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Full Length Research Paper

Proposed design of DC low voltage acceleration system

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A novel approach was given by both beam simulation (using SIMION computer program) and analytical treatment, which are useful tools for the design of a constant gradient acceleration system. An analytical treatment is used to simulate the beam line within a single gap accelerating system. The tracing of the beam line inside the gap shows a decrease of the beam output radius with the increase of the accelerating voltage ratio applied to the gap up to an optimal value. Beyond this optimal value, the beam line aberration appears in the form of cross over. A series of simulation studies were made in order to determine optimum conditions for acceleration of space-charge-dominated argon gas with different incident energies at constant gradient acceleration system. Beam simulation is carried out to reveal both the influence of the space charge effect and incident beam energy on the beam emittance and beam radius. The influence of voltage ratio and inner accelerating tube diameter has the same influence on the output beam emittance. From the beam simulation, the appropriate voltage ratio is 3 and inner accelerating tube diameter is 15 mm. Both analytical and simulation studies have a good agreement results.

Key words: SIMION computer program, DC acceleration system, beams emittance.

INTRODUCTION

Along with the development of computer and calculation techniques, numerical simulation has been a main tool to assist design and research of ion beam system. With high accuracy and velocity, numerical computation can study the effects of ion extraction system on characteristics of ion beams such as ion beam emittance. Also, simulation of ion beam injection into the accelerating tube for appropriate design of tube radius determines the accelerator acceptance to match the beam emittance of the beam that exit from the ion source. Also, the simulation of beam trajectory inside the accelerating column is necessary to avoid ion beam aberration such as crossover inside and outside of over the accelerating tube. The applications of accelerators include various branches of science and technology, medical treatment, and industrial processing. Accelerator scientists invented many advanced technologies to produce beams with qualities required for each applica-tion (Lee, 2004; Stanley, 2002). Computer modeling of charge particle beam is an important part 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). The aim of these simulations is always to investigate the beam quality, which is necessary to adjust the beam conditions for the required applications. In this work, beam simulation is carried out to reveal the influence of the space charge effect on the beam emittance and beam radius. Also, influence of the incident energy on the ion beam quality (beam emittance and beam radius) was studied. Indeed, the influence of the tube diameter on beam emittance for the singly charged argon ion trajectories was investigated. Samples of ion beam simulation inside the accelerating column with different input energies 10, 30 and 50 keV were performed.

AN ANALYTICAL PRESENTATION FOR SINGLE GAP ACCELERATION COLUMN

The variation of the cross section of a beam propagating along the axis of an accelerating section can be determined using (Wilson and Brewer, 1973; Abdelaziz et al., 1996):

$$\frac{\partial^2 r}{\partial z^2} + \frac{V_o'}{2V_0}\frac{\partial r}{\partial z} + \frac{V_o'' r}{4V_o} = \frac{-\rho r}{4V_o \varepsilon_o} \quad (1)$$

