Journal of Engineering and Technology Research Vol. 2(8), pp. 219-225, November 2010
Available online at http:// www.academicjournals.org/JETR
ISSN 2006-9790 ©2010 Academic Journals

Full Length Research Paper

Two and three electrostatic lens systems for focusing of charged particles

M. M. Abdelrahman

Accelerators and Ion Sources Department, Nuclear Research Center, Egyptian Atomic Energy Authority P. O. Box 13759 Inchas, Atomic Energy, Cairo, Egypt.
Physics Department, Alzulfi College of Science, Majmaah University, Saudi Arabia. E-mail: moustafa82003@yahoo.com.

Accepted 2 November, 2010

Design of the focusing lens system has been done by using SIMION computer program which is used to trace and simulate the ion beam during its transport. A parallel beam of singly charged nitrogen ions of diameter 2 mm with energy of 3 keV was started at a distance of 50 mm before entering the lens system. In order to design the system, we studied it with different parameters in the presence of space charge. This study includes design and optimization of the operating parameters for the two-and-three cylinder lens systems. In a two-cylinder lens system, the first electrode was set at zero volts and the voltage applied to the second electrode was varied from 0 to –8 kV. Influence of the negative voltage applied at the second electrode for the–two-lens system on both the beam emittance and the beam diameter has been investigated for singly charged nitrogen ion trajectories. Beam emittance and beam diameter as a function of the tube diameter of the two-cylinder lens system have been studied. Also, beam emittance and beam diameter for a singly charged nitrogen ion as a function of the focusing points at different distances measured directly from the end of the-two-lens system has been investigated. Influence of the atomic masses of the different elements has been studied on both the beam emittance and beam diameter. The same study has been done for the-three cylinder-lens system.

Key words: Two-and- three cylinder lens systems, acceleration voltage, beam emittance and beam diameter, SIMION computer program.

INTRODUCTION

Computer simulation codes provide a powerful tool for the optimization of charged particle systems. However, the right program has to be selected to take full advantage of the computer. Computer modelling of charged particles is important in the investigation of processes that take place in different electro-physical equipments and has been used for about 50 years (Litovko and Oks, 2006) . There are three classes of computer programs for simulation of the charged particle beams (Wolf, 1995; Spädtke, 1989):

(1) Envelope models, where the beam is described by ellipses in different projections of phase space. These ellipses are transformed by a matrix (transfer matrix), for each optical element of the beam line. This kind of program can be used to analyze and optimize static beam transport sections (drift, electrostatic lenses, solenoids and quadrupoles or sector magnets).
(2) The particle tracking program, which is more advanced than envelope models, which can be used to transfer matrices by tracking single particles instead of three ellipse parameters.
(3) The ray tracing program, where this kind of program can be used to simulate the charged particle beam within the extraction and ion beam transport system. One of these ray tracing programs is SIMION 3D 7.0 which now is a full windows program (Dahl, 2000), featuring 3D electrostatic-magnetic arrays, data recording, charge repulsion, solid geometry definition files and a user program interface.

The original version of SIMION program was an electrostatic lens developed by D.C.McGilvery at Latrobe University in Australia (1977) (Dahl et al., 1990). Electro-static lenses are widely used to control beams of charged particles with various energy and direction in several fields (Sise et al., 2005; Humphries, 1999; Livingston and Belwett, 1962). They are used in focused ion beam systems, where they are more effective than magnetic lenses. The aim is to concentrate as many particles as possible, in as small volume as possible. The optical properties of electrostatic lenses are fixed by the voltage ratios. The focusing of charged particles with an electrostatic field could be obtained by devices that consist of a sequence of the accelerating electrodes with cylindrical symmetry has lens–like properties. In this paper, Design of the two and three electrostatic lens systems has been done using SIMION computer program.

