128: Stable Transport of Intense Elliptical sheet Electron beam through Elliptical Tunnel under Uniform Magnetic Field

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Abstract: *A novel approach of sheet electron beam transport under uniform magnetic field through a tunnel of particular shape and size is described here. The space charge field for rectangular beam trough rectangular tunnel, elliptical beam through rectangular tunnel, elliptical beam through elliptical tunnel is analyzed numerically. This analysis shows that component of space charge field along direction of beam width (x-axis) reduces significantly and varies nearly linear with x by transporting elliptical beam in elliptical tunnel and keeping tunnel walls very close to beam. Simulation result of OPERA 3D software and CST particle studio shows that stable transport of intense sheet beam through an elliptical tunnel under uniform magnetic field is possible.*

Keywords: Sheet electron beam; space charge field; effect of tunnel shape and size; uniform magnetic field; beam transport; suppression of edge effect.

Introduction

Sheet electron beam technology is the promising technology to fulfill the emerging needs of very high pf^2 microwave sources. But stable long distance transport of less relativistic intense beam is still an issue due to Edge effect. These instabilities occur due to $\mathbf{E}\times\mathbf{B}/B^2$ velocity drift. We have proposed a simplified approach to minimize edge curling.

Effect of tunnel shape and size on space charge field

Space charge potential of sheet electron beam transporting through a conducting tunnel is given by the Poison's equation

$$\nabla^2\Phi=\rho/\epsilon_0$$

With boundary condition:

$\Phi(x=\pm a/2) = \Phi(y=\pm b/2) = 0$ for rectangular tunnel and $\Phi=0$ on the periphery of $(4x^2/a^2) + (4y^2/b^2) = 1$ for elliptical tunnel. Here a and b are width and height of tunnel and ρ is volume charge density.

Fig.1 shows the cross-sectional view of an elliptical sheet beam transporting through an elliptical tunnel. Beam width, beam height and beam transport direction are chosen along x , y and z-axes respectively. OPERA 3D software [1] is used to solve the Poison's equation numerically. SCALA solver of this software solves electrostatic problems by finite element method.

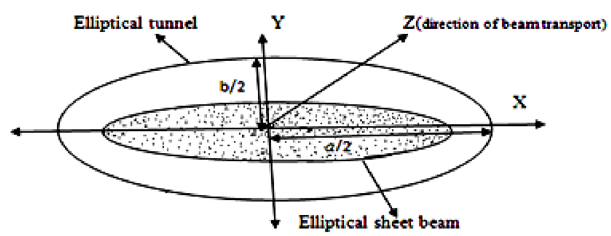


Figure 1. Cross-sectional view of elliptical sheet beam transporting through elliptical tunnel

Using specified current density emitter, beam of current 50 A and kinetic energy 20 keV is emitted from a required surface. Here the emitting surface does not behaves as emitter but rather behaves as beam waist position. For fine mesh generation, tunnel length is limited to 5 mm only. Space charge field is analyzed for rectangular sheet beam through rectangular tunnel, elliptical sheet beam in rectangular tunnel and elliptical sheet beam in elliptical tunnel. Beam kinetic energy and current are same in all the cases. Fig.2. shows the comparison result of variation x-component of space charge field (*Ex*) with x for beam cross-section 20 mm×1 mm and tunnel cross-section 23 mm× 1.8 mm. Here Ex is normalized to the maximum value of *Ex* at beam edge in all the three cases. This figure indicates that *Ex* suppresses significantly and varies nearly linear with x for an elliptical beam in elliptical tunnel.

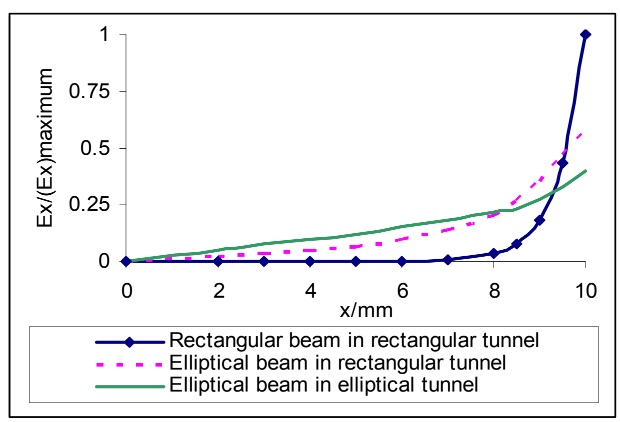


Figure 2. Variation of normalized *Ex* with x showing effect of tunnel and beam shape on *Ex*

Fig.3 shows effect of elliptical tunnel size on variation of Ex with x for elliptical beam. By decreasing the height of elliptical tunnel, Ex is suppressed although there is slightly non-linear variation near beam edge. In case of rectangular tunnel, Ex near beam edge increases sharply by keeping side walls close to beam. It is due to effect of image charges on side wall. But in case of elliptical tunnel, available tunnel height near beam edge decreases. Hence Ex does not increase near beam edge by decreasing elliptical tunnel width due to increase in magnitude of effective image charge on both side walls and vertical walls.

