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Effects of External Magnetic Field on Focusing and Energy Distribution of Primary Electrons in an Ion Source

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Abstract

The effect of the applied voltage and magnetic field on the defining slot in focusing and energy distribution of the primary filament electron beam was studied theoretically. In this work, SIMION 8.1 software was used to determine the best operational conditions for focusing and the distribution of the electron beam in the ion source system. Furthermore, the Larmor radius on the slot was calculated in two dimensions for different values of magnetic flux density. The results showed that the values of flux density and slot voltage play an effective role in improving the dimensions of beam spot and energy distribution in the source. The dimensions of beam spot were reduced by about 71% at voltage value of slot 75 volt and flux density 780 G. In addition; the kinetic energy distribution for electrons were computed at different magnetic flux and obtaining a homogeneous beam energy. The results of this research support the calculations of plasma source designers.

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1. Introduction

The cathode (filament) in the ion source is one of the most important and effective parts in determining the efficiency of the ion sources [1–4]. In the sources of high ion currents, the direct heating method with a tungsten or tantalum filament is used to generate primary electrons by thermionic emission according to Richardson equation [5].

$$J(T) = A_R T^2 \exp\left(-\frac{\varphi_W}{k_B\, T}\right) \quad \dots(1)$$

$$A_R = \frac{4\pi\, m_e k_B^2 e^2}{h} \quad \dots(2)$$

where A_R is Richardson constant, φ_w is the filament work function, m_e is the mass of an electron, k_B is Boltzmann constant, h is plank constant and T is the temperature. The filament is supplying the ion source with the initial accelerated electron beam which collision the gas atom inside the chamber at a certain voltage to form a plasma [6,7]. In a high ion current source, direct heating method with external magnetic field is used in different applications such as ion implantation and electromagnetic separation system. [8-11]. The electron beams moves in the electric and magnetic field according to the Lorentz equation [4].

$$\vec{F} = e\vec{E} + e\vec{V} \times \vec{B} \quad \dots(3)$$

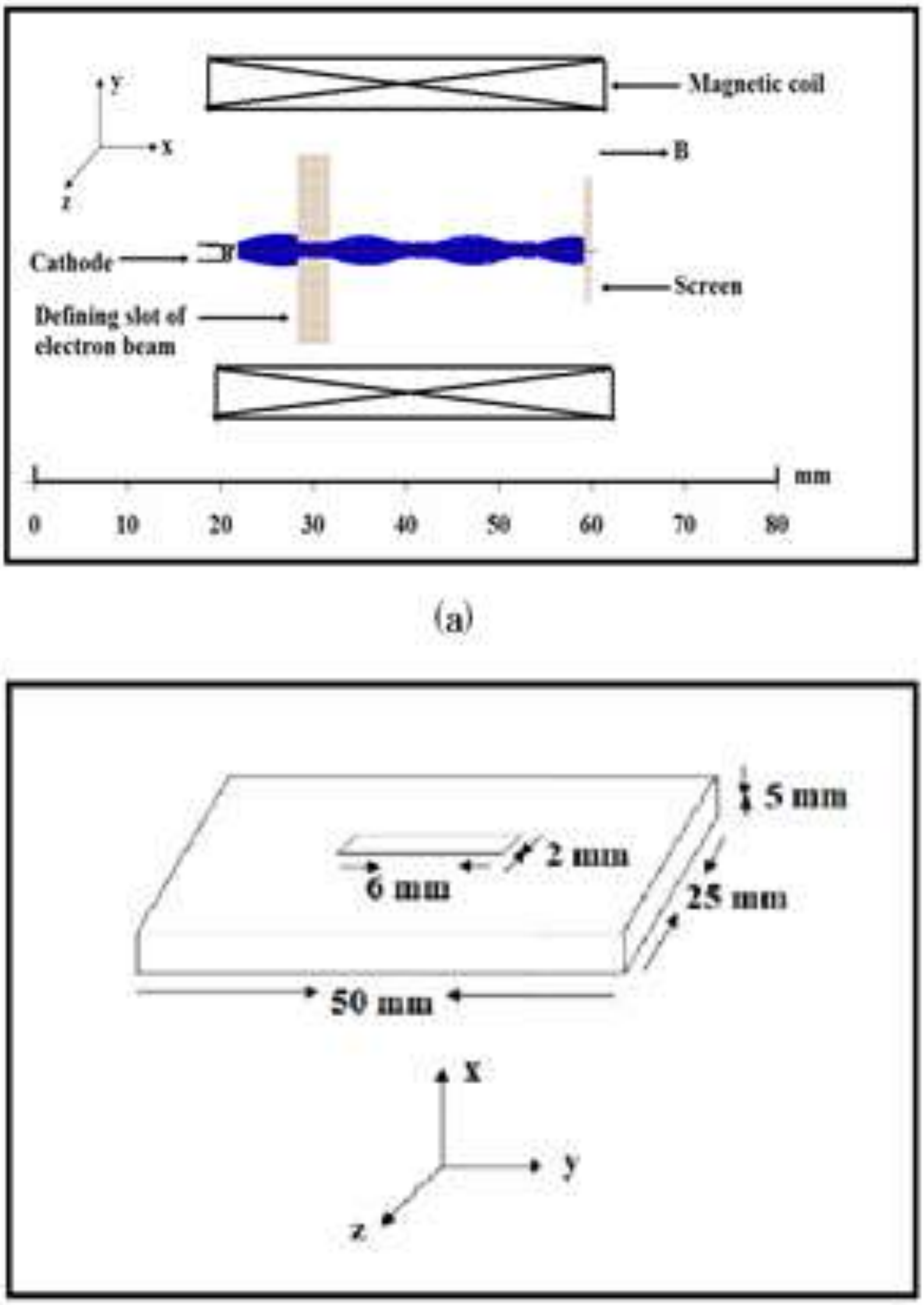
$$\vec{F} = \vec{F_e} + \vec{F_m} \quad \dots(4)$$

where e is the electron charge, E is the electric field, B is the magnetic flux density, v is the electron velocity, F_e and F_m are electric and magnetic forces, respectively. The electric force F_e changed the velocity component along the flux, while the magnetic force F_m changed the velocity component in perpendicular direction of the flux. So, the electron beam will be confined to a helical motion along the lines of the field with Larmor radius R_L and gyrofrequency ω_c given by equations (5) and (6) [5, 12, 13, 14 and 15].

$$R_L = \frac{mv}{qB} \quad \dots(5)$$

$$\omega_c = \frac{qB}{m} \quad \dots(6)$$

The magnetic field plays an important role during the process of confinement the primary electrons inside the ion source chamber and increasing the density of the ions. [16,17,18,19,20,21]. One of the technical problems facing the ion sources' performance is the collision of primary electrons with defining slot as a result of their lack of focus, which leads to decrease the efficiency of ion source [22, 23, 24]. In this work, the defining slot voltage, confinement and kinetic distribution beams were discussed and simulated using SIMION 8.1 software.



