Thermal and Structural Modeling of high Efficient Multi-stage Depressed Collector for Space Applications

Vishant Gahlaut, A Mercy Latha, RK Sharma, RK Gupta, V Srivastava and SK Ghosh
Microwave Tubes Area, CSIR - Central Electronics Engineering Research Institute,[1] Pilani (Rajasthan):333031

PA Alvi
Department of Physics,
Banasthali University, Banasthali, Rajasthan, India

Abstract- **Increasing requirement of traveling-wave tubes (TWTs) with miniature size, less weight, high efficiency, high power, etc increases complexity of TWT packaging for thermal modeling. Two-third of the total power consumption of a typical TWT is dissipated in the collector. The rise in temperature due to the dissipated power in the collector has to be drained out efficiently without creating any hot spots. This paper discusses temperature distribution and deformation in the collector electrodes using different materials in a multi-stage depressed collector (MDC) during operation for typical space applications.**

Keywords- thermal modeling; packaging; dissipation; MDC; space applications.

I. INTRODUCTION

In satellite, the TWT is the single major satellite power consuming element, and, therefore, a space TWT should be designed for a high efficiency value [1]. High efficiency of a TWT is, mainly, depends on the efficiency of MDC that recovers spent electron beam energy at suitable electrode potentials. In a practical TWT the electrons emerging out from the interaction structure with a velocity spread with various energy classes need to be collected. The depressed potential reduces DC input to the tube and causing an overall efficiency enhancement of the TWT and also reduces thermal load in the collector. The geometry and potential of electrodes are the critical design parameters in enhancing the collector efficiency and in reduction of thermal loading [2]-[4].

The collector has to collect the spent electron beam which strikes on its electrodes and generates substantial heat. Maximum power for a typical TWT is dissipated in the collector. The rise in temperature due to the dissipated power in the collector has to be drained out efficiently either by conduction and or by radiation cooling without creating any hot spots. Hence, special considerations are to be given in designing the MDC. In order to avoid failure of the tube due to high voltage breakdown or melting of the tube and minimize the thermal stresses at the joints, choice of suitable material with lower thermal expansion coefficient is important. Thermal analysis of MDC is helpful in selecting the suitable material and thermal stress to enhance the collector reliability [5]-[7].

This paper presents the thermal and structural analysis of multistage depressed collector for space TWT. A 3D Finite Element Analysis (FEA) has been carried out using COSMOS [8] and ANSYS [9]. Temperature distribution at various electrodes has been studied and corresponding dimensional deformation have been estimated. The input boundary conditions are taken in form of thermal power loss and the ambient temperatures held at -25^{0}C and +80^{0}C to qualify for space conditions.

II. THERMAL MODELING

As discussed earlier, axi-symmetric model of collector for space TWT has been modeled in Solid Works and imported in COSMOS (Fig.1(a)) for performing thermal and structural analysis. Same model has been used in ANSYS (Fig. 2(b)) with same inputs and boundary conditions as done in COSMOS. The simulations have been carried out with different materials for electrodes at different ambient condition. Thermal power dissipated at each stage of collector has been taken as input, as seen in Table-1 along with boundary conditions applied. Comparisons of maximum temperature achieved at different electrode materials are presented in figure 3(a) & (b) using COSMOS and ANSYS codes. To study the practical feasibility, thermal and structural analysis are carried out in COSMOS based on finite element (FE) analysis, under different surrounding conditions, typically, -25 ^{0}C, +25 ^{0}C, +80 ^{0}C. Maximum temperature distribution among the electrodes for different materials like copper and graphite at different ambient temperatures are presented in figure 4(a) & 4(b) respectively.

TABLE 1. INPUT AND BOUNDARY CONDITIONS

Heat Power (at electrodes)	1st electrode = 11.7 W 2nd electrode = 7.0W 3rd electrode = 6.6 W 4th electrode = 18.7 W
Ambient temp.	25^{0}C
Radiation	At all open surfaces with emissivity according to material.
Heat transfer coefficient	At outer surface of collector 100 (W/m^{2}K)
Thermal Resistance	0.0001 (K- m^2/W) at brazed joints

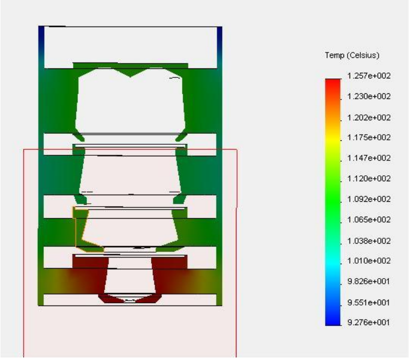

Figure. 1(a). Temperature distribution in MDC using copper electrodes obtained from COSMOS

