3D MODELING ACTIVITY FOR NOVEL HIGH POWER ELECTRON GUNS AT SLAC

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Abstract

The next generation of powerful electronic devices requires new approaches to overcome the known limitations of existing tube technology. Multi-beam and sheet beam approaches are novel concepts for the high power microwave devices. Direct and indirect modeling methods are being developed at SLAC to meet the new requirements in the 3D modeling. The direct method of solving of Poisson's equations for the multi-beam and sheet beam guns is employed in the TOPAZ 3D tool. The combination of TOPAZ 2D and EGUN (in the beginning) with MAFIA 3D and MAGIC 3D (at the end) is used in an indirect method to model the high power electron guns. Both methods complement each other to get reliable representation of the beam trajectories. Several gun ideas are under consideration at the present time. The collected results of these simulations are discussed.

INTRODUCTION

It is advantageous for multi-beam high power devices that the external magnetic flux guides each individual beam that is emitted from the cathode. This is known as confined flow focusing. The challenge is to develop electron guns and the associated magnetic optic system to confine and compress the electron beams and transport them through the separate beam tunnels to the spent beam collector. This is fundamentally a three-dimensional problem. Asymmetry of the focusing magnetic field can lead to partial interception of the beam. The beam interception creates the power losses and leads to the thermal deformations. To avoid these limitations it is necessary to develop methods of 3D computer simulation and create the mathematical model. A new approach for 3D analysis of the electron guns and beam optics utilizes a combination of MAFIA 3D and TOPAZ 3D. An algorithm based on perturbation theory provides a 3D correction to the 2D, self-consistent field solutions. The combination of TOPAZ 2D or EGUN (in the beginning) with MAFIA 3D and MAGIC 3D (at the end) is used as an indirect method to model the high power electron guns also.

3D MODELING OF MULTIBEAM GUNS **

The amount of RF power that can be produced in a linear beam microwave tube is dependent on the amount of beam power that can be transmitted through the device. Space charge forces that occur as the beam is bunched in device, limit the amount of current that can be transmitted. In order to increase the power, it is necessary to increase the beam voltage. This leads to reduced efficiency and complicates the power supply. One way to reduce the space charge forces is to use a multiplicity of electron beams. They will travel through individual beam tunnels. This allows operation at significantly lower voltage while enhancing the RF performance. Additionally multi beam mode operation reduces the required magnetic power. For example, the reduction in beam voltage for the same level of rf power for the multi-beam klystron as compared to single-beam design is shown in Fig. 1. Here N is a number of the beamlets.

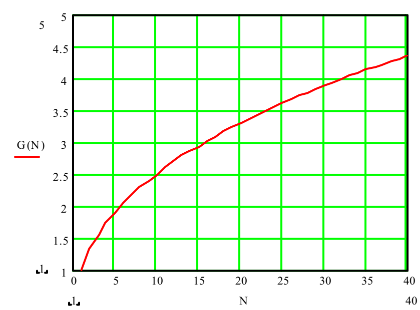

Figure 1

It is seen that the beam voltage can be reduced by factor 2.5 if the ten-beam configuration of klystron is employed.

The SLAC algorithm for a design of the MBG optical system was described in [1]. This algorithm was used for design of MBGs under SBIR grants (see footnote **). Additionally, the MBG for TESLA L-band klystron with initial triode configuration and post acceleration stage was investigated. The advantage feature of proposed klystron gun is a fact that the klystron is connected with DC power supply directly, i.e. without klystron modulator. Only the grid control pulser is required. This pulser has a DC grid bias that shuts off the multi beam gun between pulses. The intermediate electrode (modulating anode) separates the grid controlled region and the post acceleration stage and plays a role as a klystron gun arc protection.

Some of the results of the 3D MBG design, which were performed for Calabazas Creek Research, Inc, are presented. The sketch of MBG is shown in Fig. 2. Here the cross section of the iron dome behind the cathode is shown. The shape of the dome is made in such a way that the magnetic flux distribution in the region between a pole piece and the cathode duplicates the distribution for the case when the cathode is on the axis. A 3D cutaway picture of the iron dome is shown in Fig. 3. The presence of radial magnetic field (**Br**) in the beam optical system is the result of the beamlet sheer in accordance with $[\vec{v}_z \times \vec{B}_r]$ azimuthal component. The behavior of the off-axis confined flow beamlet is presented in Fig. 4.