(a)

(b)

Figure 1. Schematic of (**a**) main parts of proposal system. (**b**) dimensions of defining slot for primary electron beam.

2. Proposal System

Figure 1 shows the schematic diagram for proposal system. The primary electrons are emitted from the cathode (filament) with negative biased and accelerated to collision with gas atoms through a slot (2x6 mm^2) at in the middle of defining slot of the electron beam. The magnetic field was generated in the direction of the electron beam by using coils to confine and focusing electron beam.

3. Acceleration of Primary Electron Beams

The primary electrons are generated and accelerated at a sufficient voltage to ionize the atoms through defining slot and produced the plasma inside ion source. The purpose of using the slot in ion source to determine the values of electron current, and also it protected ions from hitting with filament. In this work, the problem of hitting primary electrons and energy distribution of the beam was solved. This can be done by applying a certain value of magnetic flux. As well as, the voltage of slot was studied to minimize these hitting of electron on its surface, which leads practically to reduce the drain current and stabilize the power supplies for the source.

4. Distribution of Magnetic Flux Density

Five values of magnetic flux were assumed to generate a flux along the x- direction of the system. SIMION 8.1 software was used to calculate the distribution of flux density for these values. Figure 2 shows five distributions of magnetic flux density (B1-B5) as a function of distance in x- direction of primary electrons.

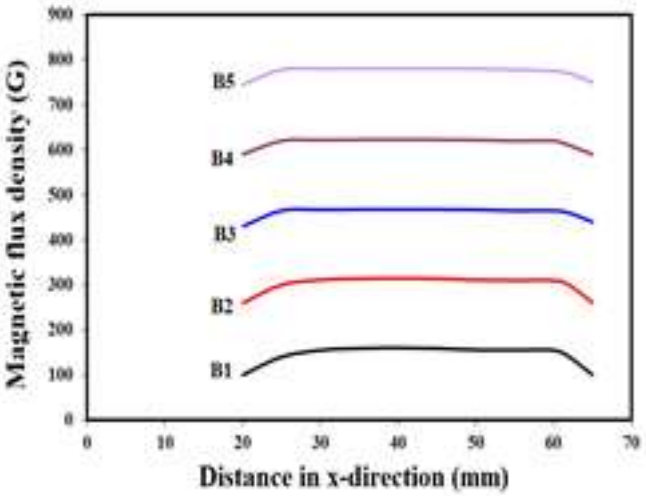


Figure 2. Magnetic flux density distribution as a function of the distance in an x-direction of system.

5. Effects of Defining Slot Voltage

The effect of defining slot voltage V_d (50, 75, 100, 125 and 150 volts) on the variation of electron-beam spot shape in the z and y-directions at the defining slot were studied with different values of the magnetic flux densities as shown in Table 1.

Table 1. Primary electron beam parameters for different values of the voltage and magnetic flux density in the center of defining slot at yz –plane

B (G)	V_d = 50 volt		V_d = 75 volt		V_d = 100 volt		V_d = 125 volt		V_d = 150 volt	
	Δy (mm)	Δz (mm)	Δy (mm)	Δz (mm)	Δy (mm)	Δz (mm)	Δy (mm)	Δz (mm)	Δy (mm)	Δz (mm)
155	3.2830	2.7046	3.2149	2.6875	3.2992	2.7196	3.2489	2.7386	3.2659	2.7726
311	2.4990	2.4285	2.5259	2.4156	2.4674	2.4221	2.5253	2.4673	2.5125	2.5001
467	2.2412	2.2089	2.2432	2.1702	2.3481	2.1896	2.2606	2.2400	2.2473	2.2700
622	2.0991	2.1406	2.1314	2.0895	2.1056	2.0976	2.1250	2.1200	2.1573	2.1621
780	2.0281	2.0022	2.0410	1.9810	2.0022	1.9842	2.0927	1.9847	2.0604	1.9958

It is clear from Table 1, that the minimum values of Δz was obtained at V_d =75 volt for all values of applied magnetic field as shown in Figure 3. This result was in agreement with Somacal computation behavior [25].

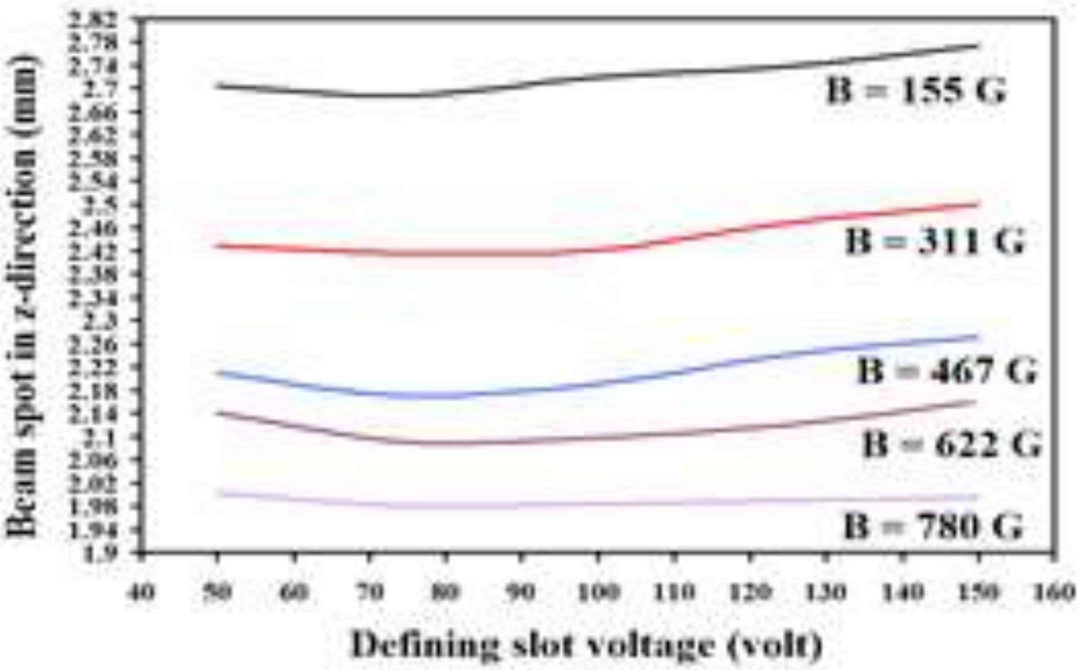
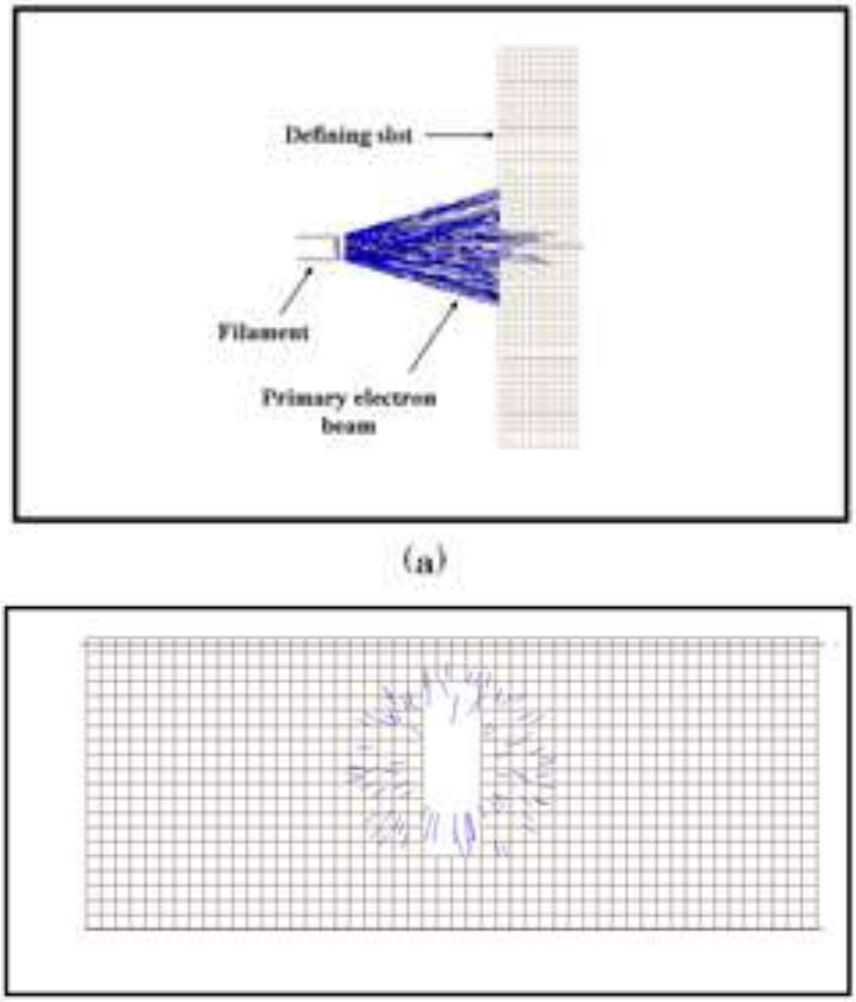


