Joint Simulation of Electron Optical System and Beam-wave Interaction of V Band Folded Waveguide TWT

XiulingGe, Jin Xu*, Lingna Yue, Hairong Yin, Guoqing Zhao, Wenxiang Wang, Z.G. Lu, T. Tao, H.R. Gong, Y.B. Gong, Yanyu Wei

National Key Laboratory of Science and Technology on Vacuum Electronics
School of Electronic Science and Engineering,
University of Electronic Science and Technology of China
Chengdu, Sichuan, 610054, China
*E-mail: alionxj@uestc.edu.cn

Abstract: *In order to make the design results of the traveling wave tube (TWT) coincide with the experiments very well, we need to build a bridge between the actual electron situation and the beam-wave interaction. In this paper, considering the actual magnetic field distribution, the macro particle data at the waist position is processed by MATLAB to meet the needs of the interaction calculation model, so as to realize the integrated design of electron gun, magnetic system and interaction calculation using CST studio suite.*

Keywords: macro particle; folded waveguide; TWT.

Introduction

TWT has been widely used in radar, satellite communications and other fields due to its advantages of wide bandwidth and high efficiency. Usually, in order to simplify the calculation of beam-wave interaction, the movement of ideal electrons in the periodic magnetic field is adopted. But in the real TWT, the difference trajectories of electron beam have a great influence on the overall performance of the device. In order to consider the real particle information in the calculation of beam-wave interaction, the macro particle information obtained from the electron gun calculation should be rearranged to meet the requirements of interaction calculation. In the calculation of the beam-wave interaction, the influence of the actual magnetic field on the electron beam fluctuation is taken into account. By adopting such a joint simulation, the calculated results of the TWT could be consistent with the experiment.

Macro particle data processing

V-band traveling wave tube has been widely studied in the field of near-field confidential communication, satellite communication and satellite countermeasures as amplifier devices. In order to make the actual traveling wave tube performance consistent with the experimental conditions, the CST particle tracking was used to design and simulate the electron gun. The macro particles were about 10,000 in the electron gun simulation in order to obtain reliable results. After simulation of the electron gun, electron trajectory is obtained, shown in figure 1.

Figure 2 shows the spatial position distribution of macro particles at the beam waist. Figure 3 shows the velocity distribution at the beam waist in Z directions. In figure 3, the abscissa represents the particle number, and the ordinate is the particle velocity in m/s. As can be seen from figure 3, the maximum velocity of the particle in the direction is 7.516×10^7 m/s, the maximum speed in the X, Y direction is about 2×10^6 m/s, about 1⁄38 of the maximum speed in the Z direction, indicating that the Z direction speed is much larger than X, Y speed.

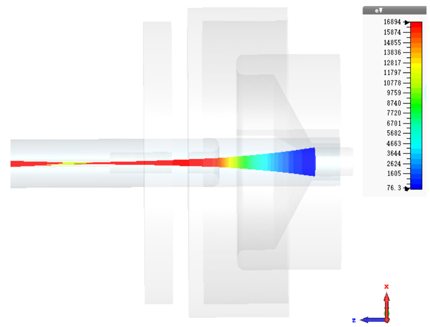

Figure 1. pierce-type electron gun model with electron trajectory

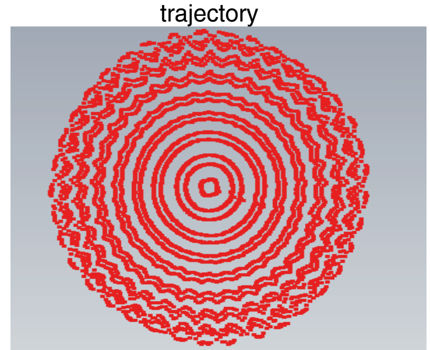

Figure 2. spatial position distribution of macro particles at the beam waist

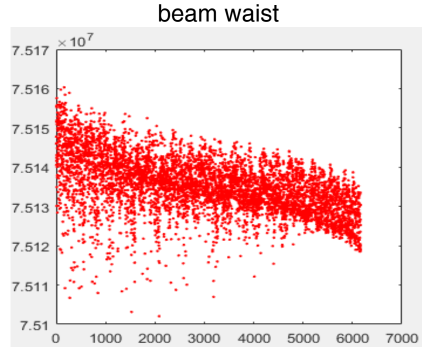

Figure 3. velocity distribution diagram in Z direction

By setting up the particle monitor, the macro particle information at the specified position—beam waist position can be obtained. The macro particle data included position of x, y, z, Momentum, current, charge, mass at the waist position. Since the number of particles calculated by electron gun is huge (thousands or even tens of thousands), and so many macro particles become unrealistic when we attend to use the particle source to calculate the beam-wave interaction in time domain. So it is necessary to process the particle data at waist position from the result of electron gun simulation. Using MATLAB software to rearrange these particles data, adjust the number of macro particles and make the new particle data to meet the requirements of interaction calculation.