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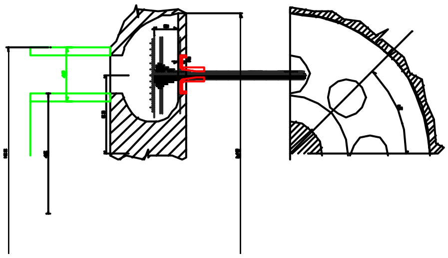


Figure 2

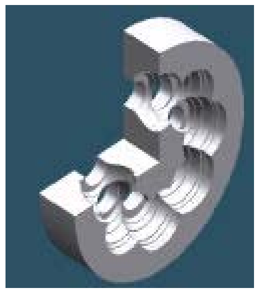


Figure 3

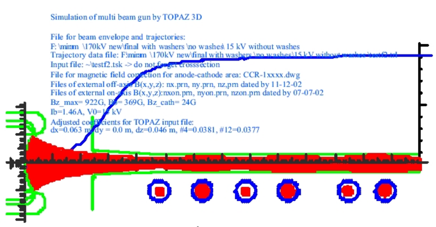


Figure 4

This beam envelope and its cross sections correspond to the case where the ratio between radius of the solenoid and the radius of the bore circle is approximately 2. The designed shape of the iron dome was insufficient to provide 100% transmission through the whole length of the device. A Fig. 5 illustrates **Br** distribution along beam axis.

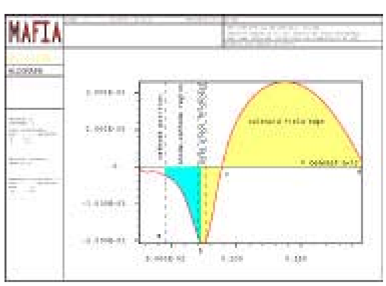


Figure 5

In this case, the fringe solenoid field contains large enough area with Br. There are several methods to compensate this field. It was found that the field straighteners in the solenoid part effectively suppress the beamlet sheer and allows the beam transmission to reach 100% (see Fig. 6).

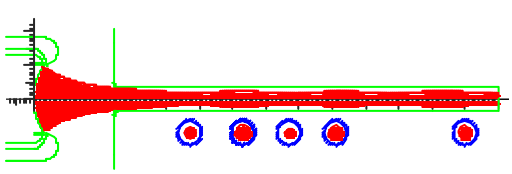


Figure 6

The iron dome shape around the cathode region and the field straighteners in the solenoid part provide the excellent duplication of on-axis magnetic field [2]. The MBG test bench is under construction. The results of the experimental study of this geometry are expected during this year.

3D MODELING OF SHEET BEAM GUNS

Studies of MBG for the high power X-band electron devices show that cathode current is high (more than 15 A/cm^2 in our example) reducing the cathode lifetime. The klystron with a sheet beam can overcome some limitations of the multi-beam devices. The design of sheet-beam guns (SBG) is fundamentally a three-dimensional problem. Two methods are currently used to design the SBG at SLAC. Direct and indirect modeling methods are developed to meet the new requirements in 3D modeling. The direct method of solving of Poisson's equations for the SBGs is employed in the TOPAZ 3D tool. The combination of TOPAZ 2D and/or EGUN (in the beginning) with MAFIA 3D and MAGIC 3D (at the end) are used in an indirect method to model the high power electron guns. Both methods compliment each other to get reliable representation of the beam trajectories. Currently two SBG geometries are under study. They are shown as quarter model of the whole geometry in Fig. 7 and 8.

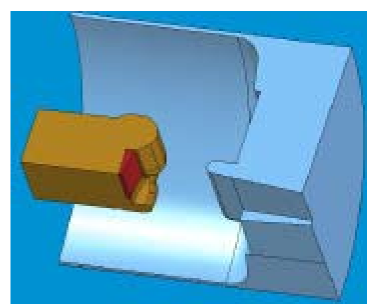


Figure 7

The gun of Fig. 7 represents the diode type gun with three elements: cathode (red), focus electrode, (yellow), and anode (grey). This is Vb=490 kV and Ib=250 A gun with the 100 x 72 mm^2 cathode area.

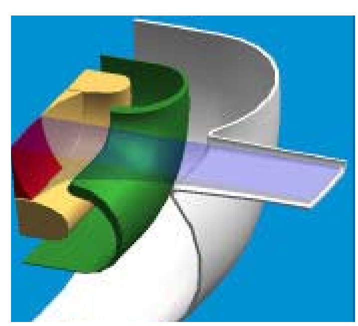


Figure 8

The gun shown in Fig. 8 represents the triode configuration with the intermediate electrode (green). This electrode separates the beam formation region and post accelerating stage. The purpose of this electrode is to protect the cathode area against arcs. It can be also used as the modulating anode for some applications. The pulsed control voltage in this case is smaller than the beam voltage and isolated x-fmr is necessary in this configuration. The most attractive modification of proposed gun is the gridded version gun that is shown in Fig. 8. This version is being developed for Calabazas Creek Research, Inc with funding from DoE. The current design parameters are as follows: Vb=415 kV, V1=150 kV, Ib=270 A (Vg=9 kV for grid control of SBG). The cathode area is 100 x 84 mm^2. Both SBGs have the beam compressive and non-compressive planes. The problem was to find a shape of focus electrode, so the beam trajectories were similar to the 2D trajectories in the beam compressive plane. Especially it was necessary to pay attention for the trajectories at the corner of the cathode. Some of the studied focus electrodes for the diode version of SBG are shown in Fig. 9.

