Thermal and Structural Analysis of Multi-stage Depressed Collector for G-band Traveling Wave Tubes

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Abstract: *The Multi-stage depressed collector (MDC) is used as an essential efficiency enhancement technique in traveling wave tubes (TWT). Two-third of the total power consumption of TWT is dissipated in the collector. In this paper, thermal and deformation analysis of MDC in G-band are implemented by using ANSYS. Temperature distribution of the MDC at given power supply are fully simulated, maximum deformations meanwhile in MDC at different ambient temperature are carefully compared with. The simulated prediction is in agreement with the experimental results.*

Keywords: Thermal Modeling; Multi-stage Depressed Collector ; Deformation

Introduction

High efficiency of a practical traveling wave tube mainly depends on the multi-stage depressed collector (MDC) which recovers spent electron beam energy at appropriate electrode potentials [1]. MDC do well in enhancing the overall efficiency in TWT and also in reducing thermal load with its structure. Therefore, the geometry and potential of electrodes are the critical design in improving the collector efficiency together with the reduction of its thermal loading.

Maximum power for a typical TWT is dissipated in the collector. The rise in temperature due to the dissipated power in collector has to be drained out, otherwise it will weaken the insulation between the slow wave structure and the collector [2]-[4].

This paper presents the thermal and structural analysis of MDC for space TWT. A 3D Finite Element Analysis (FEA) has been carried out in ANSYS. Temperature distribution at various electrodes has been investigated and dimensional deformation have been estimated subsequently. This research will provide effective guidance to the MDC research and its optimum structural design [5].

Thermal Analysis

With regard to the thermal model of MDC, the way about the heat transfer is mainly based on thermal conduction and heat radiation. Equation for heat conduction is defined as follows:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z\frac{\partial T}{\partial z}\right)+\rho Q=\rho c\frac{\partial T}{\partial t} \qquad (1)$$

where ρ is material density of MDC, c is material specific heat, and K_x, K_y, K_z is the thermal conductivity of materials in various directions, respectively.T is temperature, and Q is the thermal flow. From the equation, it is obviously show that the first three parts represent the heat transfer into the unit model . And the fourth is heat generation of the model, while the fifth item is the change of model temperature.

When the thermal equilibrium is reached, the transient heat equation changes into the steady-state heat balance equation. Therefore, the equation is simplified as follows:

$$\frac{\partial}{\partial x}\left(k_x\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_y\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k_z\frac{\partial T}{\partial z}\right)+\rho Q=0 \qquad (2)$$

For heat radiation, the heat flow between the two planes is clearly proportional to the four squares of the absolute temperature of the object surface.

$$Q_{ij}=\varepsilon\sigma A_1F_{12}\left(T_i^4-T_j^4\right) \qquad (3)$$

Where T is the absolute temperature of the surface, σ is Stefen-Boltzmann constants , A_1 is radiating surface area of 1, F_{12} is the shape factor of radiation surface 1 to 2, ε is the radiation rate on the surface.

The intensity of radiation is mostly depends on the material radiation rate, the surface contact area and the temperature difference of MDC obviously. The heat which comes from the electron beam is progressively transferred to the collector surface by heat conduction, and then radiates to the surrounding.

As discussed earlier, axis-symmetric model of collector for G-band TWT has been modeled in ANSYS [6]. The simulation is carried out with different electrode potential. Thermal power dissipated at each stage of collector has been taken as input along with boundary conditions which are presented in Table-1. Meanwhile, the structural model of the MDC in ANSYS software is truthfully depicted in Fig.1. After modeling geometry and defining parameters, the temperature distribution of the MDC is given in Fig.2.

