International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.10 No.13, pp 214-218, 2017

Theoretical Study to calculate some parameters of Ion Optical System

***Bushra Joudah Hussein**

***Department of Physics/ College of Education for Pure Science (Ibn Al-Haitham)/University of Baghdad, Iraq**

Abstract: In this study Matlab program build to study the effect of main parameter of quadrupole magnet lens. The study included theoretical analysis using matrices representation to calculate the focal length, lens power, effective length and displacement (the bandwidth envelope) for Horizontal and Vertical plane. Results showed the increasing in effective length caused decreasing in focal length of the system for horizontal and vertical plane, the opposite action appeared with lens power. Furthermore the increasing in effective length caused decreasing in Horizontal displacement (beam envelope) for horizontal plane, the opposite action appeared for vertical plane.
Key Words : Ion Optical, Focusing lenses, Quadrupole Magnet, Magnetic lens.

1. Introduction

A charged particle motion is determined mainly by interaction with electromagnetic forces [1]. Focusing systems of most installations of particle-beam technology are really intended for beam focusing, that is, obtaining a very small beam cross section (point focusing) [2]. New types of focusing systems, such as quadruple lenses, edge focusing in sector-shaped magnets, alternating gradient focusing, and so on, were invented and contributed to the successful development of plasma physics with steadily increasing energies and improving performance characteristics [3]. Applying the formalism of geometric optics the quadruple magnetic lens can be described as a thin focusing lens [4]. The current research aims to study the focal length of quadrupole magnet system to get the best values that leading to minimum band width or best focusing which is achieved in more control on beam transport systems.

2. Theoretical parts

2.1 Ion Source

The source consists of the front plate of the ion source, which is known as the plasma electrode, and at least one other electrode, the puller electrode, which provides the electric field for accelerating the charged particles from the ion source to form an ion beam. The intensity of the particle beam depends, as a first approximation, on the flux of charged particles hitting the plasma electrode aperture. The emitting plasma surface area has a concave shape, which depends on the plasma density and the strength of the accelerating electric field at the plasma surface [3,5].

2.2 Ion Optical System Focusing

As in light optics, a space in which a beam propagates without any forces acting on beam particles as field free region is called drift space. In this space, beam particles maintain their direction of motion, like a divergent or parallel beam remains divergent or parallel [6]. The characteristic property of such focusing lenses is that a light ray is deflected by an angle proportional to the distance of the ray from the center of the lens. With such a lens a beam of parallel rays can be focused to a point .To keep the particle beam together and to generate specifically desired beam properties at selected points along the beam transport line, focusing devices are required [7]. The most suitable device that provides a material free aperture and the desired focusing field is called a quadrupole magnetic lens [8, 9]. There are two parameters terms applied to lenses, the lens power and the focal lengths. The strength of a lens is determined by how much it bends orbits. Shorter focal lengths mean stronger lenses. The inverse of the focal length is lens power. It characterizes different optical systems in terms of the minimum focal spot size and maximum achievable particle flux. [5].

2.3 Quadrupole Magnet Lenses

Magnetic lenses are widely used to control beams of charged particle with various energy and directions in several fields. Therefore their focal properties have been extensively studied theoretically and also experimentally. The simplest magnetic lens is a donut-shaped coil through which the beam passes, preferably along the axis of the coil [1, 10]. A quadrupole is a magnetic element that has four poles, two norths and two souths. They are symmetrically arranged around the centre of the magnet. There is no magnetic field along the central axis [11]. These magnets are used to focus the particle beam. In quadrupole magnet the field lines all cancel each other out at the centre of the quadrupole so a particles beam feels no force as it passes through the centre. [3, 7]. Its field, concentrated between the four magnetic poles. In order to keep the beam confined in both transverse planes, it is necessary to have a sequence of quadrupoles with alternate polarity [12]. The quadrupole magnet lens converts the orbit vector ui = (x_i, x_i') into the vector u_f = (x_f, x_f'). The components of u_f are linear combinations of the components of ui. The operation can be written in matrix notation u_f=A_F u_i if A_F is taken as [1]:

$$A_F = \begin{bmatrix} \cos(L\sqrt{k}) & \sin(L\sqrt{k})/\sqrt{k} \\ -\sqrt{k}\sin(L\sqrt{k}) & \cos(L\sqrt{k}) \end{bmatrix} \quad (1)$$

If the poles of quadrupole magnet are rotated 90^o, the lens defocuses in the other direction then:

$$A_D = \begin{bmatrix} \cosh(L\sqrt{k}) & \sinh(L\sqrt{k})/\sqrt{k} \\ -\sqrt{k}\sinh(L\sqrt{k}) & \cosh(L\sqrt{k}) \end{bmatrix} \quad (2)$$

where the subscript Fand D denotes focusing and defocusing respectively.