Interaction calculation and analysis

By processing the actual electron beam data generated by the simulation of the electron gun, the number of macro particles is decreased to 160.Using new macro particle as beam-wave interaction sources to calculate beam-wave interaction, as shown in Figure 4

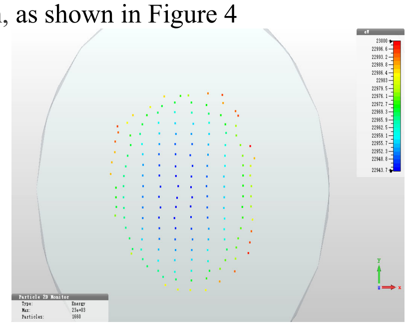

Figure 4. spatial position and energy distribution of processed macro particles

In order to make the interaction result more realistic, considering the effect of the actual magnetic field on the electron beam fluctuation when performing the interaction calculation. Figure 5 shows the magnetic field distribution in the z direction of periodic permanent magnet (PPM). The magnetic field period is 10mm, the magnetic field in the gun area is about 0.04T, and the peak value of the magnetic field when stable is about 0.3T.

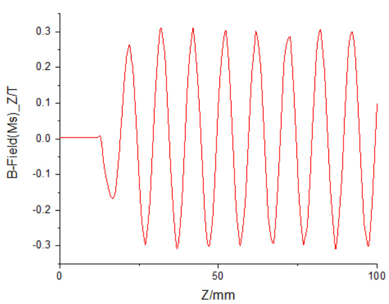

Figure 5. magnetic field distribution on axis

In general, the ideal DC electron beam is adopted to simulated in PIC simulation. Because of an ideal electron beam, there is almost no fluctuation during the beam transport. But the actual electron beam has not only longitudinal velocity, but also transverse speed. Even with ideal uniform magnetic field, the electron trajectory still has certain fluctuation, so that the electron beam will be closer to surface of the slow wave structure during the beam transport. Figure 6 is particles cluster diagram, at this time, the particles exchange energy with the electromagnetic field, so the input signals are amplified.

The figure 7 shows the output power comparison between the actual electron emission and the ideal one in the frequency range between 56GHz and 60GHz. It can be seen that the output power in the ideal case from 56GHz to 59GHz is larger than the actual case. but at 60 GHz, the actual output power is greater than the ideal situation.

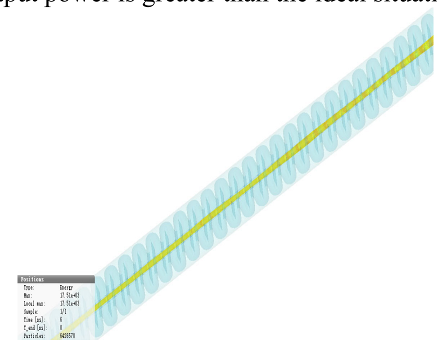

Figure 6. electron beam trajectory

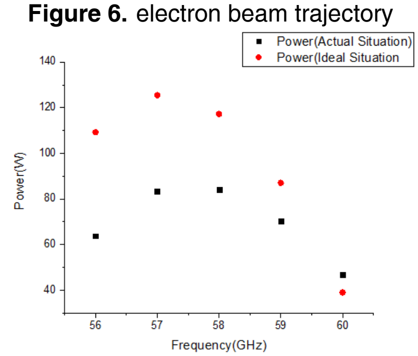

Figure 7. comparison of output power

Conclusion

In this paper, the joint simulation of electron optical system and beam-wave interaction of a V band folded waveguide TWT considering the real macro particles and PPM is introduced. Firstly, the electron information at the waist position can be achieved by electron gun simulation, and then the particle data at the waist position was processed with MATLAB. Finally, as the emission source, the new combined macro particles were imported into the interaction calculation model. Under the condition of the periodic magnetic field, the simulation results show that is conducted with the output power in the actual case is lower than the ideal case. The results considering the actual distribution and velocity of electrons should be more consistent with the performance of the real device.

Acknowledgements

This work was supported in part by 973 program (Grant No. 613233).

References

1. Yan Hou. Theoretical and experimental research on tortuous waveguide TWT [D]. University of electronic science and technology.2013.
2. Zhibing Xu, Guanfeng Wang. Life evaluation and experiment of a certain type of traveling wave tube [J]. Aviation maintenance and Engineering, 2015, 47 - 49.
3. Liu Yang. Research on a new type of v-band slow-wave TWT [D]. University of electronic science and technology.2012.
4. Yukun Qin. Integrated design of electronic optical system of travelling-wave tube [D]. University of electronic science and technology.2009.