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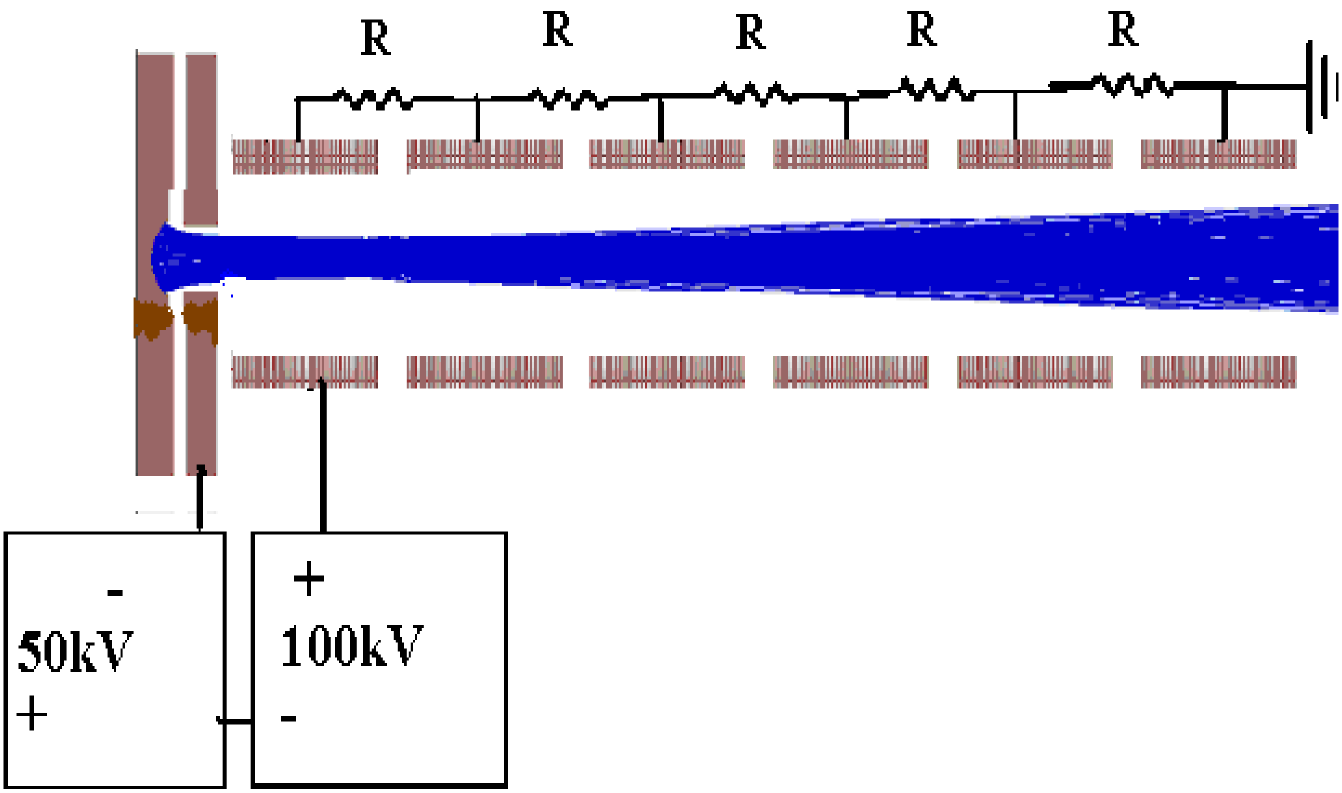

Figure 1. Schematic diagram of the constant gradient accelerator and both potential and electric field distribution.

The right side of paraxial equation includes the voltage applied to the beam and the term of mass as:

$$\frac{1}{2}mv_0^2 = eV_0 \quad (2)$$

For simplification as described by Wilson and Brewer (1973), V_0 (z) is:

$$V_0(z) = \frac{v^2}{2e/m} \quad (3)$$

where $V_o\{z\}$ is the potential on the axis and the primes denotes derivatives with respect to z. ρ represents the space charge density. Neglecting the space charge effect, the right hand side of Equation 1 is equal to zero and its solution will take the form:

$$\left(\frac{r_4}{\sqrt{V_2}r_4^*}\right) = M_{14}\left[\frac{r_1}{\sqrt{V_1}r_1^*}\right] \quad (4)$$

Equation 1 was solved (Wilson and Brewer, 1973) to determine the ray path between the input and output of the accelerating section (Figures 1 and 2) located at a given distance apart along the Z axis. Defining the input and output of an ion optical element (r_1, r_1^*, V_1), refer to the conditions of beam radius, half-angle of beam divergence and the input voltage. (r_4, r_4^*, V_2) are the conditions of the beam at the outlet.

Where:

$$M_{14} = \left[\frac{r_4}{\sqrt{V_2}r_4^*}\right] = \begin{bmatrix} \dfrac{3\sqrt{V_1}-\sqrt{V_2}}{2\sqrt{V_1}} & \dfrac{2d}{\sqrt{V_1}+\sqrt{V_2}} \\ \left[\dfrac{3\{V_2-V_1)}{8d}\cdot\dfrac{\sqrt{V_1}-\sqrt{V_2}}{\sqrt{V_1V_2}}\right] & \dfrac{3\sqrt{V_2}-\sqrt{V_1}}{2\sqrt{V_2}} \end{bmatrix}$$

Equation 4 is used to study the influence of the variation of the accelerating voltage ratio applied to the double aperture lens, shown in Figure 2 on the beam radius, at the exit of the gap. Also the same equation is used to trace the beam line trajectory within the gap under different input beam radius and accelerating voltage ratios as shown in Figures 3 and 4. These studies show that there is an optimal voltage ratio that corresponds to the minimum output beam radius. Beyond this optimal value, the beam aberration appears in the form of crossover.