The parameters *L* represented the effective length of quadrupole magnet (in metre) and *k* represented the strength focusing factor (in m^{-2}) [13]. The thin lens approximation is done by making the (kL) small and by keeping the first term of Taylor series for the cosine and sine. The matrix then takes the form

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

Where *f* is the focal length, in case of quadruple given by [7, 14]

$$1/f = kL \quad (4)$$

3. Results and Discussion

The main parameters effect on the behavior of charged particles beam passing through a system of quadrupole magnet can be fixed, these parameters are k (strength focusing factor), and the effective length (L) which the product of these two parameter gives us the inverted focal length of the lens magnetic. So any changing in the one of these parameters gives different lens which means new beam profile. In this study the action of quadrpole magnet lens as focusing or defocusing elements in horizontal plane or in vertical plane this effect was calculated using a computer program that has been built for this purpose (see table 1) which indicates the focal length, lens power and displacement for horizontal and in vertical axis for different values of effective length we note in it when the increasing in effective length causes decreasing in focal length for horizontal and vertical plane, the opposite action appears with lens power.

Table (1): The Focal Length, Lens power and displacement for x and y axis for different values of Effective Length

Effective Length L mm	Focal Length for x-axis f_x mm	lens power for x-axis P_x mm^{-1}	Focal Length for y-axis f_y mm	Lens power for y-axis P_y mm^{-1}	Horizontal displacement x mm	Vertical displacement y mm
100	2.40	0.41	10.00	0.10	17.42	10.69
200	1.22	0.83	5.03	0.19	15.74	11.23
300	0.83	1.20	3.12	0.32	12.95	11.90
400	0.61	1.63	2.40	0.41	11.87	12.72
500	0.50	2.01	2.00	0.50	10.99	13.68
600	0.42	2.45	1.51	0.66	9.46	14.79
700	0.35	2.83	1.43	0.69	8.96	16.06
800	0.31	3.20	1.26	0.78	6.86	17.49
900	0.27	3.61	1.11	0.90	4.17	19.11
1000	0.25	4.09	1.00	1.00	3.90	20.92
1100	0.22	4.44	0.91	1.09	2.64	22.95
1200	0.20	4.82	0.82	1.22	1.93	25.21
1300	0.19	5.24	0.77	1.29	1.29	27.72
1400	0.17	5.61	0.71	1.40	0.98	30.52
1500	0.16	6.08	0.67	1.49	0.52	33.62

Figure 1 illustrate the focal length as a function of effective length for horizontal and vertical axis, the best focus occurs for high values of L which means good focusing properties of quadruple magnet as thin lens where shorter focal lengths mean stronger lenses [1]. While Figure 2 notes that the relationship is extrusive, an increase of effective length value increases the power of the lens because the lens power is the inverse of the focal length. Figure 3 and 4 indicate the relation of horizontal and vertical displacement as a function of focal length respectively. In two forms note that the horizontal displacement (beam envelop) increases with increased focal length, that means there is a focusing for charged particle beam in horizontal plane while opposite action appears in vertical plane.

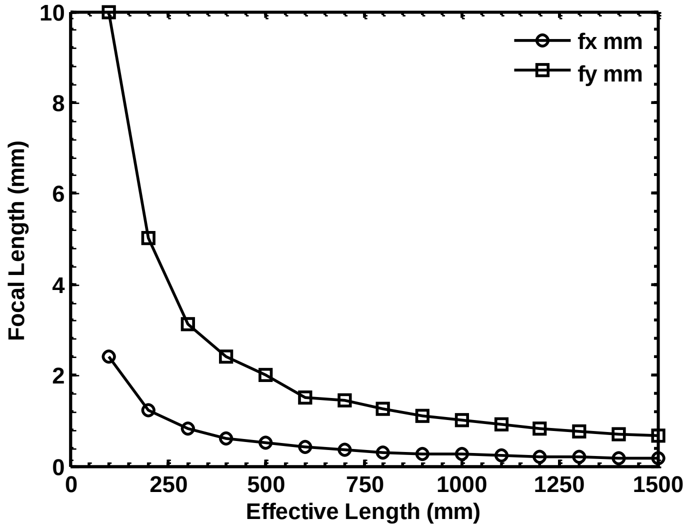

Figure 1: Variation of focal length as function effective length for x and y axis

