3D METHOD FOR THE DESIGN OF MULTI OR SHEET BEAM RF SOURCES*

V. Ivanov, K. Ko, A. Krasnykh, SLAC, CA 94025, USA
L. Ives, G. Miram, Calabazas Creek Research, Inc., CA, USA

Abstract

Lowering the voltage of the RF sources can reduce the cost of future accelerator systems. This can be accomplished using multiple beam guns or guns with sheet beam in tubes creating high RF power. However, the optical design is almost impossible without 3D analysis, since the devices are no longer axis-symmetric. A new approach for 3D analysis of the electron gun and beam optics utilizes a combination of 3D MAFIA and TOPAZ computer programs. An algorithm based on perturbation theory provides a 3D correction to the 2D, self-consistent field solutions. This information is used to study propagated charged particles through the problem domain. Applications of this technique to the design of a high power multiple beam guns is discussed.

1 INTRODUCTION

The cost, reliability, and efficiency of RF sources are very important for future accelerators. Tradeoff analysis shows that the use of low perveance multi beam or sheet beam optic system is mainly desirable for the development of high power modern RF sources. In the past 2D numerical methods and accordingly its mathematical models were developed and successfully used for a design and optimization of electron guns and devices as well. As an example EGUN [1] and POISSON/SUPERFISH [2] are a powerful tools for design of the axi-symmetrical klystron guns and its magneto-optical system.

The unperturbed passage of beam current from cathode through RF system is main concern of a designer. Usually the confined flow focusing is employed for a modern high power RF sources. This type of focusing is less sensitive to beam perturbations. The special magnetic circuits providing desired focusing field allow creating uniformly distributed magnetic flux in the cathode region.

Due to asymmetry of the off axis magnetic field distribution the electron beam will spin and introduce excessive scalloping causing beam interception on the high power tube system. The power losses lead to the thermal deformations. To avoid these limitations it is necessary to develop a mathematical model for 3D computer simulation. The goal of present paper is to show the developed algorithm to solve this problem.

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2 MATHEMATICAL MODEL AND ALGORITHM

The most part of well-known codes use Finite Difference Method. It is proposed the use of Boundary Element Method. This method results in more precisely solution for complex geometries. The solution φ of Poisson's equation

$$\nabla^2\varphi = \frac{\rho}{\varepsilon_0} \qquad (1)$$

with known initial boundary conditions is obtained with the following integral representation

$$\varphi(x,y,z) = \frac{1}{4\pi\varepsilon_0}\int_V \frac{\rho dV}{R_0} + \frac{1}{4\pi\varepsilon_0}\int \frac{\sigma dS}{R_i}, \qquad (2)$$

for unknown density of surface charges σ. A cubic spline approximation for σ and the algorithms of regularization for kernel and edges singularities are used [3] in algorithm. Meshing of volume, boundaries and surface charge distribution gives a linear system of equations. The field components are obtained by analytical differentiation of the representation of (2). Then the motion equations are integrated with known

$$\begin{aligned} \frac{d}{dt}(p_x) &= q(E_x + v_y B_z - v_z B_y) \\ \frac{d}{dt}(p_y) &= q(E_y + v_z B_x - v_x B_z) \\ \frac{d}{dt}(p_z) &= q(E_z + v_x B_y - v_y B_x) \end{aligned} \qquad (3)$$

initial data. The MAFIA-3D static solver evaluates the external magnet field components Bx, By, and Bz. The self-consistent electric and magnetic fields of the beam are taking into account with the charge and energy conservation laws

The Child-Lengmuire law

$$\frac{d}{dt}\rho = -div(\vec{j}) \qquad (4)$$

$$\vec{j} = \vec{v}\rho$$

$$j_0 = \vec{n}\cdot\min\left[j_{\max}, \frac{4\sqrt{2}\varepsilon_0}{9e\sqrt{m}} \cdot \frac{e\sqrt{(\varphi(h)-\varphi_0)^3}}{h^2} \right] \qquad (5)$$

is employed for thermionic cathode emission in a space charge-limited mode.

The example of TOPAZ 3D algorithm for the multi beam confined flow gun is shown below. The field distribution for the confined flow multi beam guns is dominated by the fringe fields and has to be calculated as 3D problem. The flow chart of algorithm is presented on the Fig.1.

