

OPEN ACCESS

Optimization of Electron Beam Transport for a 3-MeV DC Accelerator

To cite this article: S Baruah *et al* 2012 *J. Phys.: Conf. Ser.* **390** 012070

View the [article online](#) for updates and enhancements.

You may also like

- [Effect of cage bias and electron emission on the two-electron temperature groups in a hot cathode discharge](#)
Jocelyn Sangma, Narayan Sharma, Monojit Chakraborty et al.
- [Study of high DC voltage breakdown between stainless steel electrodes separated by long vacuum gaps](#)
N. Pilan, S.M. Deambrosis, A. De Lorenzi et al.
- [Research of emission current in fluorescent lamps](#)
Igor V Grebenev, Olga V Lebedeva and Svetlana V Polushkina



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Optimization of Electron Beam Transport for a 3-MeV DC Accelerator

S. Baruah¹, D. Bhattacharjee², R. Tiwari³, G.K. Sahu¹, K. B. Thakur¹, K.C. Mittal² and L.M. Gantayet

¹ Laser & Plasma Technology Division

² Accelerator & Pulse Power Division

Beam Technology Development Group, BARC, Mumbai

E-mail: sbaruah@barc.gov.in

Abstract. Transport of a low-current-density electron beam is simulated for an electrostatic accelerator system. Representative charged particles are uniformly assigned for emission from a circular indirectly-heated cathode of an axial electron gun. The beam is accelerated stepwise up to energy of 1 MeV electrostatically in a length-span of ~3 m using multiple accelerating electrodes in a column of ten tubes. The simulation is done under relativistic condition and the effect of the magnetic field induced by the cathode-heating filament current is taken into account. The beam diameter is tracked at different axial locations for various settings of the electrode potentials. Attempts have been made to examine and explain data on beam transport efficiency obtained from experimental observations.

1. Introduction

A 3-MeV, 30-kW DC Accelerator is under development at Electron Beam Centre, Kharghar, Navi Mumbai for industrial applications. Initial beam trials were conducted for up to 1 MeV beam energy and the beam transmission efficiency was found to decrease with the increase of either the anode-cathode potential difference or the total beam current (at a constant anode-cathode potential difference). In order to find a tangible explanation to this, beam trajectory simulation was carried out considering all the ion-optical elements from the cathode up to the end of the accelerating column containing ten accelerating tubes. The simulation is done without considering space-charge of the beam for this low perveance ($\sim 10^{-9}$ A/V^{3/2}) gun following Schiller *et al.* [1].

2. Electron gun and the accelerating column

The DC accelerator setup is explained elsewhere in details [2]. The accelerator primarily consists of an electron gun, an accelerating column, a magnetic steering, a focussing arrangement and a magnetic beam scanner for product irradiation as shown in Figure 1. The electron gun [3] uses a LaB₆ pellet of diameter 8 mm and thickness 1 mm for thermionic emission, which is indirectly heated by a tungsten filament. The filament power is maintained between 100 W and 150 W. The anode-cathode potential difference can be varied from 1 - 5 kV. The accelerating column consists of 10 accelerating tubes. Each tube is about 30 cm long and has 20 titanium electrodes (dynodes). It can sustain a voltage of 335 kV with evacuation inside (10^{-7} mbar) and pressurized SF₆ environment outside (6 atm.) [4]. After the accelerating column, a beam line (ID ~ 95 mm) is used for propagation of the beam towards a 2D steering magnet (inside the pressure vessel) located 400 mm away from the exit of the accelerating

column. This is followed by a vacuum pumping port, a focusing coil, a scanning magnet and a scan-horn. The focusing coil can provide a maximum of 5000 ampere-turns for reducing the beam size. The scanning magnet is at a distance of about 3 m from the exit of the accelerator column. It is used to scan the electron beam on the product requiring irradiation. The scan-horn has an exit window of size 1000 mm x 50 mm with a 50-micrometer thick titanium foil. The beam current is collected by a 3-mm thick aluminium collector kept below the scan-horn. The total beam current is obtained from the power supply circuit, using the return currents from the dynodes and the collector.