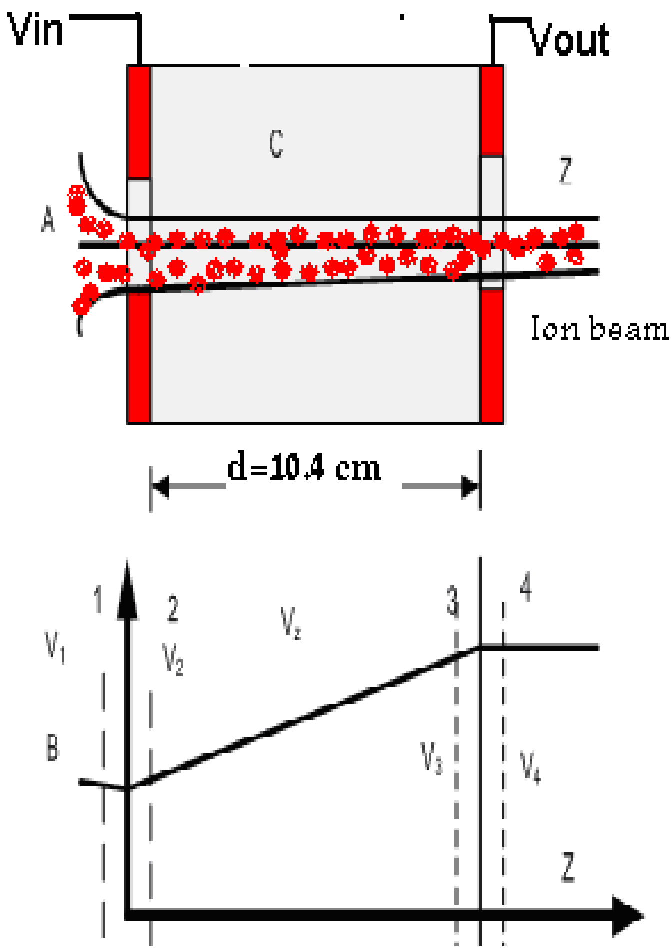

Figure 2. Schematic diagram of the single gap accelerating column with the variation of the potential distribution along the beam line.

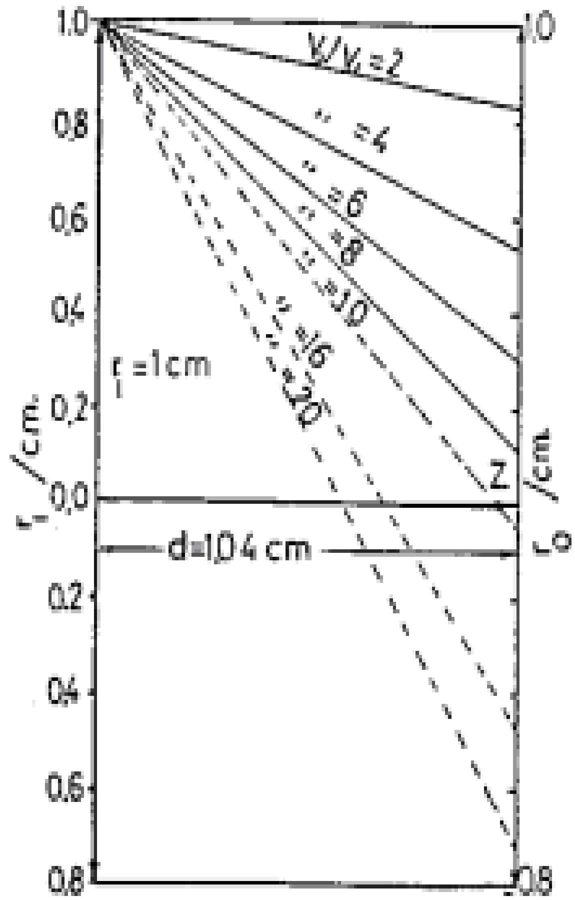

Figure 3. Beam line within the gap at different value of the acceleration ratio (input beam radius 1 cm).