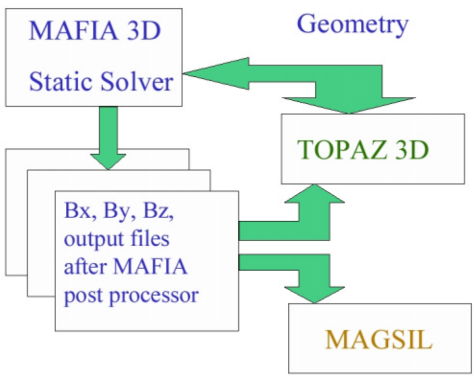

Figure 1: Algorithm of magnet optic design

Input file goes through M + S modules of MAFIA. After simulation the post processor creates three output files with field distribution. MAFIA result is loaded into TOPAZ 3D computer program for the trajectory analyze. Magnetic flux lines govern a beam for confined flow guns. A new tool MAGSIL produces these lines in X and Y planes. Equilibrium radius of the beam can be adjusted by observation of the data and correct the geometry and initial parameters if it is necessary. An example of MAGSIL usage is shown in Fig. 2.

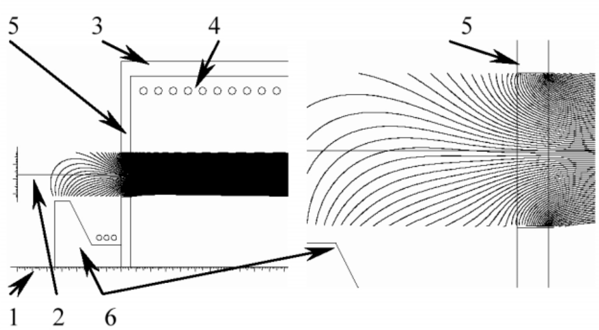

Figure 2: Magnetic flux lines of the fringe field of iron container are shown here. 1 is main axis of system; 2 is offset axis; 3 is iron container with a solenoid 4; 5 is iron pole piece with holes for beams; 6 is an additional magnetic circuit with a mushroom shaped iron and coil

The boundary problem with absence of the beam field has axial symmetry. Self-consistent non linear problem (2)-(5) can be solved by iteration method. Really this problem is 3D one, but we can consider the influence of 3D external magnetic field as perturbation of 2D self-consistent field. Thus we provide 2D iteration till the convergence, then we take into account particle tracking in total 3D field. In order to analyze the beam envelope we take eight azimuth boundary trajectories on the cathode surface and evaluate theirs distribution in output cross-section.

3 RESULTS OF SIMULATIONS

TOPAZ 3D at SLAC is used for a simulation of sheet beam klystron gun, confined flow multi beam klystron guns as well as axis symmetry klystron guns. For the first example, to show the features of TOPAZ, a result of fine resolution studies is presented in Fig. 3.

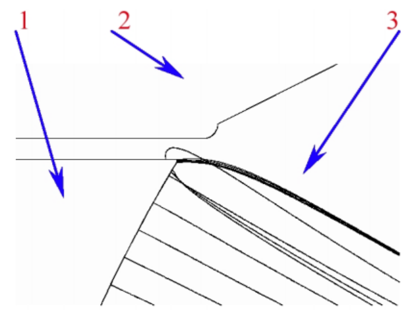

Figure 3: 1- is a cathode of gun; 2- is its focus electrode; 3 - is trajectories from different emission surfaces of the cathode edge

A new feature of TOPAZ allows generation of trajectories in the Windows Metafile Format. This format can easily be imported into MS Word, ACAD and other shells and then analyzed and printed with good quality.

The sheet beam allows braking through the limitation of cathode loading for the high pulse power of the classical electron devices. The result of the sheet beam electron gun simulation is shown in Fig. 4. Here the trajectory of the 3.2 kA/m current represents the gun with the 15.5 microperveance. The output power of the 10 cm wide electron beam would be approximately 110 MW.

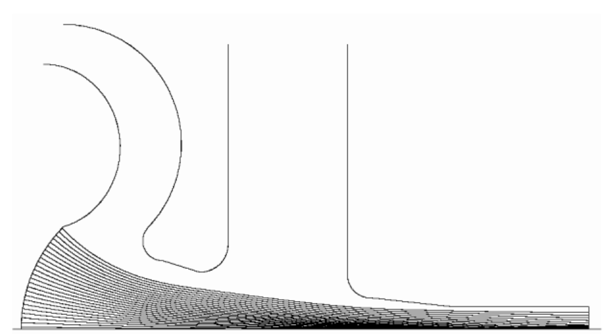

Figure 4: Sheet beam simulation.