Figure 3. Variation of the electron beam spot in z- direction as a function of defining slot voltage for different values of magnetic flux at slot.

6. Effects of Magnetic Field on Beam Path

The effect of the magnetic field projection on the path of electron beam (see Figure 2) was studied and attempt to reduce the hitting of accelerated electrons on the defining slot with a voltage of 75 volt. Figure 4 shows the path of the electron beam on the defining slot in the absence of magnetic field. It is noted from the figure spread and dispersion of the beam on the defining slot. In order to focus and confinement the electron- beam through the slot, several values of magnetic flux at defining slot were applied to confine the electron beam in a circle path along a line of magnetic field at a Larmor radius to reduce hitting of beam on defining slot. Figure 5 shows the path of the electron beam at the defining slot in present of magnetic field. The variation of Larmor radius ΔRy and ΔRz at the defining slot in yz-plane was computed for different values of magnetic flux B at the center of the circle path as shown in Table 2. From Table 2, it is observed that by increasing the magnetic flux density values B, the values of the Larmor radius in yz-plane are reduced and lead to confine of the electron beam. Figures 6, Figure 7, Figure 8, Figure 9 and Figure10 shows the focusing of primary electrons' beam on the slot by applying different values of magnetic flux. It is noted that the beam spot reduced as magnetic flux density increased. On the other hand, the effect of magnetic flux at screen, Bs, on the spot shape of the primary electron beam was studied in the yz plane. The screen was positioned at 30 mm behind the defining slot. The values of Bs and beam spot are estimated at the center of screen as shown in Table 3 and figure 11. The same behavior of electron distribution was obtained by Dougar-Jabon [26].



(a)

(b)

Figure 4. Shows the spread and dispersion of the electron beam on defining slot at V_d =75 volt and B =0. (**a**) side view.(**b**) front view.

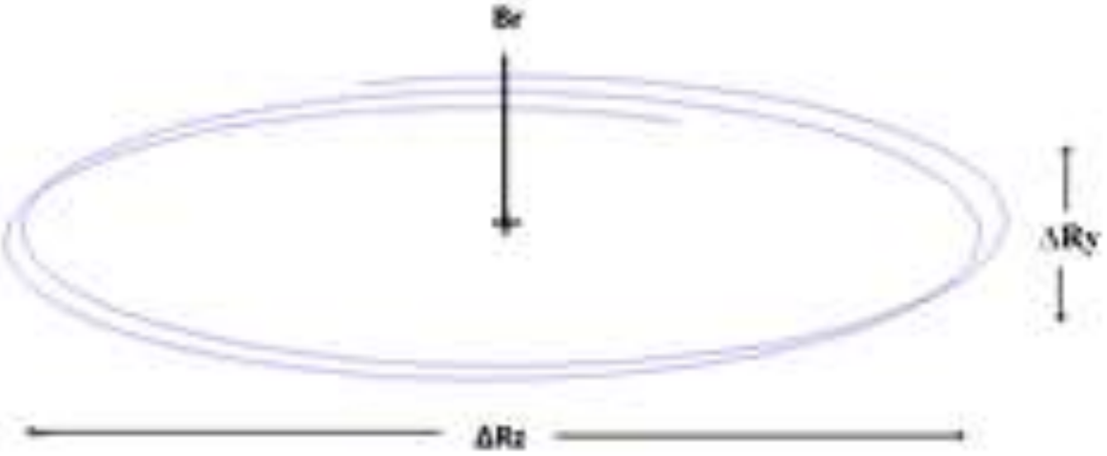
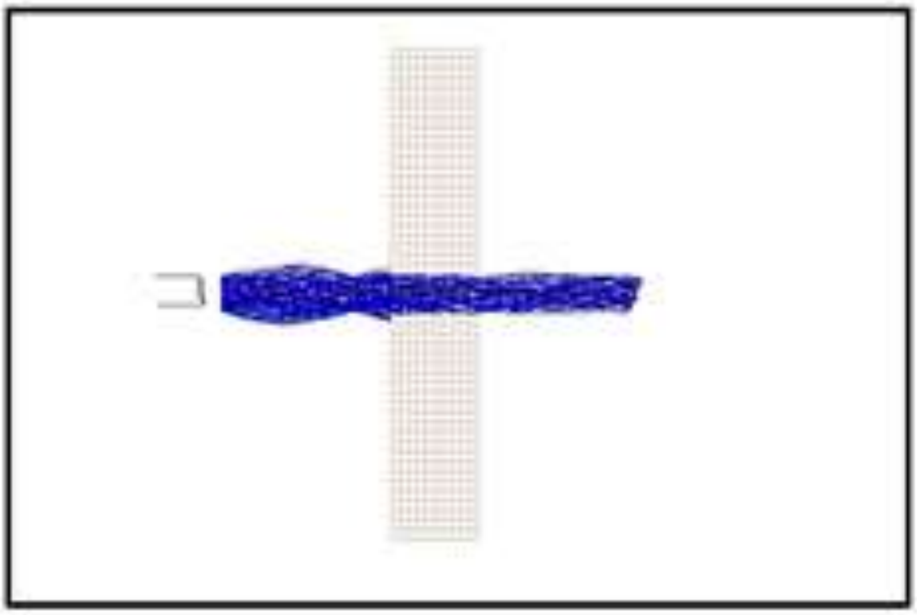


Figure 5. Larmor radius at defining slot at V_d=75 volt and B=780 G.