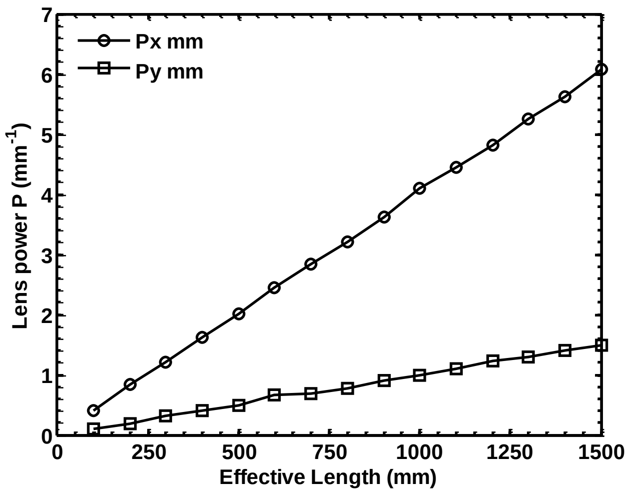

Figure 2: Variation of Lens power as function Effective Length for x and y axis

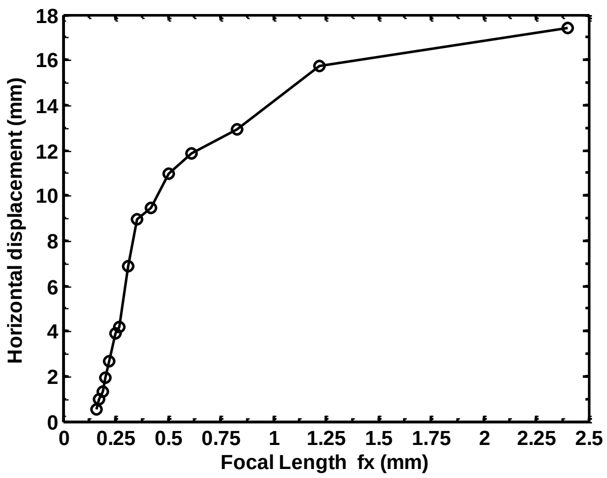

Figure 3: Variation of horizontal displacement with focal length for x-axis

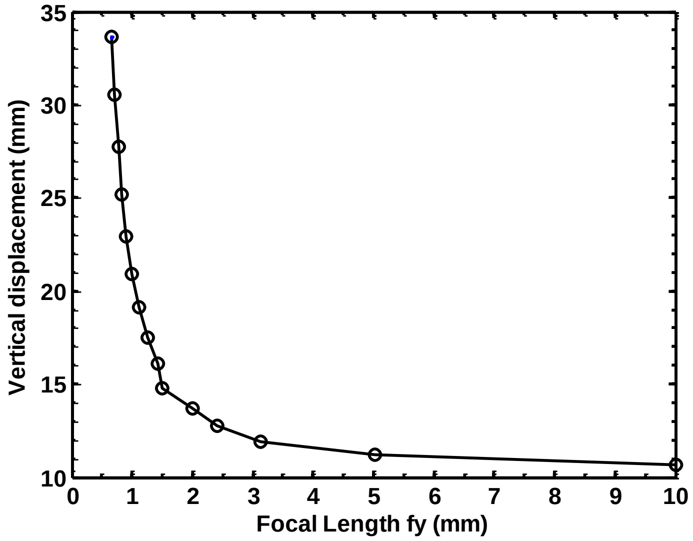

Figure 4: Variation of vertical displacement with focal length for y-axis

4. Conclusions

The results have shown that quadrupole magnet acts as focusing element for the horizontal plane while acts as defocusing element for vertical plane. The increasing in effective length causes decreasing in focal length for horizontal and vertical plane, the opposite action appears with lens power. Furthermore the increasing in effective length causes decreasing in horizontal displacement (beam envelope) for horizontal plane, the opposite action appears for vertical plane

References

1. Humphries, S. Principles of Charged Particle Acceleration. Published by Jon Wiley and Sons. University of New Mexico, Copyright 1999.
2. Molokovsky, S.I.; Sushkov, A.D. Intense Electron and Ion Beams,Springer-Verlag Berlin Heidelberg, Printed in Germany 2005.
3. Reiser, M. Theory and Design of Charged Particle Beams. WILEY-VCH Veriag Gmbh and Co. KGaA, Weinheim, Printed in the Federal Republic of Germany 2004.
4. Mikhail, A. Transport Properties of Intense Ion Beam Pulse Propagation for High Energy Density Physics and Inertial Confinement Fusion Applications, PhD, university of candidacy, 2010.
5. Kalvas, T. Beam Extraction and Transport, Department of Physics, University of Jyv¨askyl¨a, 40500 Jyv¨askyl¨a, Finland, January, 2014.
6. Meier, J. Matching of the beam from a negative-ion source for capture in a Penning trap, Diploma thesis, University of Heidelberg, Germany, December 2007.
7. Wiedemann, H. Particle Accelerator Physics. Fourth edition. Springer- Verlag Berlin Heidelberg 2015.
8. Hock, K. Quadrupole Magnet. Cockcroft Institute, Liverpool University, 2010.
9. Halbach, K. Conceptual Design of a Quadruple Magnet with Adjustable Strength. Nucl. Inst. Meth. 1983, 206, 353.
10. Wollnik, H. Optics of Charged Particles, Academic Press, Orlando, 1987.
11. Wildner ,E. Accelerator Physics Transverse Motion. NuFACT School. 2009.
12. Lombardi,A. Beam Lines. CERN Accelerator School, Geneva, Switzerland, September, 2006.
13. Roncarolo , F. A Ccuracy of the Transverse Emittance Measurements of the CERN Large Hadron Collider. PhD Thesis. Milano, Italy. 2005.
14. Parker, W. Computation project simulating the focusing and collimation of an electron beam through the beam delivery system of the international linear collider, February 2015.

*****