Figure 1 show the proposed constant gradient accelerator which is composed of number of single gaps accelerating column. The following study was carried out to trace the beam line within the gap. In the situations where the ions move close to and with small angle to the axis, the familiar paraxial theory can be applied to determine the beam trajectories.

SIMULATION STUDIES

A series of simulation studies were made in order to determine the factors affecting the operating conditions for the beam transport in a constant gradient accelerating system. The influence of different beam incident energies inside tube radius on both beam radius and emittance at studied.

SIMION 3 D Version 7.0 (Dahl, 2000; Dahl et al., 1990) is a software package primarily used to calculate electric fields and the trajectories of charged particles in those fields when given a configuration of electrodes with voltages and particle initial conditions, including optional RF (quasistatic), magnetic field, and collisional effects. This program provides extensive and supporting functionality in geometry definition, user programming, data recording, and visualization.

Simulation of the singly charged argon ion trajectories for flat plasma was studied with and without space charge effect using a model of constant gradient acceleration system with the aiding of SIMION computer program. The simulation process was carried out at an assumption of a constant plasma density. In this work, beam simulation was carried out to reveal the influence of the space charge effect on the beam emittance and beam radius. Also, influence of the incident energy on the ion beam quality (beam emittance and beam radius) was studied. Indeed, the influence of the tube diameter on beam emittance for the singly charged argon ion trajectories was investigated. Samples of ion beam simulation inside the accelerating column with different input energies 10, 30 and 50 keV (Figures 5a to c) were performed.

Space charge depends on the geometry of the

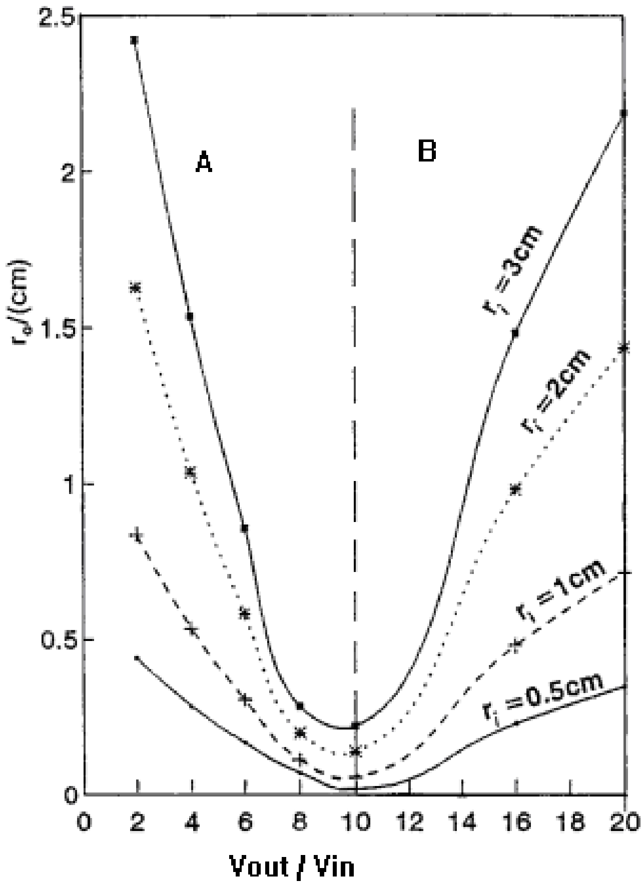

Figure 4. Variation of the beam output radius with the acceleration ratio.