Table 2. Variation of Larmor radius in yz-plane at defining slot for different values of B at V_d=75 volt

B (G)	ΔR_y (mm)	ΔR_z (mm)
155	0.713572	0.726257
311	0.376153	0.363839
467	0.246660	0.243020
622	0.176201	0.176960
780	0.134140	0.146034



(a)

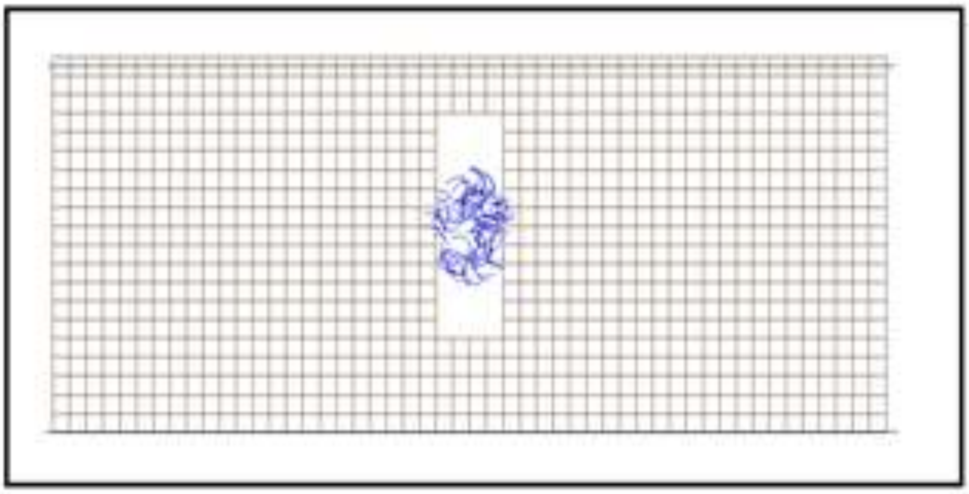


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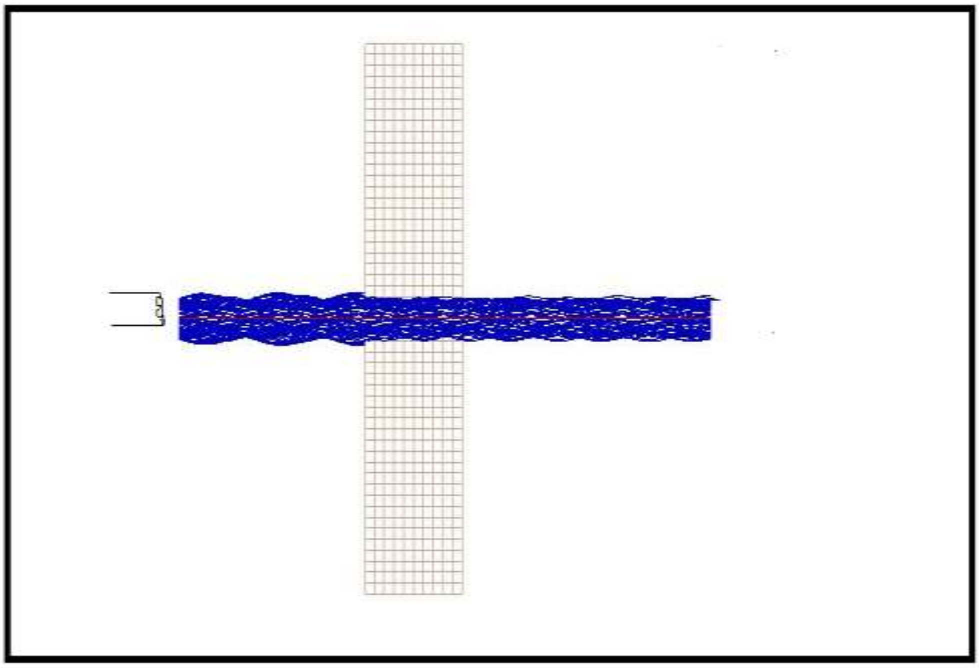
Figure 6. Shows the projection electron beam on defining slot at V_d =75 volt and B =155 G (**a**) side view. (**b**) front view.



(a)

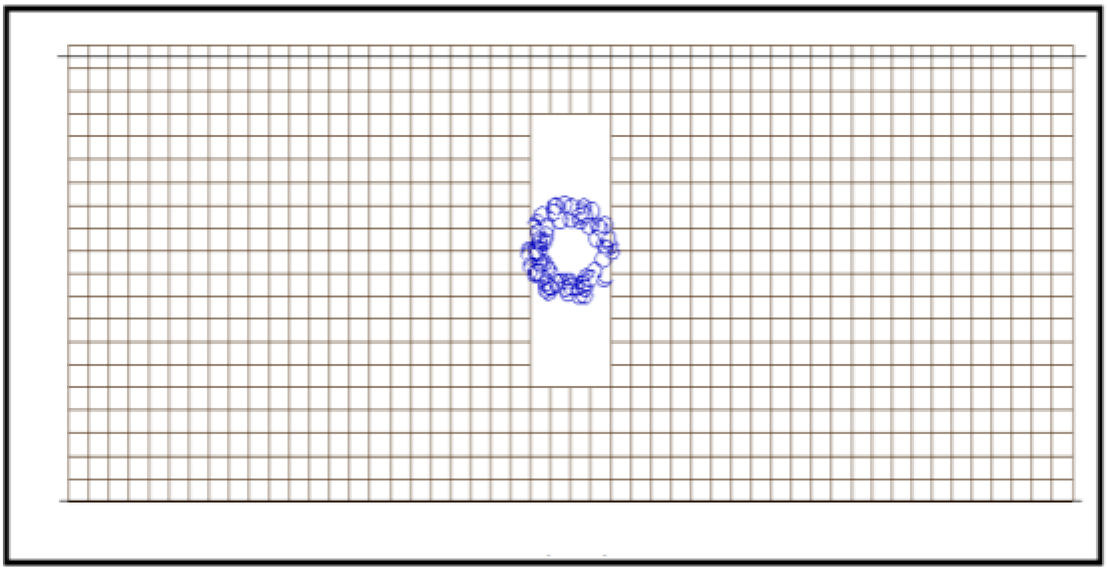


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Figure 7. Shows the projection electron beam on defining slot at V_d =75 volt and B =311 G (**a**) side view. (**b**) front view.