In this study, characteristic parameters for two and three lens systems have been studied and investigated with space charge of 0.1 mA. Simulation of singly charged nitrogen ion trajectories was with a constant plasma density. The positions and elevation angles were measured with energy of 3 keV at a distance of 50 mm before entering the lens system. Beam emittance was calculated, using the separate standard deviations of the positions (σy) and the elevation angles ($\sigma\alpha$) for singly charged nitrogen ion trajectories;

$$\varepsilon = \sigma_y \sigma_\alpha \quad (1)$$

Design of the two-cylinder lens system

This system consists of two electrodes with dimensions as shown in Figure 1. This kind of electrostatic lens system is produced by the field between the ends of the two co-axial cylinders where the two cylinders have the same diameter (Litovko and Oks, 2006).

Design of the three-cylinder lens system

This kind of lens is used in particle accelerators, ion implantation and mass spectrometers (Sise et al., 2005; Septier, 1967; Spangenburg, 1948).

If the voltage of an intermediate electrode (V2) is adjusted to be out from the range of the voltages of the outer electrodes (V1) to (V3), then we get 'Saddle field lenses'. Because the potential distribution becomes saddle shaped, in which the three potentials are different for the three electrodes but the voltage of the intermediate electrode is larger than the outer electrodes. The focal length of this lens is shortened gradually as the potential (V2) of the intermediate electrode either increases beyond (V3) or decreases below (V1). When the potential of the two outer electrodes is of the same value (V3 = V1), this type of electrostatic lens is called an einzel lens. This lens system consists of three electrodes as shown in Figure 2.

RESULTS AND DISCUSSION

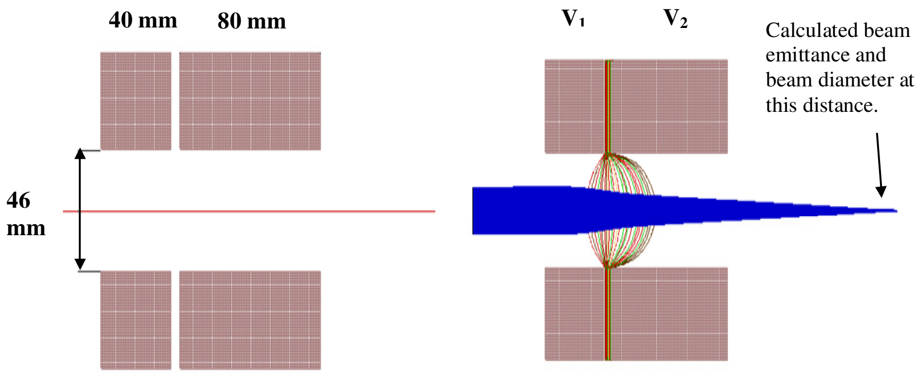
Beam emittance and beam diameter as a function of the gap width have been studied for the two and three cylinder lens systems (Figure 3). The gap width represents the distance between the two coaxial cylinders for the two element lens and it also represents the distance between each of the pairs of coaxial cylinders for the three element lens. It was found that an increase of the gap width is accompanied by an increase of the beam dia-meter for both two and three cylinder lens systems. Also, minimum beam emittance for the two lens system at a focusing voltage V2 = - 5500 V was found at gap width of 7 mm whereas minimum beam emittance for the three lens system at a focusing voltage VIE = - 4500 V was found at a gap width of 9 mm and beam emittance for a three-cylinder lens system was smaller than for a two-cylinder one.

Beam emittance and beam diameter as a function of the focusing points at different distances for singly charged nitrogen ion trajectories of the two and three cylinder lens systems have been investigated (Figure 4). Minimum beam emittance was found downstream of 350 mm for the two-cylinder lens system while minimum beam emittance for the three cylinder-lens system was found downstream of 340 mm. Minimum beam diameter for a two-cylinder lens system was found at 250 mm and minimum beam diameter for a three cylinder-lens system was also found at 350 mm.

Beam emittance and beam diameter as a function of the diameter of the lens systems have been investigated (Figure 5). Minimum beam emittance was found at a diameter of 46 mm and length of the first electrode equals 40 mm and second electrode of 80 mm for the-two- cylinder lens system. Minimum beam emittance was found at a diameter of 50 mm and length of the first electrodes equal 40 mm and the intermediate electrode of 80 mm for the three-cylinder lens system. Minimum beam diameter for both two and three-cylinder lens systems were found at 36 and 44 mm, respectively.