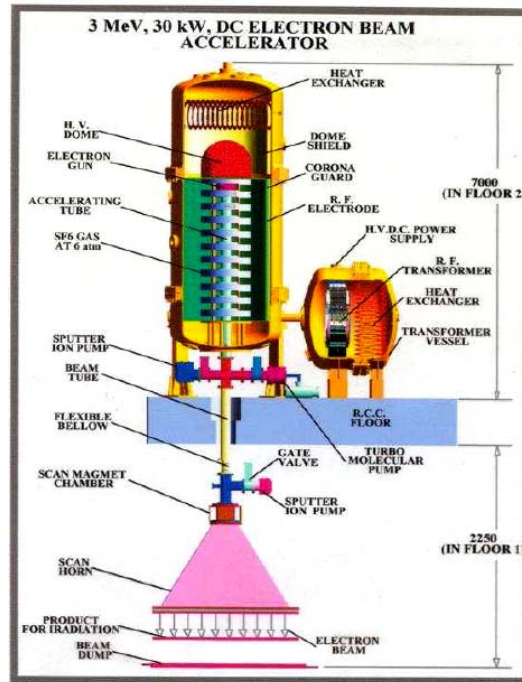


Fig. 1. Schematic of the 3-MeV DC Accelerator

3. Beam trials and gun alignment

Beam trials were conducted at 1 MeV beam energy [5]. The beam current transmission efficiency is shown in Figure 2 (Curve A) as a function of the anode-cathode potential difference, V_{A-C} , of the electron gun maintaining the beam power at 1 kW. The steering and the focusing coils were optimized to obtain the highest possible beam current. The curve shows the maximum transmission efficiency at $V_{A-C} = 1.5$ kV, which falls gradually with the increase of V_{A-C} from 1.5 kV to 4.5 kV.

The beam transmission was measured as a function of the beam current from 1 mA to 4 mA keeping V_{A-C} constant at 1.5 kV. The transmission efficiency was found to decrease gradually from ~78% to 66% with the increase of the electron beam current. [5].

It was later found that both the anode and the cathode were tilted from their positions by about 1 mm and 0.5 mm, respectively with respect to the beam axis. After correcting the alignment of the anode and the cathode, beam transmission was measured again. The transmission efficiency was found to be slightly lower than before, while the general trend of the curve remained same (Curve B, Figure 2). To understand the behaviour of the electron beam propagation through the ion-optics, simulations were carried out using charged particle simulation software SIMION [6]. The results from the simulation are presented in the next section.

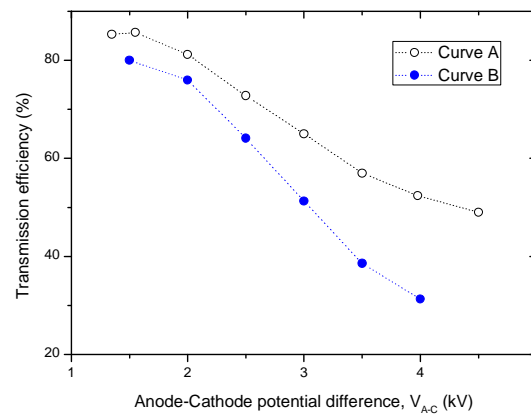


Fig. 2. Transmission efficiency as a function of the anode-cathode potential difference [5].

4. Simulation of the beam trajectories

The electron beam simulations are carried out for a beam energy of 1 MeV. An exact replica of the electron gun along with the accelerating column is modelled in 3D taking advantage of their cylindrical symmetry. The direction of beam propagation is taken as the X-axis of the coordinate system and hence, the beam cross-section lies in the YZ plane. A sectional view of the electron gun with the first accelerating tube is shown in Figure 3. Circular distribution is used for assigning the initial locations of the electrons (1000 – 5000) on the surface of the disc-type cathode (diameter 8 mm) of the electron gun. The cathode and the grid electrode (separation ~ 8 mm) are kept at the same potential (-1 MV) and a potential difference of $V_{A-C} = 4.5$ kV is assigned between the anode and the cathode (separation ~ 25 mm). The gun is followed by an accelerating column consisting of 10 tubes (each of length ~ 30 cm). Each tube has 20 electrodes, and each consecutive electrode of the ten accelerating tubes is kept at a higher potential with respect to the preceding one so that the final energy of the electron at the exit of the accelerating column is 1 MeV. The computational volume is $500 \times 16 \times 16$ cm³, and 10 grid points per 1 mm is considered for computing the electric field.

