Numerical Simulation of Electron Bunching Characteristics of Inductive Output Tube

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Abstract: *In this paper, in order to study 650MHz inductive output tube, according to the basic principles of electrodynamics, the influence of the gap and field strength between the cathode and grid, the bias voltage of grid and frequency offset on the modulation density of electron beam is simulated and analyzed, and the verification is carried out by using the three-dimensional electronic optics software.*

Keywords: inductive output tube; grid; modulation density; electronic optics

Introduction

The inductive output tube (IOT) is a type of gridded and compact vacuum electron device, which offers some advantages over klystrons in terms of efficiency, such as higher basic efficiency, power regulation possible at full output power, inconsequential drop of efficiency at reduced output power. Due to the proven reliability and high electrical efficiency, IOT has established its position in the television transmitter service. Scientific applications, like proton accelerators, require hundreds to over thousands of kilowatts, the electrical power requirement and the operating cost are tremendous. Therefore, a high electrical efficiency RF amplifying system is in demand. In IOT, the grid, cathode and the input waveguide constitute the input resonator. Through the grid voltage and the high frequency field strength between the cathode and the grid, the modulated density electron beam is generated. Therefore, the design of the grid is very important.

In this paper, in order to design 650MHz inductive output tube, the influence of the gap and electric field strength between cathode and grid, the bias voltage of grid and frequency offset on the modulation density of electron beam is simulated and analyzed by using the code originated from the basic principles of electrodynamics, and the verification is carried out by using the three-dimensional Beam Optics Analysis code.

Simulation

The parameters of designed inductive output tube are as follows: operating frequency 650MHz, anode voltage 32kV, grid voltage 68V and the gap between cathode and grid 0.5mm. The layout of the grid and cathode is shown in Fig. 1. In this paper, only the effect of the electric field strength between the grid and cathode and grid voltage on electron emission is considered, and the capture of electrons by grid structure is not included.

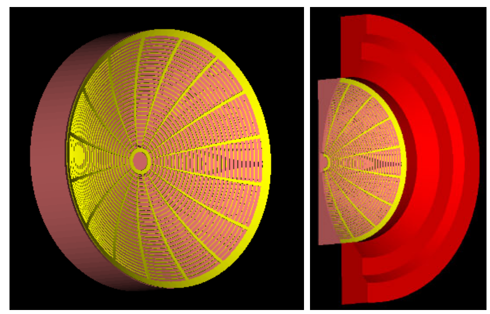

Figure 1. Three-dimension model of the grid and cathode

When the grid voltage is 68V and the electric field strength between cathode and grid is 136V/mm, the modulated electron beam is as shown in Fig. 2 and Fig. 3. The pass rate of electron through the grid is 80.8%. Fig.2 is a local zoom of the cathode and grid area in Fig. 3.

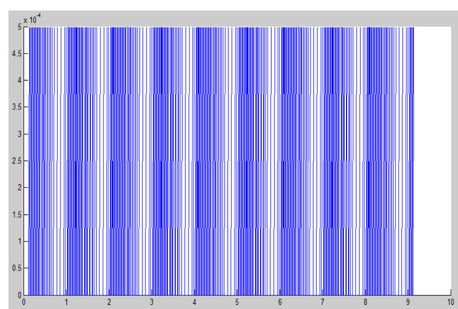

Figure 2. Distribution of electrons between cathode and grid

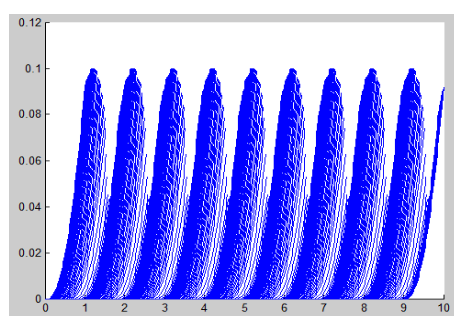

Figure 3. Distribution of electrons in anode region

Under the above conditions, the three-dimensional Beam Optics Analysis software is used to simulate the electron clustering, which is shown in Fig. 4. It is obvious that the farther the beam drifts, the more obvious the clustering is through the modulation of the grid. The trajectory of the electron beam with the designed magnet configuration is illustrated in Fig. 5. The designed magnet meets the design requirements according to the beam trajectory simulation.

In order to present the effect of the grid voltage on the electron modulation, under the condition that the grid voltage is 32V and 0V respectively, the distribution of electrons is shown in Fig. 6 and Fig. 7, and the ratio of electrons passing through the grid is 64.2% and 38.8% respectively. The calculation of the relationship between the passing rate and the grid voltage shows that the passing rate of electrons basically varies linearly with the grid voltage.

When the electric field strength between the cathode and grid is reduced by half, the distribution of electrons is shown in Fig. 8. It can be seen that the electron passing rate is increased from 80.8% to 84.9%, the impact of the electric field strength on the passing rate is not obvious, but the density modulation of electrons is obviously weakened.