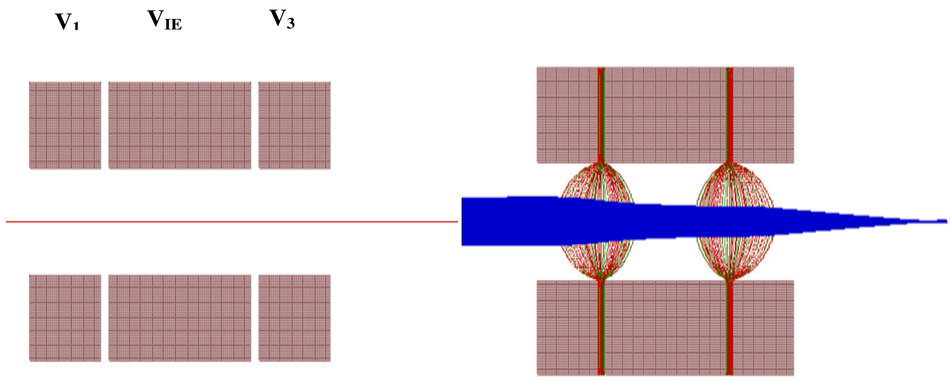
Influence of the focusing voltage on beam emittance for the two–cylinder lens has been studied (Figure 6). Minimum beam emittance and minimum beam diameter were found at focusing voltage applied on the second electrode of the two-lens system of -5500 and – 7000 V, respectively. The first electrode of the two-lens system was set at zero volts. Influence of the focusing voltage on beam emittance of the intermediate electrode for the three–cylinder lens system at focusing point = 340 mm, gap width = 9 mm and voltage of the outer electrodes = 0 V, has been investigated. It was found that the minimum beam emittance results at a focusing voltage VI.E = - 4500 V (Figure 6), whatever the minimum beam diameter for the three-cylinder lens system was found at a negative focusing voltage, applied to the intermediate voltage, VI.E = - 5500 V (Figure 6).

Space charge depends on the geometry of the electrodes, applied potentials and ion current. Therefore, the change of the ion current has a clear influence where other parameters were fixed. The space charge force acts as a diverging force because particles of the same charge repel each other. The influence of space charge is a disadvantage for both the quality and intensity of the extracted ion beams. The influence of space charge on both beam emittance and beam diameter has been studied studied for the two and three-cylinder lens systems (Figure 7). Operating parameters for the two and three-



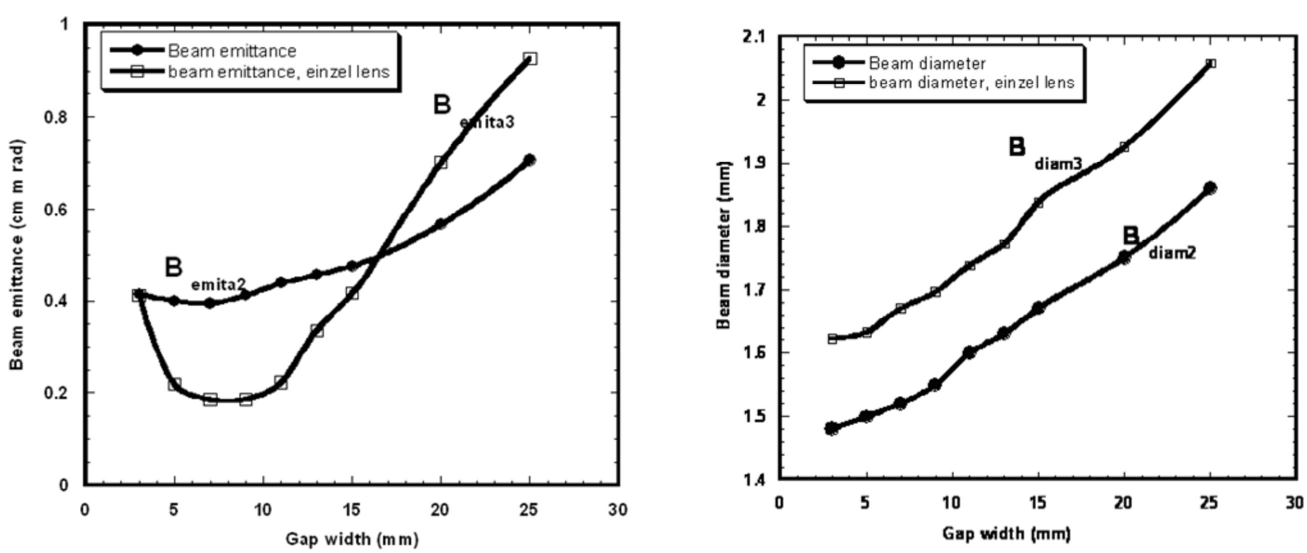
(a) Lens dimensions (b) Nitrogen trajectories with contours