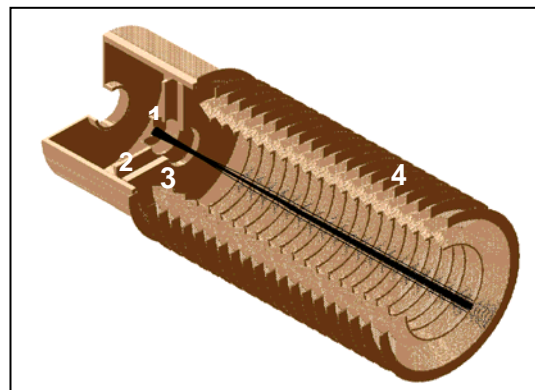


Fig. 3. A 3D sectional view of the geometry of the electron gun with the first accelerating tube.

(1) Cathode, (2) Grid, (3) Anode, (4) First acceleration tube.

Simulation is performed with $V_{A-C} = 4.5$ kV and for a beam energy of 1 MeV (after full acceleration). The trajectories are monitored and the beam-spots are recorded at different axial locations. With the prescribed setting of voltages for the electrodes (~ 200) of the accelerating tubes,

the beam-spots at the cathode, at the anode exit and at the end of the accelerating column are shown in Figure 4. Even at the exit of the accelerating column, the beam does not diverge more than 18 mm in diameter. As expected, the beam-spot is symmetric on the YZ plane with its center coinciding with the X-axis. This indicates that the beam transmission efficiency should not deteriorate provided the beam is not influenced by (i) space charge, (ii) initial thermal transverse velocity, (iii) filament current-induced magnetic field and, (iv) misalignment of electrode(s) or mis-assignment of voltage to any electrode(s).

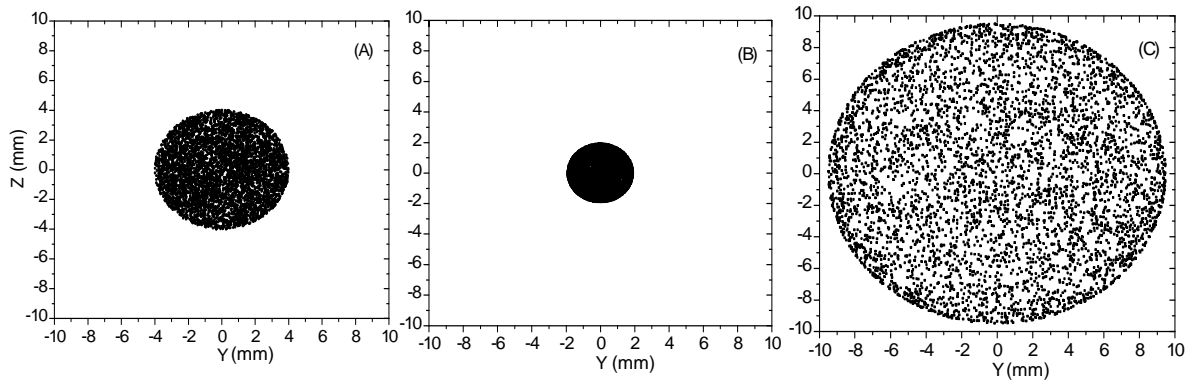


Fig. 4. Beam-spots at different axial locations of the accelerating column.
(A) On the cathode surface, (B) At the exit of the anode, and, (C) At the exit of the accelerating column. The diameter of the beam at the exit of the accelerating column is found

For a 1 mA electron beam with $V_{A-C} = 4.5$ kV, the electron gun has a low perveance (of the order of 10^{-9} A/V^{3/2}). Therefore, intrinsic space charge of the beam is negligible [1]. Furthermore, the initial thermal transverse velocity is also not expected to play a role as it dominates beam propagation only when the beam perveance is too low [1].

