SHEET ELECTRON BEAM GUN DESIGN USING ARGUS

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Abstract

An electron gun has been designed which will produce dual sheet electron beams for use in a 1MW, 120GHz quasi-optical gyrotron. This "sheet" beam, due to its inherent 3D geometry, must be simulated with a 3D code. Using the 3D PIC code ARGUS in the electrostatic relaxation mode, equilibrium electron ray traces and fields are presented. Although the study is not complete, the simulation results obtained thus far reveal many of the physics issues associated with the device. In particular, the paper studies the consequences of the $\mathbf{E} \times \mathbf{B}$ drift of the particles as it concerns the issue of segmenting the sheet beam into "beamlets" for optimization.

Introduction

The quasi-optical (QO) gyrotron[1] is a promising source of high power mm wave radiation. With a klystron configuration, efficiencies up to 45% are predicted, and output powers of several megawatts at 300GHz may be possible.

This paper describes modeling the design of an electron gun with a rectangular geometry capable of producing an electron beam which is thin in one direction (satisfying the need for the beam to lie within the waist of the radiation beam), and wide in the direction of the radiation beam axis (allowing the cross-sectional area of the "sheet" beam to be significantly greater than that of an annular beam). This allows an increase in the beam current and consequently the output power. Additionally, the sheet beam is segmented into "beamlets," such that each beamlet will pass through the resonator at the position of a peak of the standing electric field pattern. This is expected to increase the efficiency of the device by $\sim 30\%$.

Design

The geometry of the proposed design and experiment is inherently 3-dimensional. While the geometries of the gun and the beam are rectangular, the magnetic field in which they are immersed and compressed is cylindrical. In this paper, the three-dimensional, particle-in-cell simulation code ARGUS is used to investigate the equilibrium condition of the gun. For this problem, the code is run in the electrostatic relaxation mode which models the equilibrium fields, which include self fields, and the steady-state particle ray traces within the device. The paper addresses the difficulty of simulating a problem of this type. In particular, the extreme device length, high magnetic fields, and intricate structure couple together in such a way as to heavily tax the current computational capabilities of supercomputers. However, the main emphasis of the paper involves the overall device characterization and the consequences of segmentation. In the latter case, of particular importance is the skewing of a beamlet due to the $\mathbf{E} \times \mathbf{B}$ drift as it passes through the device.

Three-Dimensional Modeling

The determination of the number of computational cells in each of the coordinate directional is due solely to the need to properly resolve the fields. Thus the metallic structures must be well defined as well as the field due to the charge deposition of the rays. Secondly, to determine the particle advancing time step, the need to properly sample the fields is of concern. Thus, the time step must be small enough that it requires two steps to cross a cell and that any cyclotron orbits are properly resolved.

The sheet beam cathode is depicted in Fig. 1. The cathode has emitting surfaces on both the top and bottom, and the beamlets are evident in the figure. Shown in Fig. 2 is the ARGUS model of the anode structure with the cathode. It can be seen that the anode is about six time longer than the cathode. Note that the device is symmetric about the base plane in Fig. 2, thus, the simulation need only include the upper portion with a symmetric lower boundary condition. Modeling simply the cathode is not a difficult task for a 3D code on a supercomputer, however, modeling the whole device with particles proves to be quite formidable, requiring 41 cells in the x (vertical) direction, 350 cells in the z (axial) direction, and 61 cells in the y direction for proper field resolution. This simulation could only fit on a CRAY-2 without resorting to domain decomposition.

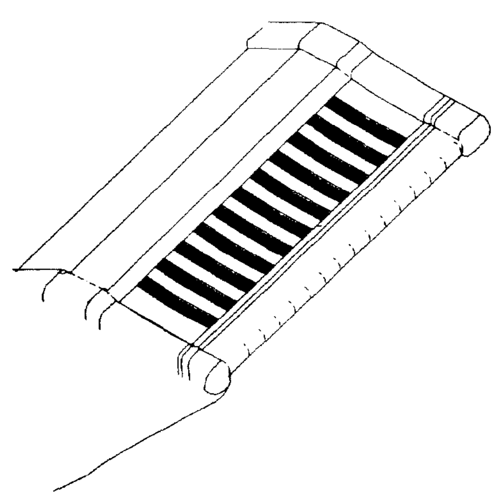

Fig. 1. Geometry of segmented sheet beam cathode.

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Fig. 2. ARGUS model of electron gun.

E × B Drift

One of the issues faced with the segmented sheet beam is that the amount of **E** × **B** drift in each beamlet is not the same due to the different y positions. Also, the electrons emitted along any one beamlet surface will also have different amounts of drift. It turns out that the amount of drift can be on the order of the interbeamlet spacing. To address this, each beamlet emitting surface is skewed (slanted) to counteract the drift rotation.