Figure 1. Two-cylinder lens system.



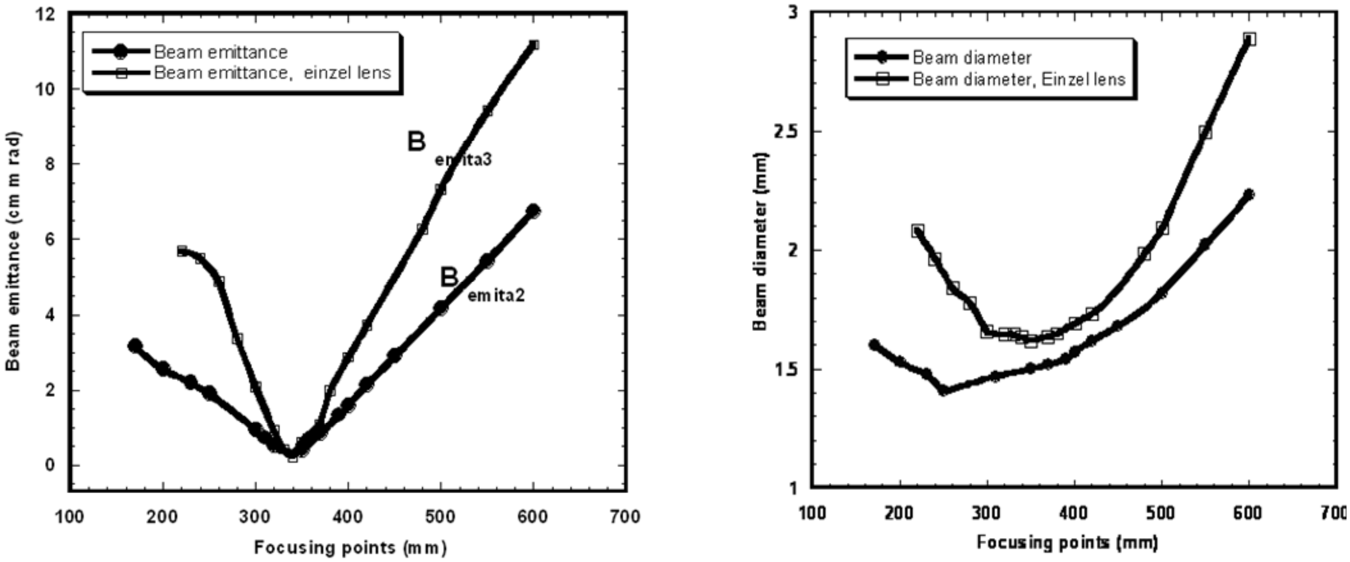
(a) Lens voltage distributions (b) Nitrogen trajectories with contours

Figure 2. Three-cylinder lens system.



