrupole magnets), including the focal length and the lens power factor, which are affected by changes in the effective length and focal factor, in addition to changes in the magnetic field strength. It was concluded that the relationship is inverse between the effective length of the quadrupole magnet and the focal length for both the horizontal and vertical axes, and we notice the opposite situation with regard to the power of lens factor, as by increasing the effective length, the power of lens factor increases for both axes because the lens power factor is the inverse of the focal length.

Conflict of interests.

There is no conflict interest

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خلاصة

الخلفية:

يتضمن البحث الحالي دراسة تأثير طول المغناطيس الرباعي على خواص حزمة الجسيمات المشحونة التي تمر من خلالها، وشمل العمل التحليل النظري باستخدام شرح المصفوفة لأنها الطريقة المثلى لتكون ممثلاً للشعاع على طول أي نظام بصري.

المواد والأساليب:

استخدمنا برنامج (الماتلاب) لدراسة تأثير الطول الفعال على المعلمات الأساسية للعدسة المغناطيسية الرباعية الاقطاب. قيم الطول الفعال هي من 500–1000 ملمتر لتحديد البعد البؤري وقوة العدسة. أشارت النتائج إلى أن زيادة الطول الفعال أدى إلى نقصان البعد البؤري الأفقي والرأسي للنظام، أما بالنسبة لقدرة العدسة فقد حدث السلوك المعاكس.

النتائج:

الطول الفعال وعامل التبئير (الذي يعطينا ناتجه البعد البؤري المعكوس للعدسة المغناطيسية) هما المعلمتان الرئيسيتان اللتان تحكمان سلوك شعاع الجسيمات المشحون الذي يمر بمجموعة من المغانط الرباعية الاقطاب. وأي تغيير في قيمة اي منهما يعطي بيانات لمنظومة جديدة. أشارت النتائج إلى أن زيادة الطول الفعال أدى إلى نقصان البعد البؤري الأفقي والرأسي للنظام، أما بالنسبة لقدرة العدسة فقد حدث السلوك المعاكس.

الاستنتاجات:

هناك مقياسان يستخدمان لتوصيف العدسات هما الأطوال البؤرية وعامل قدرة العدسة. ترتبط الأطوال البؤرية الأقصر بالعدسات الأقوى. كما ان مقلوب البعد البؤري هو قدرة العدسة. لقد تم التوصل إلى أن العلاقة عكسية بين الطول الفعال للمغناطيس الرباعي الاقطاب والبعد البؤري لكل من المحورين الأفقي والرأسي، ونلاحظ الوضع المعاكس فيما يتعلق بعامل قدرة العدسة، حيث أنه بزيادة الطول الفعال يزداد عامل قدرة العدسة لكلا المحورين.

الكلمات المفتاحية: الطول الفعال، الشعاع الأيوني، المغناطيس الرباعي الاقطاب، الخصائص البصرية والعدسات المغناطيسية