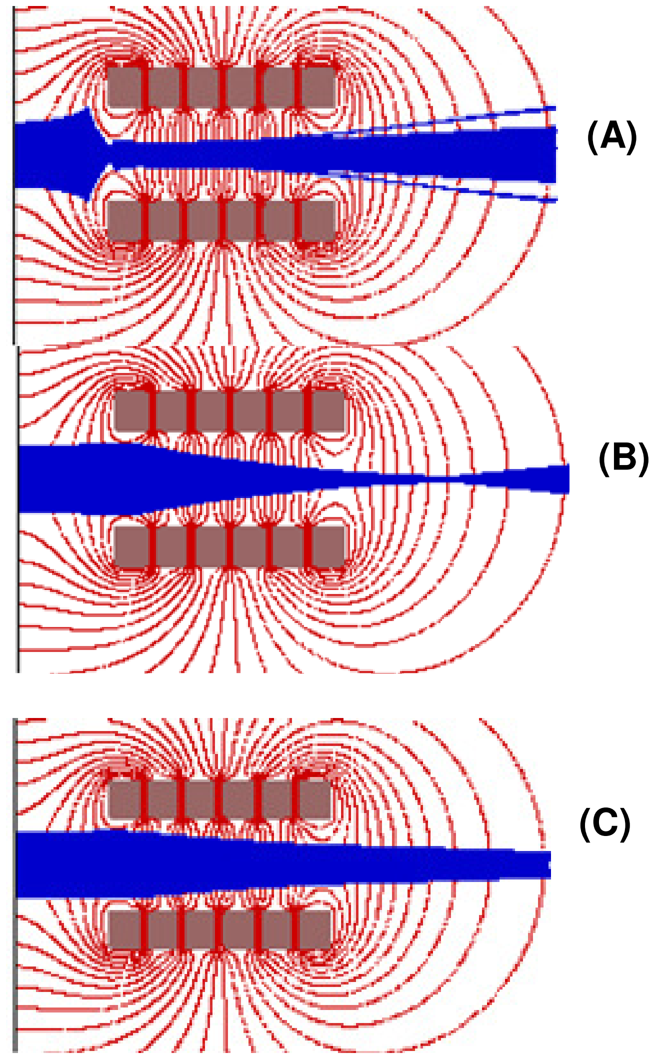

Figure 5. Samples of ion beam simulation inside the accelerating column with different input energies 10, 30 and 50 keV. (A) Input energy to the accelerator 10 keV; (B) Input energy to the accelerator 30 keV; (C) Input energy to the accelerator 50 keV.

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.

It was found that space charge has no influence on the ion beam envelope at currents of micro amps. The space charge started to have a clear influence on the ion beam envelope at currents of 1x 10^{-4} A (Figures 6 and 7). 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. Figure 6 shows the influence of space charge on the beam emmitance with different energies (10, 30 and 50 keV) for a constant gradient acceleration system. It was found that, a minimum point appeared at a current of 10^{-2} A at different incident energies. It was also found that, minimum beam emittance at an incident energy of 50 keV, and maximum one at an energy of 10 keV, where, an increase of the incident energy affects decrease of the beam emittance (Figure 6) and this can be explained by the decrease of the angle of the beam divergence which is found to be (Green, 1976):

$$\theta = \sqrt{\frac{KTi}{eV}}$$

where θ is the angle of beam divergence, for small angle $\tan\theta = \theta = r'$, KTi is the transverse kinetic energy (K is the Planck's constant), Ti is the ion temperature and eV is the axial accelerating energy.

The input energy is varied by assuming different extraction voltages of the ion source. The ion beam emittance varies also according to the extraction voltage

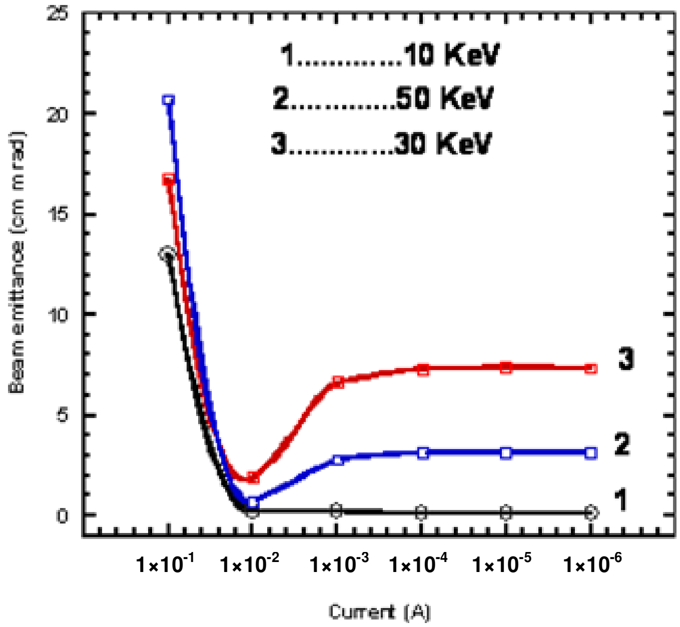

Figure 6. Relation between space charge and beam emittance for a constant gradient accelerator system.