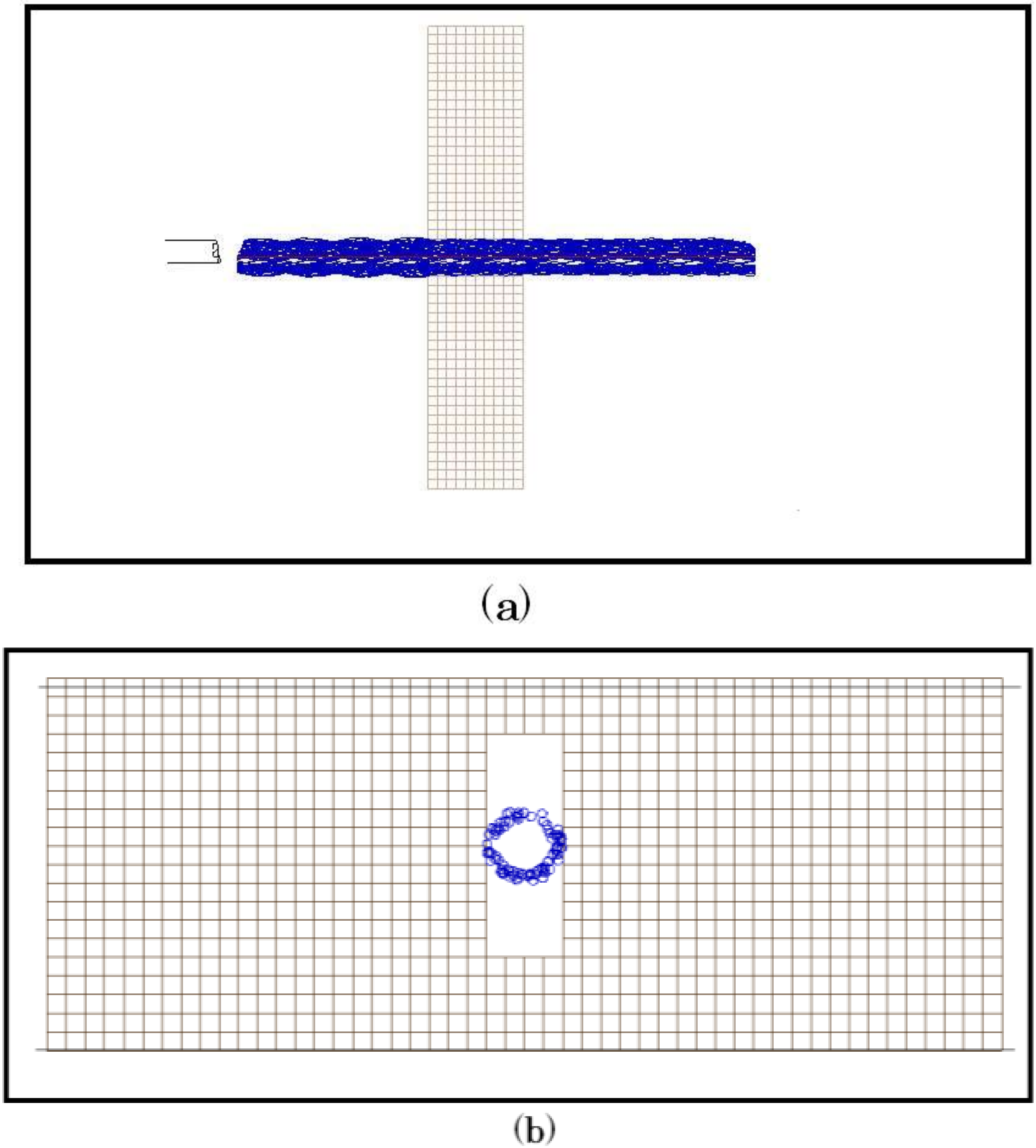
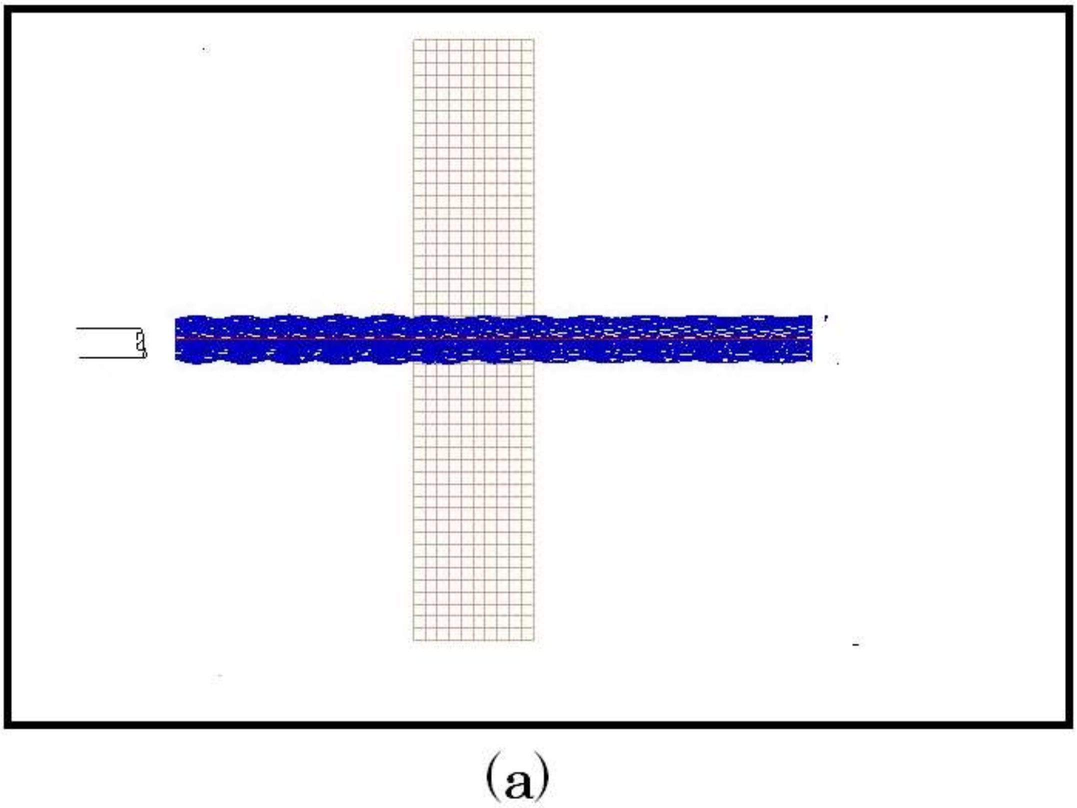


Figure 8. Shows the projection electron beam on defining slot at V_d =75 volt and B =467 G. (**a**) side view. (**b**) front view