Due to the inherently large cost of a full simulation, to provide a good estimate for the beamlet skew angle, the system was first simulated out to about 17cm (10cm from the foremost cathode position). Since the total problem length is 42.3cm, the computational requirements of this smaller simulation are significantly reduced. For example, this simulation of 41x61x130 can be run on a CRAY-XMP (this was done at SDSC) with the domain decomposed into 2 blocks since it required almost twice the 4 million word memory capability of SDSC.

To represent the beam and the beamlets, 33 rays were chosen for the 11 beamlets (three rays per beamlet). The simulation results are shown in Fig. 3 for the parameters in Table 1. This represents one of several runs made at this stage to determine exactly what slant angle was needed. This final simulation in this set of runs was sufficient to allow a reasonable determination of the skew angle to be 18°. Several aspects of the problem can be seen from the three figures. First, Fig. 3.a shows the top view of the device and includes the particle ray traces superimposed on the structure and a contour plot of the electrostatic potential. It can be seen that it is impossible to have the situation where, for all the beamlets, each ray in the beamlet lines up vertically, but the result is reasonably good nevertheless. Also evident in this figure is a shift in the y direction of all the rays. This indicates the amount of **E** × **B** drift in the device.

Voltage		80 kV
Current (Both beams, segmented)		34 A
Magnetic Field Compression		38
Cathode:	half angle	27°
	slant length	24 mm
	width	78.8 mm
	beamlet width/spacing	3.75/7.5 mm
	current density	1.7 A/cm^2

Table 1. Gun Parameters

Figure 3.b shows a side view of the system, again superimposing the particle ray traces with the potential and structure. Here, the three particles representing a beamlet can be seen leaving the cathode. What can be noted in the figure is that the particles' vertical shift is significantly different from beamlet to beamlet. Finally, from Fig. 3.c, the plot for z momentum versus z position shows that the particles all reach the maximum (80KeV) velocity by about 11cm axial position, where the z momentum plotted in the figure is actually ($\gamma\beta_z$).

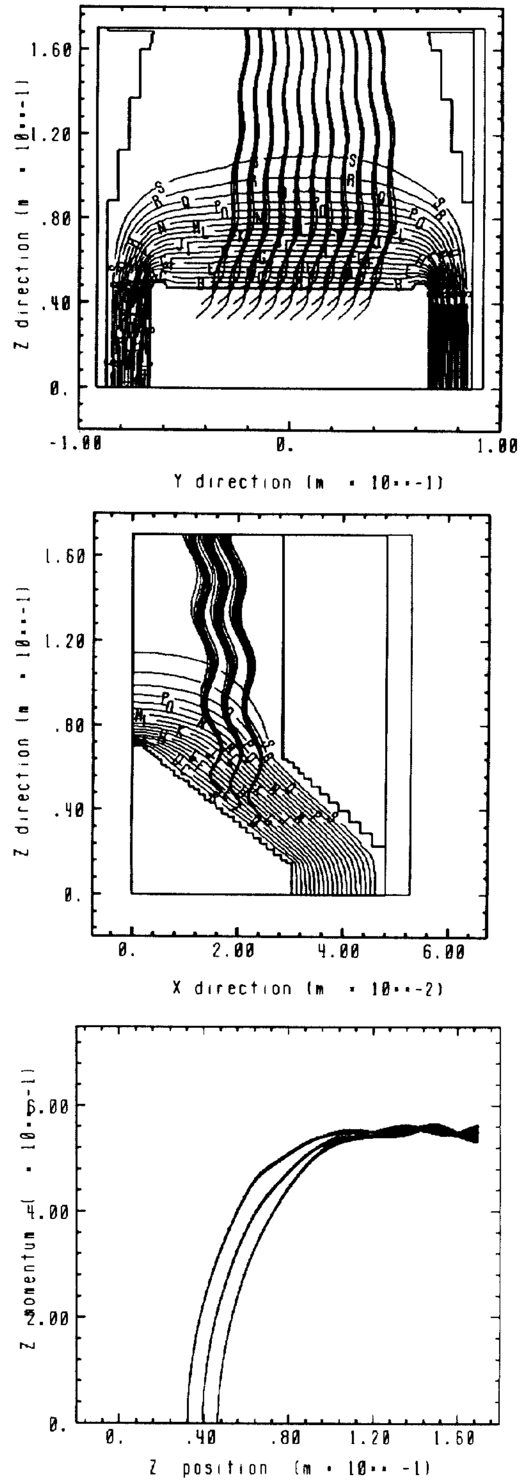

Fig. 3. Plots of a) z vs. y, b) z vs. x, and c) $\gamma\beta z$ vs. z for the accelerator region.