Table 1. Input and boundary conditions

Heat Power (at electrodes)	1st electrode= 3.8W 2nd electrode= 5.3W 3rd electrode=9W
Ambient temperature	25℃
Radiation	According to the material
Heat transfer coefficient	At outer surface of collector 100(W/m^2K)
Thermal Resistance	0.01 Ω at joints

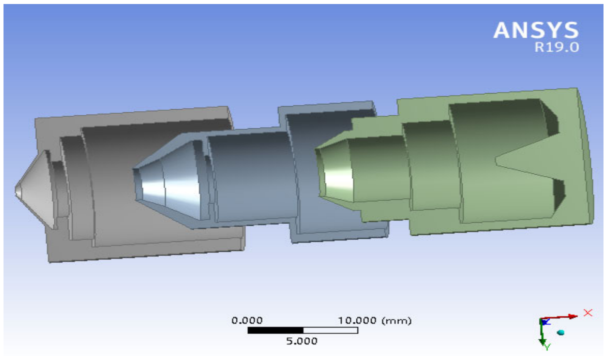

Fig.1 The schematic view of the MDC in ANSYS

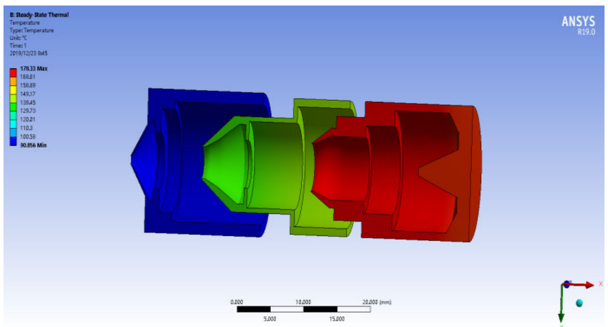

Fig.2 Temperature distribution of the MDC in ANSYS

Thermal Deformation Analysis

Owing to the thermal expansion, the dimension of the collector at operating temperature are different from the dimension at cold conditions. In order to minimize the thermal stresses at the joints, much attention should be put to the analysis of the thermal deformation.

When it is concerned to the thermal-structural analysis, the method to calculate the thermal deformation of the MDC need to be carefully selected. Unit SOLID85 have to be correctly transformed from unit SOLID70 in ANSYS software [7]. The temperature distribution obtained above is input and used as the load for thermal stress analysis, hence the thermal deformation is obtained under the current temperature distribution.

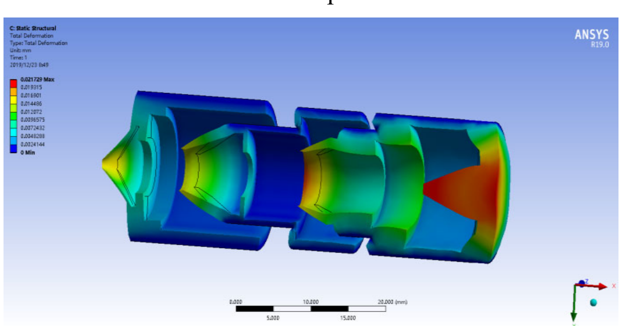

Fig.3 The thermal deformation distribution for the MDC

Assuming that the reference ambient temperature is 25℃, intuitively the deformation of the MDC under this temperature is zero. The deformation distribution of the MDC simulated by ANSYS is given in Fig.3. Expansion of electrodes raised by temperature distribution has also been studied and presented in Table-2. From the simulation results, the maximum deformation is in the range of few microns and are too small to cause the risk of short-circuit among the electrodes. More importantly, the stresses which is identical to the experiment results do not show any abnormality.

Table 2. Maximum deformation in MDC at Different ambient Temperature

Conditi-on	**Electro-de**	**Maximum Radial Displacement(in mm)**		**Maximum Axial Displacement (in mm)**	
		at 25℃	at 80℃	at 25℃	at 80℃
RF (Copper)	**First**	0.0035	0.0063	0.0083	0.0104
	Second	0.0061	0.0094	0.0145	0.0164
	Third	0.0096	0.0143	0.0184	0.0203

Conclusion

To investigate the practical feasibility of MDC, thermal together with deformation analysis of MDC for G-band traveling wave tubes are carried out by using finite element software ANSYS. The temperature of the MDC is obtained when given specific power supply. According to the simulation, the range of the temperature in MDC is about 90℃to 170℃ which is consistent with the experimental results. Meanwhile, the estimation of its deformation has also suitably been done and maximum expansion of each collector electrodes with different axis is acceptable. On the basis of above study, it shed some light on the improvement of the geometry and potential of electrodes which will strengthen the reliability of traveling wave tubes.

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