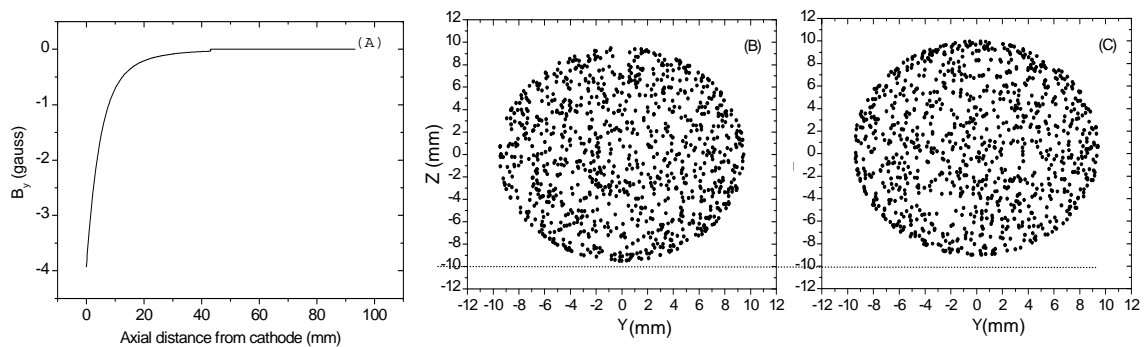


Fig. 5. Beam-spots for showing effect of filament current-generated magnetic field.
(A) Filament current-induced magnetic field at different axial locations, (B) Beam-spot at the exit of the accelerating column without considering the magnetic field, (C) Beam-spot at the exit of the column considering the effect of the magnetic field. The beam-spot is found to shift vertically by < 1 mm.

The aforesaid electron gun uses a linear coil-type tungsten filament (wire diameter = 0.5 mm) of length 14 mm and diameter 6 mm for cathode heating. A typical current of 18 A through the coil produces a magnetic field of about 4 gauss (Figure 5(A)) at the location of electron emitting surface of the cathode in a direction opposite to the net current in the coil. Incorporating this magnetic field, the beam spot at the exit of the accelerating tube is found to exhibit a vertical shift of <1 mm as shown in

Figure 5(C). Increasing the filament current would increase the shift and the beam-spot would start to appear distorted. However, for the typical current of 18 A, these effects are negligible.

Mechanical misalignment, as earlier noticed in the experiment, could have serious repercussions, especially when it comes to the cathode or the anode of the electron gun. Similarly, voltage mis-assignment to the electrode(s) could also lead to straying of the beam off the axis.

A test of beam transmission can be made with a beam very tightly focussed towards the exit of the accelerating column to eliminate dependencies on the steering and the focussing coils. Such a beam can be achieved by slightly modifying the cathode-grid-anode arrangement. Figure 6(C) shows such an arrangement. By bringing the electron emitting cathode surface to the same plane as that of the grid and also by placing the cathode holder in such a way that it does not protrude ahead of the cathode surface, beam cross-over as seen in the simulated trajectory for the original design (Figure 6(A)) can be avoided. The modification thus leads to a continuously converging beam towards the exit of the accelerating column. Near the exit of the accelerating column, the beam diameter reduces from 18 mm (Figure 6(B)) for the original design to about 1 mm (Figure 6(D)) with the modified arrangement.