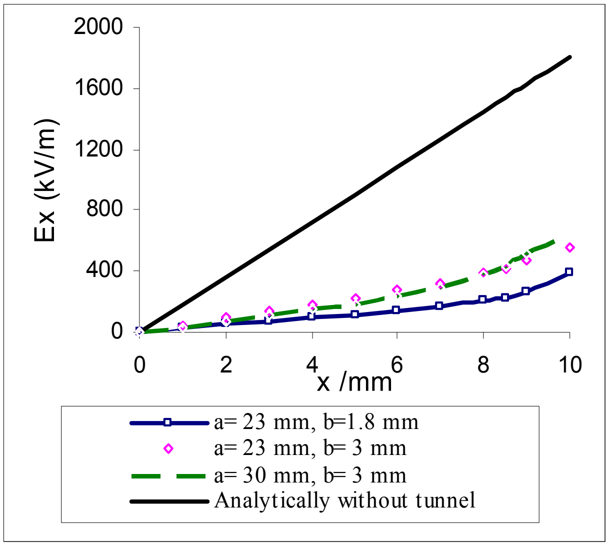
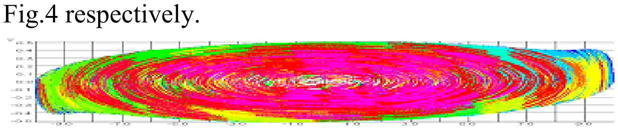


Figure 3. Variation of *Ex* of elliptical beam with *x* showing effect of elliptical tunnel size on *Ex*

Beam transport in uniform field through optimized tunnel

Above analysis indicates that edge effect under uniform magnetic field focusing can be minimized by transporting elliptical beam in elliptical tunnel an keeping both side walls and vertical walls close to beam. Simulation result of OPERA 3D and Particle Tracking code of CST particle studio [2] for transport of elliptical beam of cross-section 20 mm×1mm, current density 320 A/cm^2, beam kinetic energy 20 keV through a elliptical drift tube of tunnel cross-section 26.6 mm× 1.6 mm and length 10 cm under uniform magnetic field 1 Tesla are shown in Fig.3 and Fig.4 respectively.



a)

b)

Figure 4. OPERA 3D simulation result showing a) *Z*=10 cm and b) *x*=0 plane of elliptical beam transporting through an elliptical tunnel

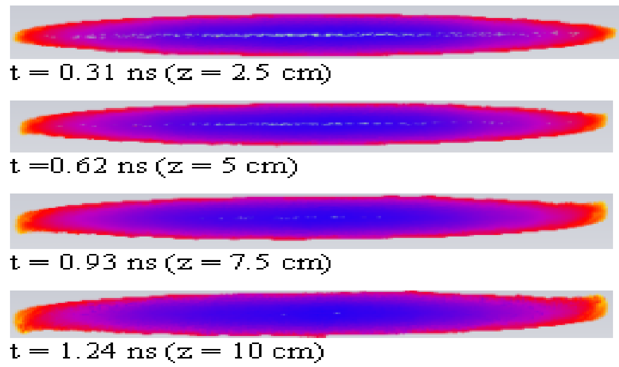


Figure 5. CST simulation result showing cross-sectional view of elliptical beam at different position of elliptical tunnel.

Fig.4 indicates that the flow is almost laminar with slightly edge curling. Fig.5 indicates the beam transport up to 7.5 cm without edge curling. After this distance edge curling is noticed which also can be suppressed by increasing fill factor or magnetic field.

Conclusion

Edge effect of sheet electron beam can be suppressed significantly by transporting elliptical electron beam through optimized elliptical tunnel under high uniform solenoid magnetic field and keeping tunnel walls very close to beam. Hence, a very less relativistic intense sheet beam for which PPM focusing are not suitable can transport up to long distance through a proper elliptical tunnel under uniform magnetic field.

Acknowledgement

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References

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