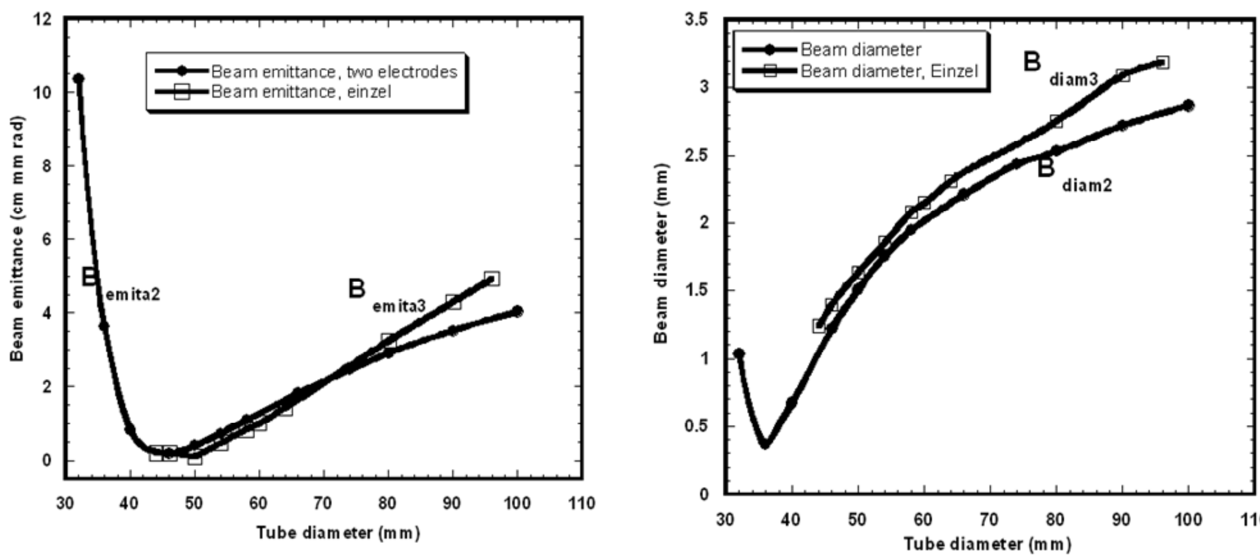
(a) (b)

Figure 3. Beam emittance and beam diameter as a function of the gap width of two (Bdiam2 and Bemita2) and three (Bdiam3 and Bemita3) cylinder lens systems at V2 = - 5500 V, VIE= - 4500 V, respectively for singly charged nitrogen ions with space charge of 0.1 mA.



(a) **(b)**

Figure 4. Beam emittance and beam diameter as a function of the focusing points measured from the end of the two (Bdiam2 and Bemita2) and three (Bdiam3 and Bemita3) cylinder lens systems at V2= - 5500 V, VIE = - 4500 V, respectively and current = 0.1 mA.



(a) **(b)**

Figure 5. Beam emittance and beam diameter as a function of the diameter of two (Bdiam2 and Bemita2) and three (Bdiam3 and Bemita3) cylinder lens systems at V2 = - 5500 V, VIE = - 4500 V, respectively and current = 0.1 mA.

cylinder lens systems have been studied with the same conditions as, voltage applied to the second electrode of the two-cylinder lens system was V2 = - 5500 V and the first electrode was set to zero volts and gap width = 7 mm. It is found that, the space charge has a large effect on the beam emittance, at current higher than 10 to 4 A. Minimum beam emittance for the lens systems was found at a current of 10 to 4 A, and started to have a large effect to have a large effect at current higher than 10 to 4 A. Minimum beam diameter for the lens systems were also found at a current of 10 to 5 A, and started to have a large effect at current higher than 10 to 5 A. Beam emittance for the three cylinder lens system was smaller than for the two one, whereas the beam diameter for the two cylinder one was found to be smaller than for the three one (10 to 5 A).