Full Problem Simulation

In this section, the most recent results from a full problem device simulation are presented. The simulation geometry is shown in Fig. 2, and the results are shown in Fig. 4. Since this was the first full simulation made, and further ones will follow, only 33 particles were used instead of a more proper amount of 120. With this smaller run, cost and computer needs can be estimated so that the future simulation schedule can be adjusted, while allowing meaningful physics to be modeled. As a note, it is expected that about 120 rays are needed to properly study detailed beamlet-to-beamlet characteristics due to beam thermalization at compression.

Figure 4.a shows the top view of the particle ray traces superimposed on the electrostatic potential contours and the structures. This figure shows that the choice of skew angle for the beamlets was quite good. As the particles become more compressed, they tend to line up quite well. This did not happen before the space charge developed. Figure 4.b shows the side view of the particle ray traces. The magnetic compression can be noted as well as the large cyclotron gyrations that are made by the particles.

Many interesting results can be found in Fig. 4.c, where z momentum ($\gamma\beta_z$) versus z position is plotted. Here, the basic physics of the gun design can be seen. After the beam is accelerated, as z is further increased, the magnetic compression begins to transfer the axial momentum into transverse direction. The amount of transverse momentum increase is quite dramatic to the point where a good portion of the axial energy is lost by the particles. It should be noted here that, as a preliminary simulation, the magnetic compression has also been decreased. The amount of compression that is expected to be used should transfer most of the energy to the transverse direction.

Conclusion

In this paper, the problem of using a sheet beam in a quasi-optical gyrotron was investigated. In particular, the case involving beam segmentation was studied. At this stage in the study, it appears that beam segmentation is very promising since beamlet resolution was quite good after compression. Also, the choice of cathode skew angle was quite good. It should be noted that the computational requirements to fully study a problem of this magnitude are significant.

Acknowledgements

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References

[1] M.E. Read, M.Q. Tran, J. McAdoo, and M. Barsanti, Int. J. Electronics, vol. 65 (3), pp. 309-325.

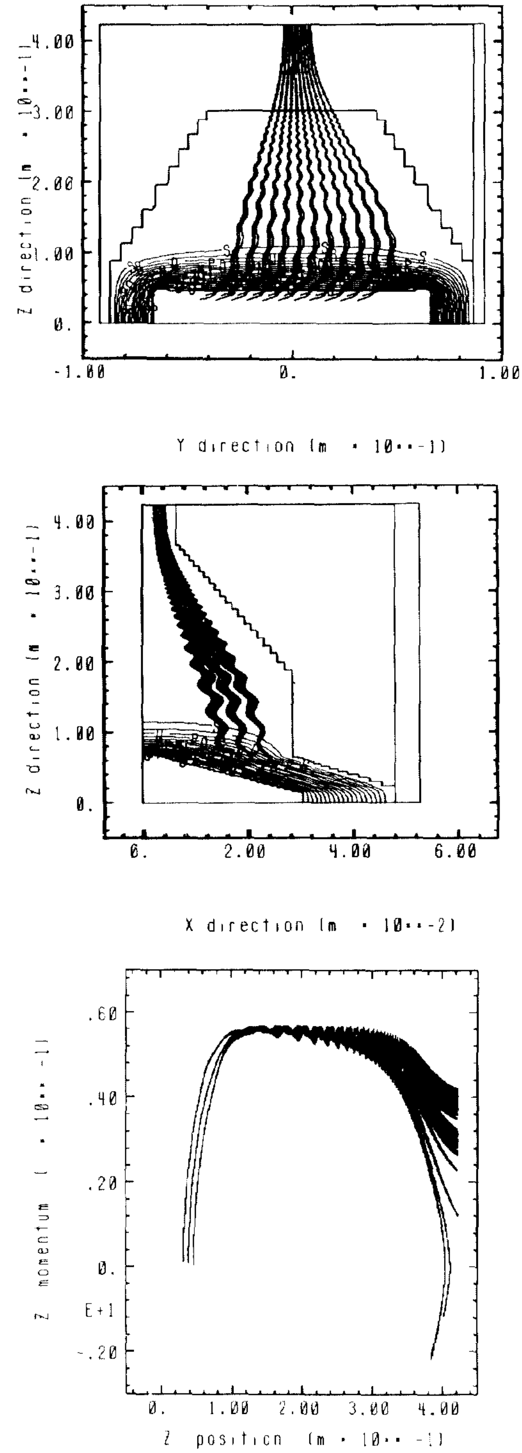

Fig. 4. Plots of a) z vs. y, b) z vs. x, and c) $\gamma\beta z$ vs. z for the full device.