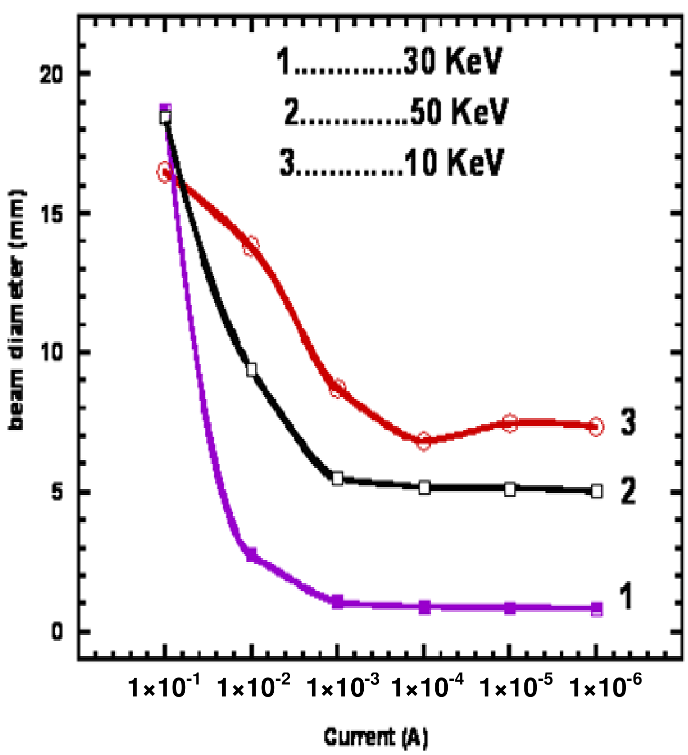

Figure 7. Relation between space charge and beam diameter for a constant gradient accelerator.

which appears from Green (1976).

Figure 7 shows the influence of space charge on the beam radius with different energies (10, 30 and 50 keV) for a constant gradient acceleration system. It was found

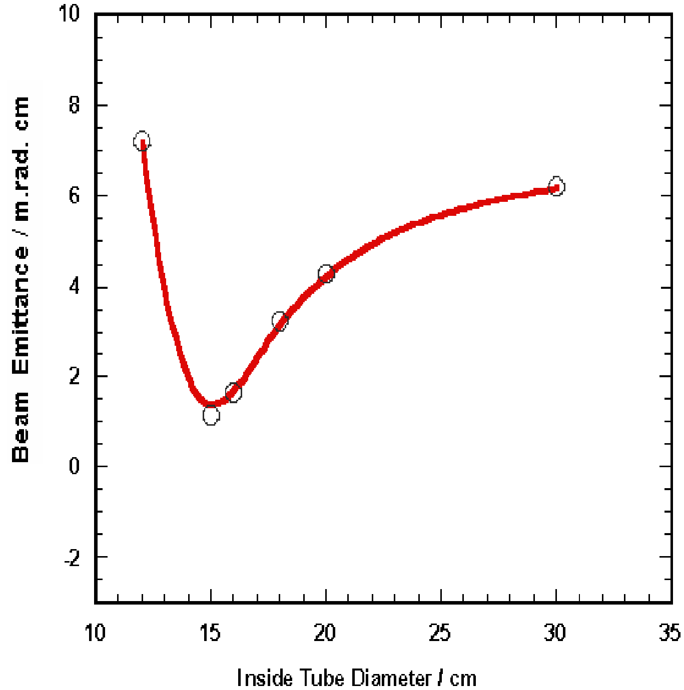

Figure 8. Relation between tube diameter and beam emittance for a constant gradient accelerator system.

that space charge has no influence on the ion beam envelope at currents of micro amps. The space charge started to have a clear influence on the ion beam envelope at currents of 1×10^{-3} A (Figure 7).