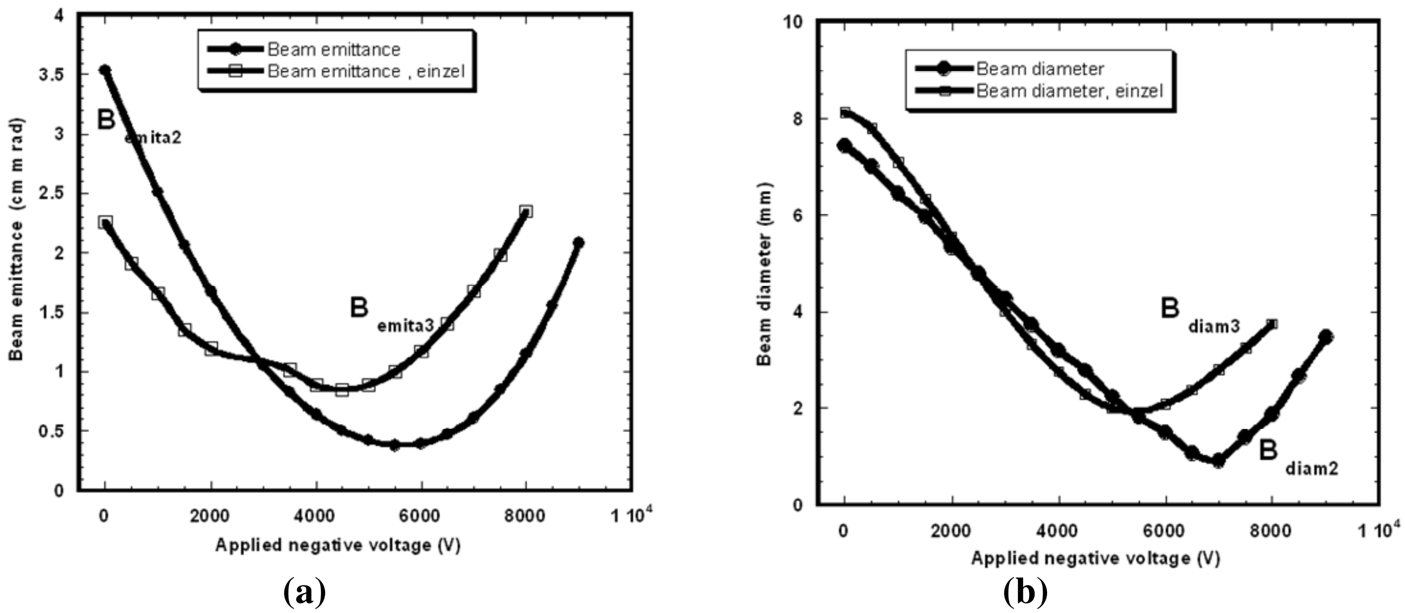


Figure 6. Influence of the focusing voltage on both beam emittance and beam diameter of the two (Bdiam2 and Bemita2) and three (Bdiam3 and Bemita3) cylinder lens systems for singly charged nitrogen ion trajectories with space charge of 0.1 mA.