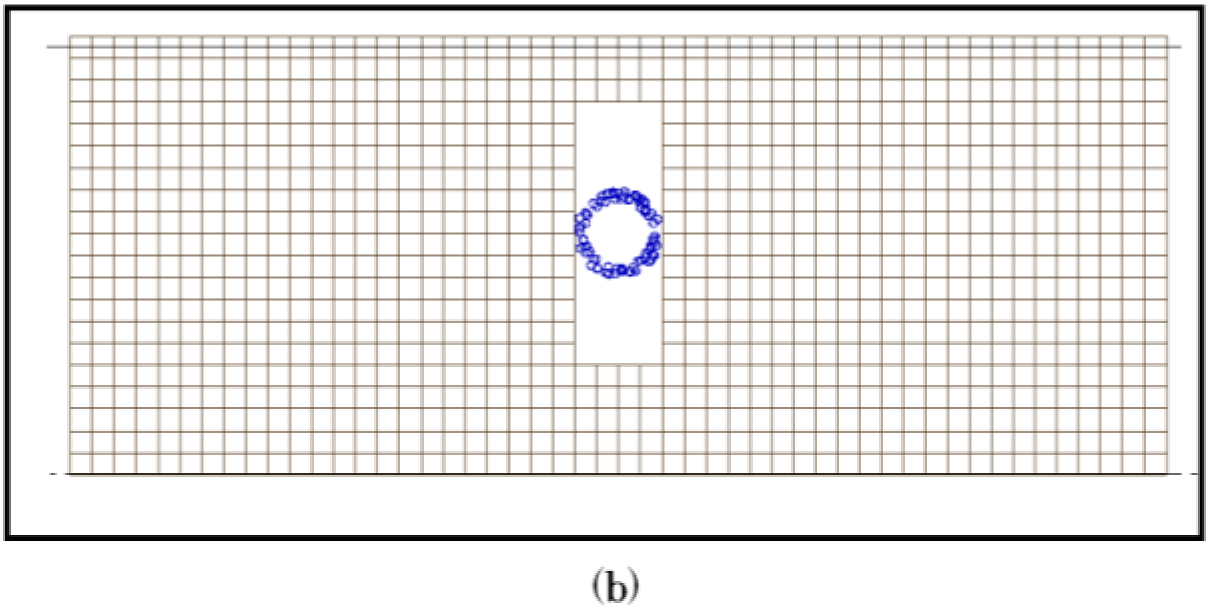
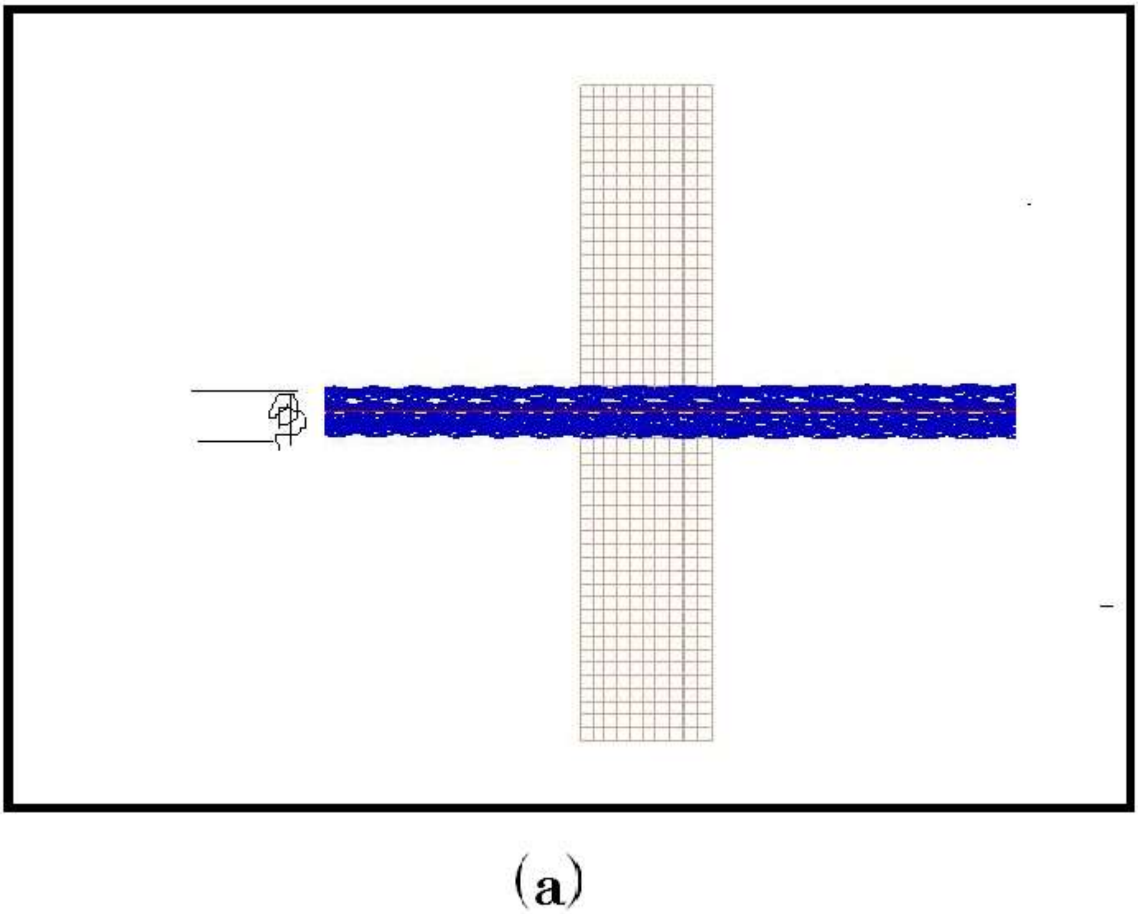


Figure 9. Shows the projection electron beam on defining slot at V_d =75 volt and B = 622 G **(a)** side view. **(b)** front view