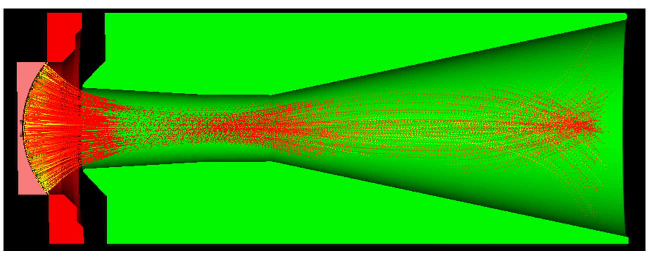

Figure 4. Simulation of electron clustering with the Beam Optics Analysis software at grid voltage 64V and electric field strength 136V/mm.

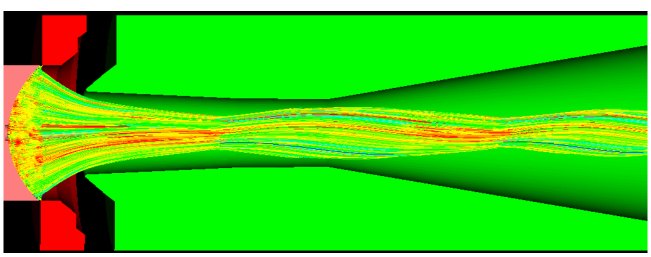

Figure 5. Trajectory of electron beam with the Beam Optics Analysis software at grid voltage 64V and anode voltage 32kV.

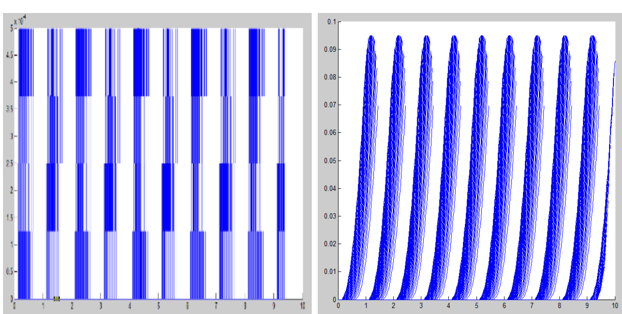

Figure 6. Distribution of electrons at grid voltage 32V

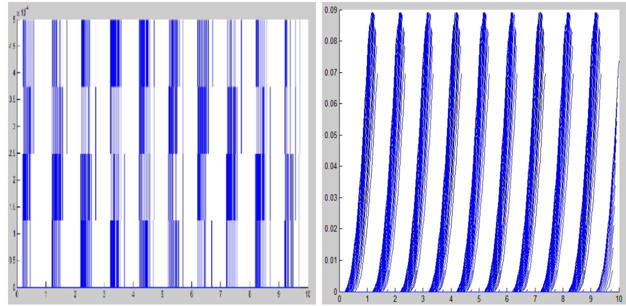

Figure 7. Distribution of electrons at grid voltage 0V

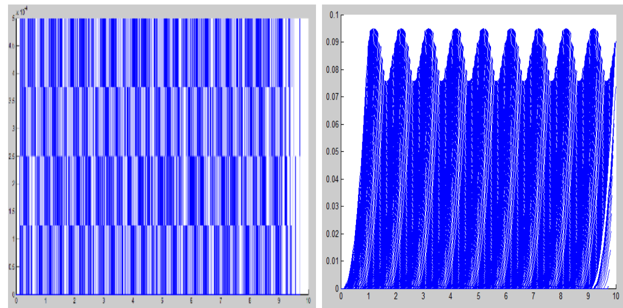

Figure 8. Distribution of electrons under the condition of half electric field strength

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References

1. H. G. Kosmahl and G. M. Branch, “Generalized representation of the electric fields in interaction gaps of klystrons and traveling wave tubes,” IEEE Trans. Electron Devices, vol. ED-20, no. 7, pp. 621–629, Jul. 1973.
2. Donald H. Preist and Merrald B. Shrader, "A high power klystrode with potential for space applications," IEEE Trans. Electron Devices, vol. 38, no. 10, October 1991.
3. Donald H. Preist and Merrald B. Shrader, "The klystrode - an unusual transmitting tube with potential for UHF-TV," Proc. IEEE, vol. 70, no. 11, November 1982.
4. C. Loring, Jr. and M. Shrader, "The klystrode, a new high efficiency, high-power electron tube for UHF industrial applications," J. Microw. Power Electromagn. Energy, vol.28, no. 3, 1993.
5. K. Nguyen, Gary D. Warren, L. Ludeking, Bruce Goplen, “Analysis of the 425-MHz Klystrode”, IEEE Trans. Elec. Dev., vol. 38, no. 10, 1991, pp. 2212–2220.
6. H. P. Freund, T. M. Antonsen, Jr., E. G. Zaidman, B. Levush, and J. Legarra, “Nonlinear time-domain analysis of coupled-cavity travelingwave tubes,” IEEE Trans. Plasma Sci., vol. 30, no. 3, pp. 1024–1040, Jun. 2002.