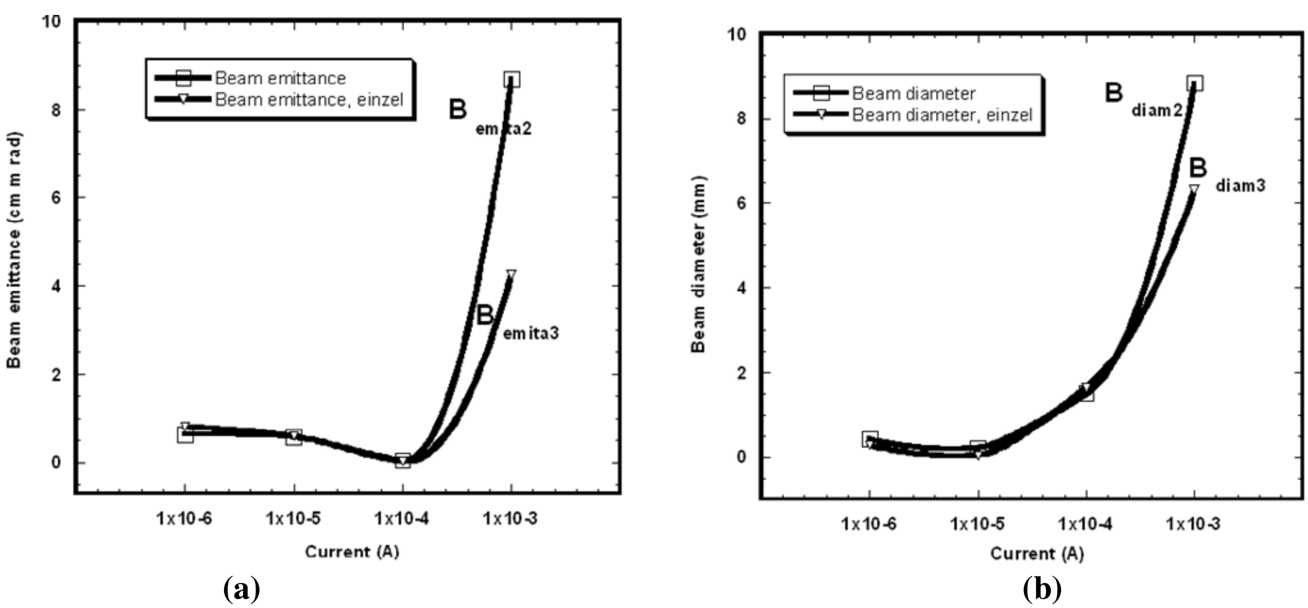
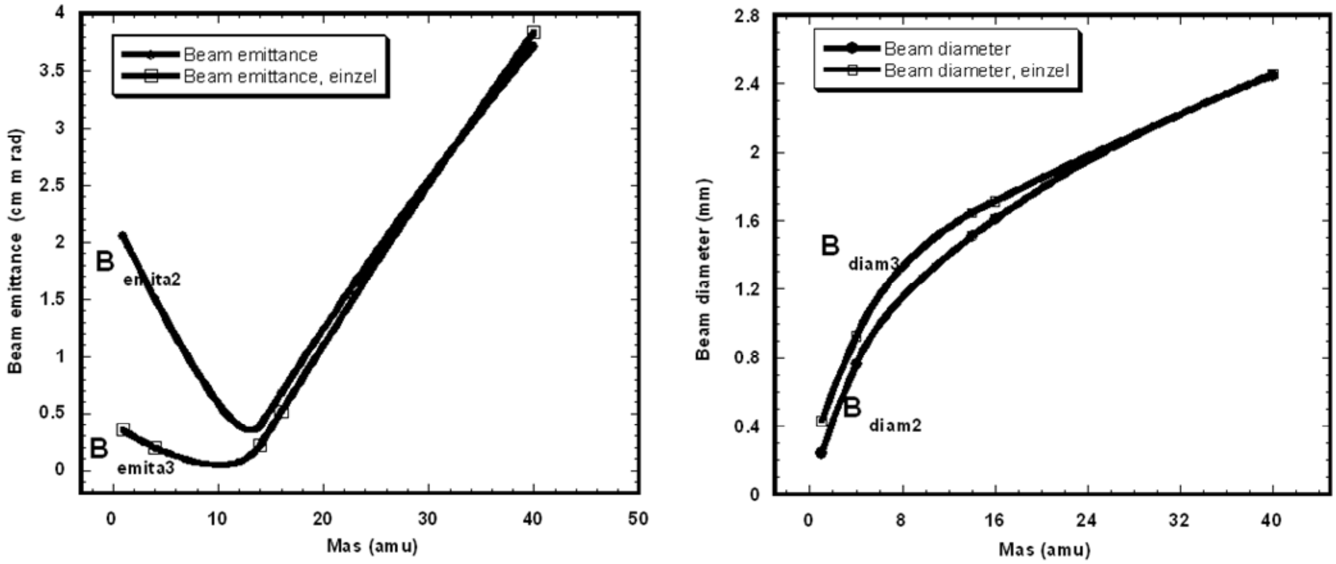


Figure 7. Influence of space charge on both beam emittance and beam diameter of the two (Bdiam2 and Bemita2) and three (Bdiam3 and Bemita3) cylinder lens systems for singly charged nitrogen ion trajectories.