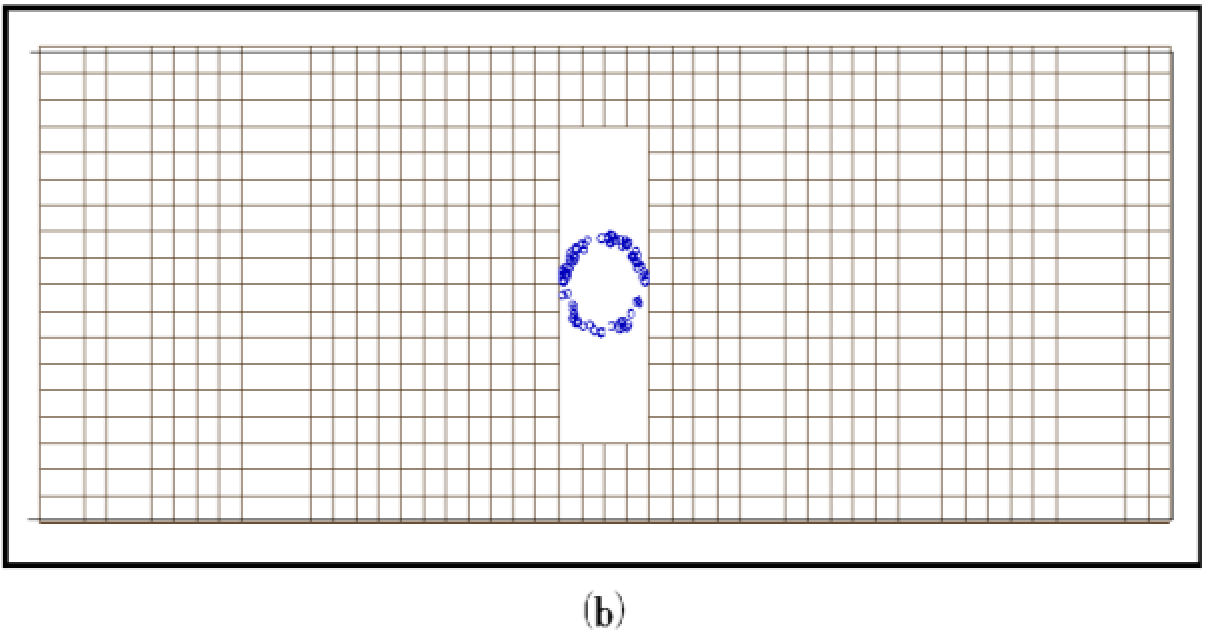
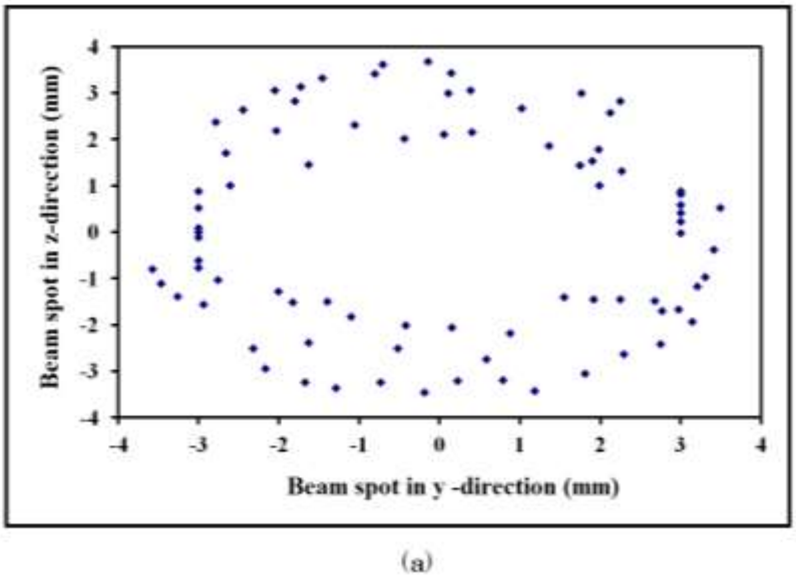


Figure 10. Shows the projection electron beam on defining slot at V_d =75 volt and B =780G **(a)** side view. **(b)** front view.

Table 3. Variation of primary electron beam spot in yz-plane for different values of magnetic flux density at the screen with V_d = 75 volt.

Bs (G)	Δy (mm)	Δz (mm)
0	7.0697	7.1284
153	2.5263	2.6401
309	2.3232	2.4513
465	2.0107	2.0299
620	1.8014	2.0000
775	1.7904	1.9980



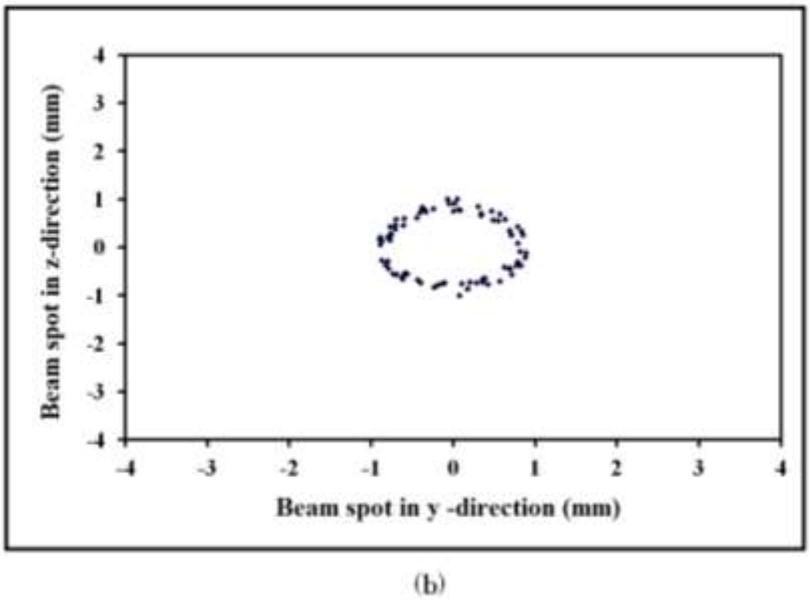
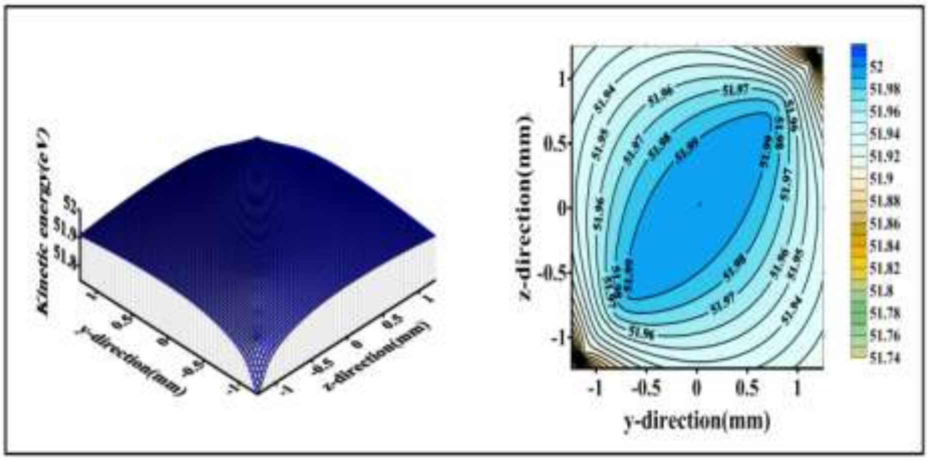