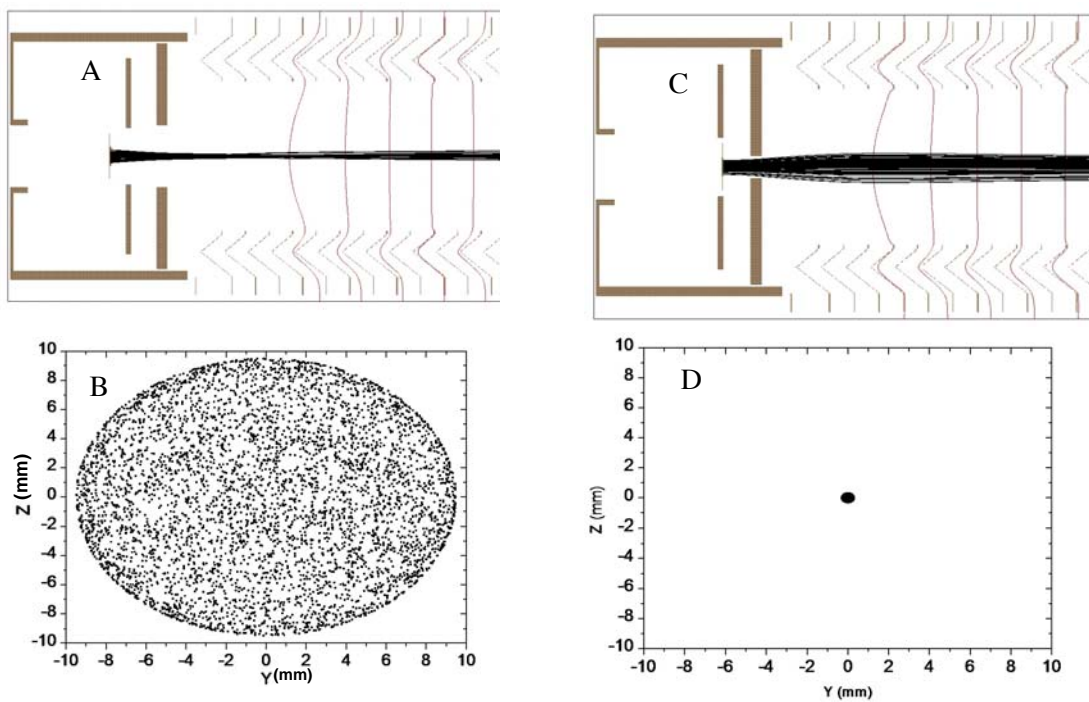


Fig. 6. Existing configuration (A) of the gun electrodes can be modified (C) to reduce beam diameter at the exit of the accelerating column from about 18 mm (B) to 1 mm (D).

5. Conclusion

Transport of a low-density electron beam for a DC accelerator system has been simulated. Beam-spots at different axial locations of the accelerator are recorded at the prescribed voltage settings and it has been found that the beam efficiency should not deteriorate till the exit of the accelerating column. It is also pointed out that the intrinsic space-charge or the initial thermal velocity spread of the electron beam is not expected to influence the beam propagation. Mechanical misalignment or mis-assignment of voltage to any electrode(s) can play a role in the experimentally observed deterioration of the beam transport efficiency. A modified configuration of the electron gun is proposed for checking beam transmission eliminating dependencies on the steering as well as the focussing coils.

Acknowledgement

Authors are grateful to A. K. Das and D. P. Chakravarthy for fruitful scientific discussions and helpful support.

7. References

- [1] Schiller S, Heisig U, and Panzer S 1982 *Electron Beam Technology* (New York : Wiley)
- [2] Majumder R, Mittal K C, Nanu K et al. 2003 *Proc. of Indian Particle Accelerator Conference (InPAC)*, Raja Ramanna Centre for Advance Technology, Indore, India 241
- [3] Jain A, Chindarkar A R and Mittal K C 2007 *Proc. of Asian Particle Accelerator Conference (APAC)*, Raja Ramanna Centre for Advance Technology, Indore, India 348
- [4] Jayaprakash D, Mishra R L, Ghodke S R, Mukeshkumar, Mahendrakumar, Nanu K and Mittal K C 2009 *Bulletin of Indian Vacuum Society* **12(3)** 3
- [5] Acharya S, Nanu K, Mittal K C et al. 2011 *Proc. of Indian Particle Accelerator Conference (InPAC)*, Inter-University Accelerator Centre, New Delhi, India
- [6] Dahl D 2000 *Int. J. Mass Spec.* **200** 3