Influence of atomic masses of different elements on both the beam emittance and beam diameter for the two-lens systems has been investigated with current of 0.1 mA for singly charged nitrogen ion trajectories (Figure 8). Minimum beam emittance for both lens systems has been obtained for nitrogen (m = 14) and beam emittance for a three-cylinder lens system was smaller than for the two-cylinder lens system (Figure 8). An increase of atomic mass was accompanied by an increase of the beam diameter for both two and three cylinder lens systems. Figure 8a shows two regions; region 1 indicates that an increase of mass number is accompanied by a decrease of beam emittance and this due to the effect of beam collimation. Considering region 2, an increase in the mass number of different elements is accompanied by an increase of beam emittance and this is due to an



(a) (b)

Figure 8. Beam emittance and beam diameter as a function of atomic mass for different elements of two (Bdiam2 and Bemita2) and three (Bdiam3 and Bemita3) lens systems of singly charged nitrogen ion trajectories.

this is due to an increase of the beam divergence and the beam diameter acts to increase the beam emittance. An increase of mass number of different elements of accelerated ions is accompanied by their slow motion and high space charge which affects beam radial expansion to increase beam diameter as shown in Figure 8b.

Conclusion

In this work, design and optimization for the two and three cylinder lens systems has been done by using SIMION computer program. This study has been done with space charge of 0.1 mA, using singly charged nitrogen ion trajectories with energy 3 keV. It was found that minimum beam emittance was obtained with two cylinder lens system of 46 mm diameter; 7 mm gap width and focusing voltage V2 = - 5500 V. It was also concluded that minimum beam emittance was found downstream from the output of the two cylinder lens system at 350 mm.

For the three cylinder lens system, it was found that, the minimum beam emittance can be obtained with three cylinder lens system of 50 mm diameter, 9 mm gap width and focusing voltage applied to the intermediate electrode equal to VIE = - 4500 V. The influence of space charge on both beam emittance and beam diameter has been studied for the two and three-cylinder lens systems. Minimum beam emittance for the lens systems was found at a current of 10 to 4 A and started to have a large effect at current higher than 10 to 4 A. Minimum beam diameter for the lens systems was also found at a current of 10 to 5 A and started to have a large effect at current higher than 10 to 5 A. Beam emittance for the three cylinder lens system was smaller than for the two one, whereas the beam diameter for the two cylinder one was found to be smaller than for the three one (10 to 5 A).

Influence of atomic masses of different elements on both the beam emittance and beam diameter for the two-lens systems has been investigated with current of 0.1 mA, for singly charged nitrogen ion trajectories. Minimum beam emittance for both lens systems has been obtained for nitrogen (m = 14), and beam emittance for a three-cylinder lens system was smaller than for the two-cylinder lens system.

REFERENCES

Dahl DA (2000). SIMION 3 D Version 7.0 User's Manual INEEL–95/0403; Idaho National Engineering and Environmental Laboratory; I D 83415.

Dahl DA, Delmore JE, Appelhans AD (1990). Rev. Sci. Instrum. 61 607.

Dahl DA, Delmore JE, Appelhans AD (1990). Rev. Sci. Instrum. 61: 607.

Humphries S (1999). Principles of charged particle acceleration; John Wiley and Sons.

Livingston MS, Belwett JP (1962). Particle Accelerators, McGraw Hill Litovko and Oks E (2006) 33rd EPS Conference on Plasma Physics, Rome. ECA. 30I: 2-104.

Livingston MS, Belwett JP, McGraw H (1962). Particle Accelerators.

Livingston MS, Belwett JP (1962). Particle Accelerators; McGraw Hill.

Litovko I, Oks E (2006). 33rd EPS Conference on Plasma Phys.; Rome, 19–23 June 2006 ECA.30I: 2-104.

Wolf BH (1995). Handbook of Ion Sources, CRC press; Boca Raton; New York .

Spädtke P (1989). The physics and Technology of Ion Sources; Brown IG(Ed.), John Wiley & Sons, New York

Sise et al (2005). Nucl. Instr. and Meth. A 554 114.
Septier A (1967). Focusing of Charged Particles; Vol. II, Academic press; New York
Spangenburg K (1948). Vacuum tubes; McGraw-Hill book company; USA
Wolf BH (1995). Handbook of Ion Sources, CRC press; Boca Raton; New York.