The basic idea of multi beam gun as well as sheet beam gun is an attempt to increase the beam current without increasing of the cathode loading. The several geometries of the confined flow multi beam guns were investigated. Some results of these studies are presented in Fig. 5 - 7. The goal of these simulations was to find a geometry, which may eliminate the trajectory perturbations due to offset of beam axis relative to the solenoid axis. The special shaped iron is used to correct off axis magnetic field near the pole piece hole region (see for example Fig 8).

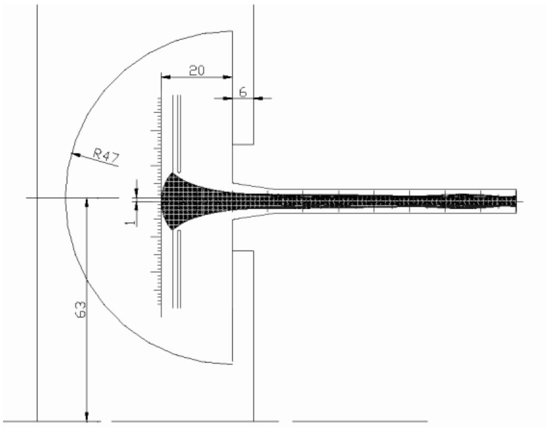

Figure 5: The beam in axis-symmetric magnet field

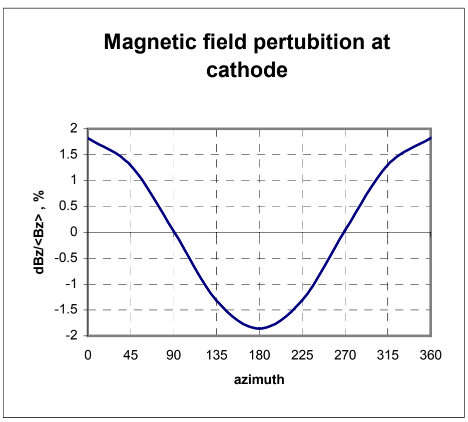

Figure 6: Field distribution over cathode surface

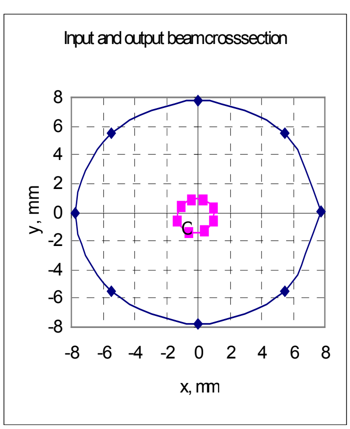

Figure 7: Initial (blue) and output (pink) beam cross-sections

Other example is shown in Fig. 8. Here the corrected magnetic flux lines near polepeace opening are presented. The picture of the flux lines is correspond to the plane where the field has the worth beam axis asymmetry. As it follows from simulations the individual beam power of 10.9 MW can be obtained if the cathode radius is 10 mm and cathode voltage is 170 kV. The combined power is 87 MW.

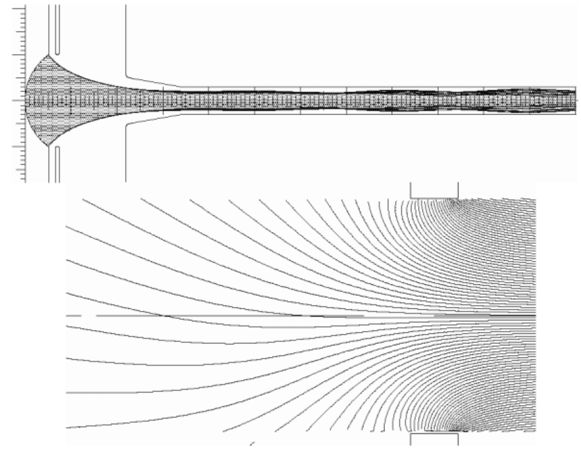

Figure 8: Corrected optics and magnetic field map near the pole peace opening.

4 CONCLUSIONS

TOPAZ is a useful and effective tool for electron gun design. Adjustment of the code for DOS window operation using an NT operating system on a PC platform has been demonstrated. There is a good agreement between EGUN and TOPAZ. An advantage of TOPAZ is the importation of 3D magnetic fields from MAFIA. This advantage is new in the SLAC TOPAZ version. The development at SLAC of the MAGSIL software is useful for this data importation. The SLAC version of TOPAZ also recognizes the magnetic fields from POISSON. TOPAZ 3D can be used to design and study fine electron optics in 3D.

5 REFERENCES

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