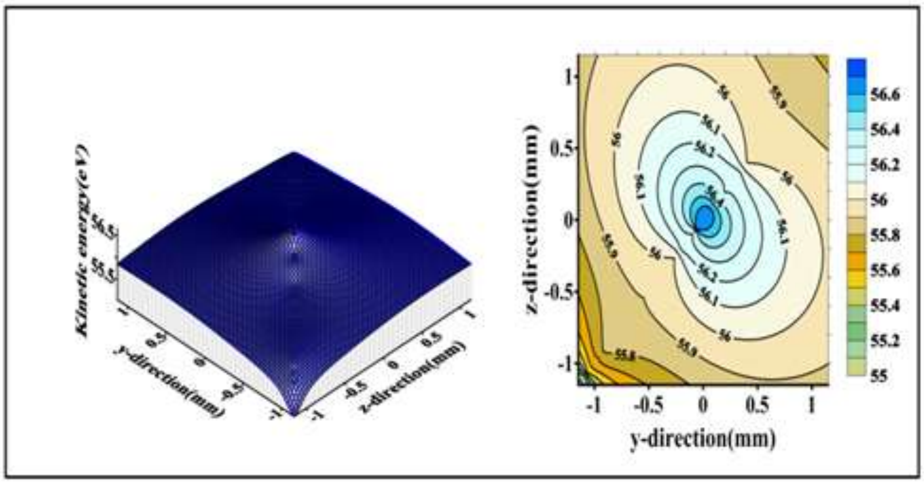
Figure 11. Variation of spot shape in yz –plane for primary electron beam on the screen at V_d =75 volt (a) Bs =0. (b) Bs=775 G.

7. Kinetic energy distribution for electrons beam

The kinetic energy distribution of the extraction electrons' beam were investigated. Figure 12 shows the distribution of kinetic energy for primary electrons at the screen in the y and z directions for several values of the magnetic flux density.



(a)



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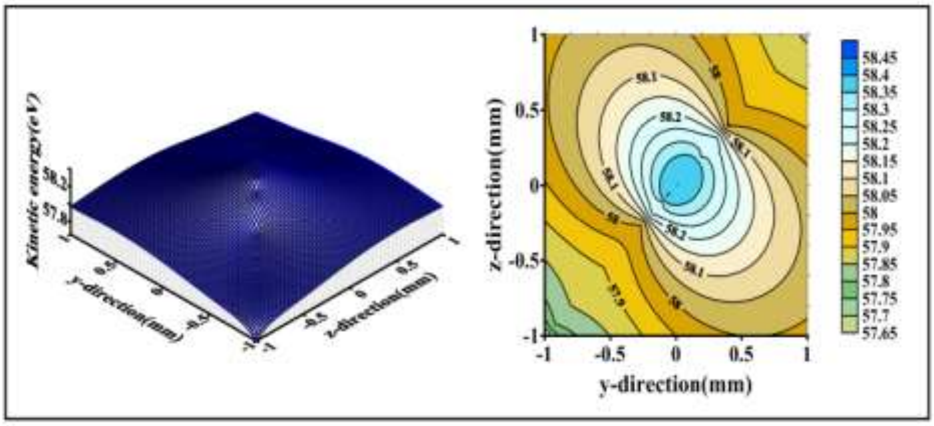

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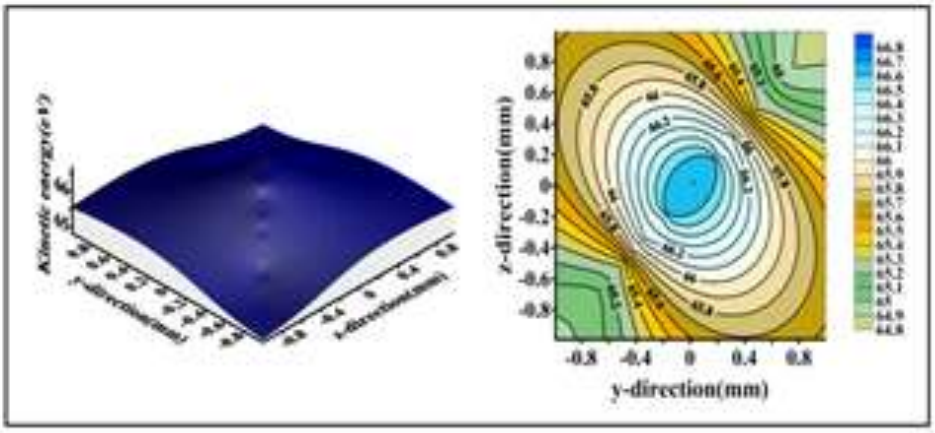

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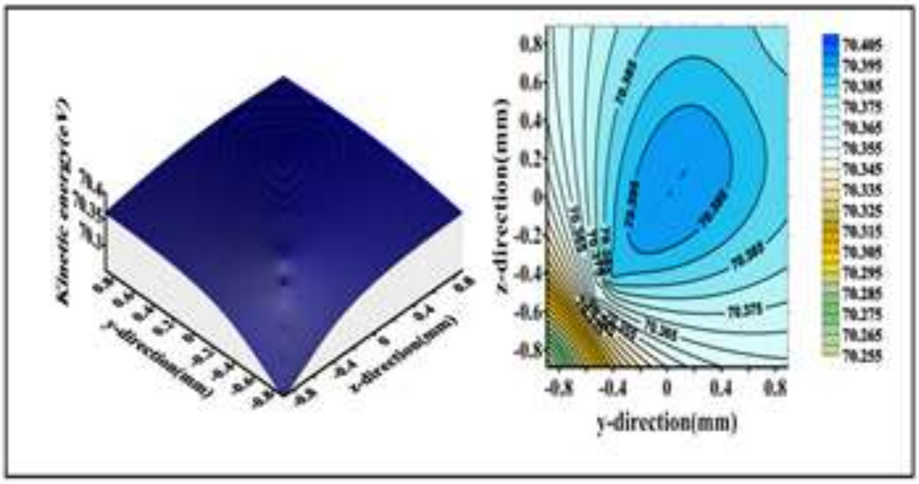

(e)

Figure12. Surface and contour distribution of extracted electrons' kinetic energy for different values of magnetic flux at the screen in the y and z directions at V_d=75 volt **(a)** B=153 G. **(b)** B= 309 G.**(c)** B=465 G. **(d)** B=620 G. **(e)** B=775 G.

The results show that at large values of magnetic flux density, the kinetic energy distribution will be more homogenous in comparison with the less values of flux density , especially for B=775 G.

8. Conclusions

The effect of the magnetic field and applied voltages on focusing and collimating of the primary electron beam at the defining slot in ion source was investigated. The calculations showed that the effective role of the flux density in the collection, beam energy distribution and controlled of the dimension of electron-beam spot. This effects causes to reduce the hitting of the beam at the slot surface. Thus, it improves the stability of the power supplies and maintains the life of the filament in the ion source system in practical experiments.. The dimensions of beam spot were reduced by about 71% at voltage at 75 volt and magnetic flux density 780 G. Furthermore, increasing the flux density led to concentrate the beam and improved the homogeneous distribution of their kinetic energy. The results support calculations of plasma source designers.

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Conflicts of Interest: The authors declare no competing interests

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