Figures 8 and 9 shows the influence of accelerating tube size (inner tube diameter) and accelerating voltage ratio have the same effect on the output beam emittance. This can be attributed to the variation of the electric field inside the accelerating tube. The appropriate accelerating voltage ratio was found to be 3 and inner tube diameter 15 mm.

Conclusion

The new achievement given by both beam simulation and analytical treatment are useful tools for design of constant gradient acceleration system. These studies clearly demonstrate the necessity of providing means for varying the incident energies for assuring high quality space-charge-dominated beams. In this work, beam simulation is carried out to reveal the influence of the space charge effect on the beam emittance and beam radius. Also, influence of the incident energy on the ion beam quality (beam emittance and beam radius) was studied. Indeed, the influence of the tube diameter on beam emittance for the singly charged argon ion trajectories was investigated. Samples of ion beam simulation

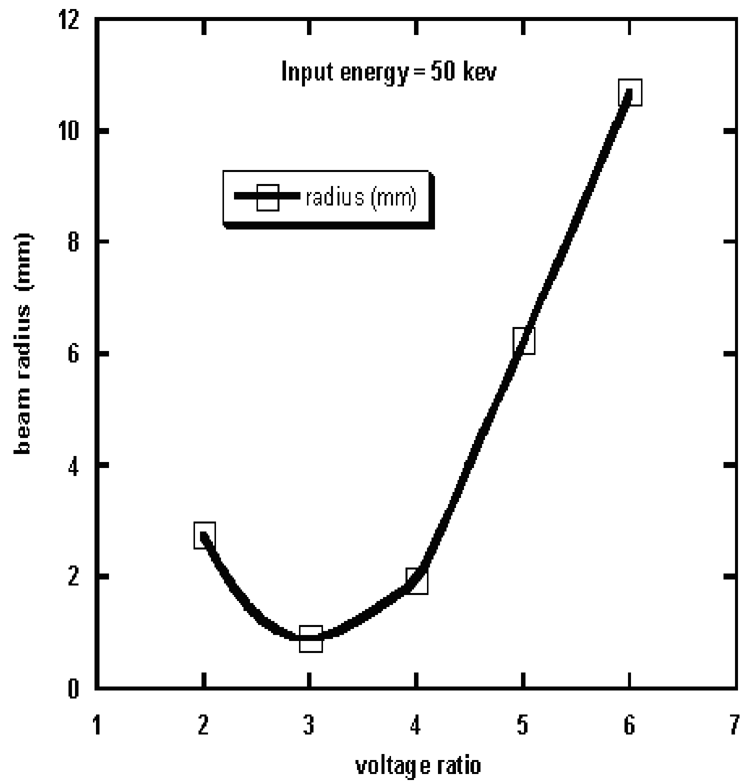

Figure 9. Influence of the variation of the accelerating voltage ratio applied to the accelerator system on both beam emittance and beam diameter at a input energy of 50 keV.

inside the accelerating column with different input energies 10, 30 and 50 keV were performed. The influence of inner tube diameter and accelerating voltage ratio has the same effect on output beam emittance. The results derived from the simulations of the ion beam optics agree closely with those predicted from elementary extraction/ acceleration theory.

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REFERENCES

Abdelaziz ME, Grant AI, Hough J (1996). Cavity perturbation technique. Rev. Sci. Instrum., 67: 3

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). A history of mass spectrometry. Rev. Sci. Instrum., 61: 607

Green TS (1976). Simulation studies for ion beam. IEEE Nucl. Sci. NS, 23: 918-925

Lee SY (2004). Accelerator Physics, World Scientific Publishing Co. Pte. Ltd, 5 Toh Tuck Link, Singapore 596224

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

Stanley H. Jr. (2002). Charged Particle Beams, John Wiley and Sons, USA

Wilson RG, Brewer GR (1973). "Ion Beams with Applications to Ion Implantation", John Wiley and Sons, New York .