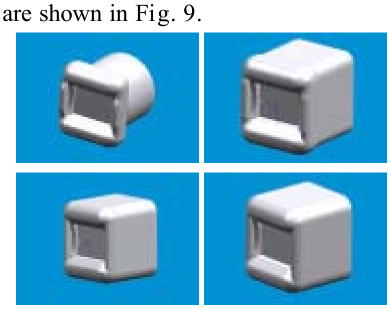
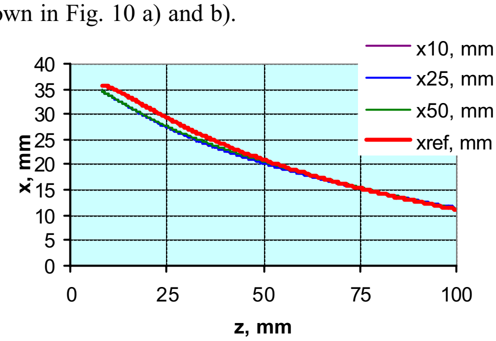
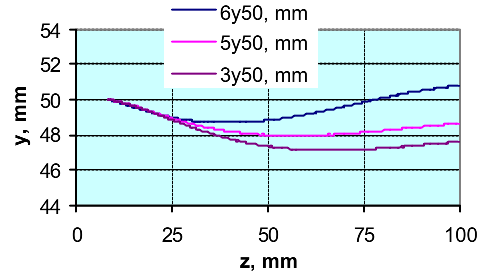


Figure 9

The difference in the shapes takes place mainly for the corner area and the non-compressive pane.

The MAFIA 3D static solver simulates the electric and magnetic fields for SBG geometry. The beam space charge has been extracted from 2D run and introduced into input MAFIA file together with the electrode potentials. The sign of the electric fields from electrodes and the beam space charge are matched to get the physical correct action on the test particle. The same takes place for the beam self magnetic field. The result of MAFIA static solution was six files with **E** and **B** components in the gun space. It was possible to get a visualization of the electric and magnetic Faraday's lines after MAFIA simulation. This feature of the indirect method is useful to get some insight regarding what the electron trajectory would look like. The components **E** and **B** are introduced into MAGIC 3D together with the initial particle momentum distribution on the cathode surface. The trajectories of test electrons are traveling into gun space and can predict the quality of the SBG geometry. The output file of MAGIC 3D contains the trajectory data that can be compared with 2D trajectories in the middle plane. The result of the comparison for the diode type of SBG with the fourth focus electrode is shown in Fig. 10 a) and b).





Figures 10 a) and b)

The picture of Fig. 10a represents the comparison between the reference outer trajectory (red curve) and trajectories of electrons, which are emitted from the cathode corner. There is practically perfect duplication of the corner trajectories with reference trajectory. The trajectories for non-compressive plane are shown in Fig. 10b where 6% deviation takes place. The method described above was employed to study the gridded version of three-electrode gun. Studies show that the original version of the SBG shown in Fig. 8 has the diverging trajectories in non-compressive plane. The new version of this gun is shown in Fig. 11.

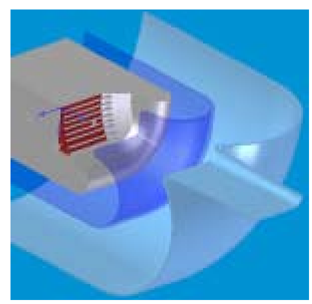


Figure 11

The shape of the focus electrode in the non-compressive plane and its corner were adjusted to meet the beam requirements for the PPM focusing channel. More results and data are available at the PAC2003 FPAB011 poster.

CONCLUSION

The 3D gun design tools have been under development at SLAC. Indirect method has been employed to model different 3D gun geometries and allows to optimize their focus electrodes. The combination of TOPAZ 2D and EGUN (in the beginning) with MAFIA 3D and MAGIC 3D (at the end) is used in an indirect method to model the high power electron guns. This method is effective to get the trajectory deviation from the reference particle.

ACKNOWLEDGEMENTS

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[2] E. Gelvich, at al., The new generation of high-power MBK, IEEE-MTT, v. 41 #1, p.15, 1993