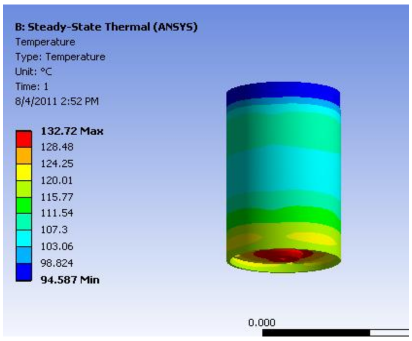

Figure 1(b). Temperature distribution in MDC using copper electrode obtained from ANSYS

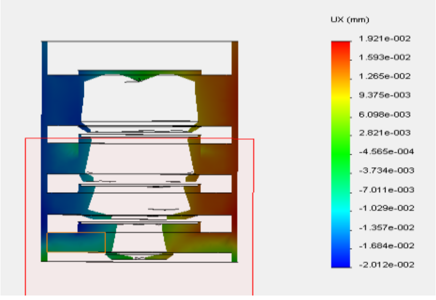

Figure 2: Radial expansion of electrodes in MDC, using copper, in COSMOS

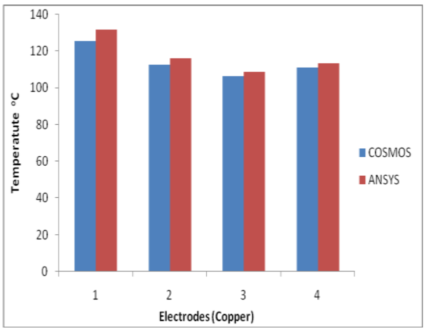

Figure 3(a). Comparison of maximum temperature distribution in copper electrode MDC using COSMOS and ANSYS

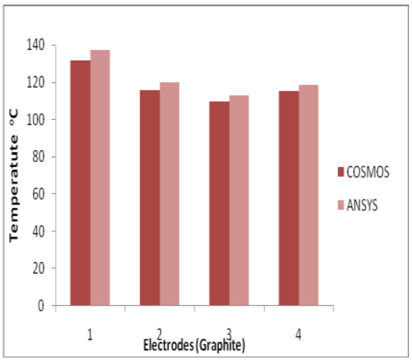

Figure. 3(b). Comparison of maximum temperature distribution in graphite electrode MDC using COSMOS and ANSYS

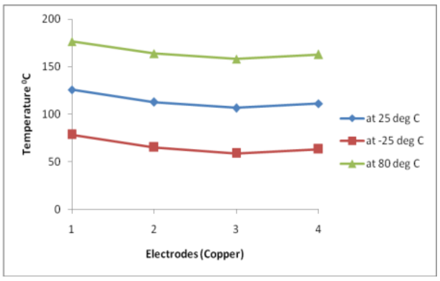

Figure 4(a). Maximum temperature distribution at different ambient temperatures in copper electrode MDC

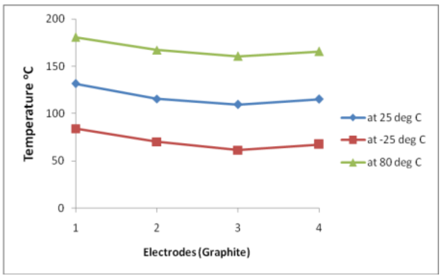

Figure 4(b). Maximum temperature distribution at different ambient temperatures in graphite electrode MDC

III. STRUCTURAL ANALYSIS

Due considerations have to be given in designing the collector assembly in order to minimize the thermal stress and structure deformation due to temperature distribution in the collector assembly. Study on dimensional deformation has also been carried out due to maximum temperature at different electrodes and have been found to be within tolerance limit (fig.2). Expansion of electrodes due to temperature distribution has also been studied and presented in Table-5 and Table-6. It can be seen from the simulation, that expansion of electrodes in copper electrode MDC is less as compared to in graphite electrode MDC. Expansion of electrodes, under both conditions, are in the range of few microns and are negligible, eliminating the risk of short-circuit among the electrodes or electrodes to ground. Similarly, the stresses developed do not show any abnormality too.

TABLE 2. MAXIMUM DEFORMATIONS OF GRAPHITE ELECTRODES IN MDC AT DIFFERENT AMBIENT TEMPERATURE

Condition	**Electrode**	**Maximum Radial Displacement (in mm)**			**Maximum Axial Displacement (in mm)**		
		at 25^{0}c	***at -25^{0}c***	***at 80^{0}c***	***at 25^{0}c***	***at -25^{0}c***	***at 80^{0}c***
RF (Copper)	First	0.0091	0.0043	0.0152	0.038	0.017	0.061
	Second	0.0051	0.0022	0.0082	0.022	0.009	0.035
	Third	0.0054	0.0024	0.0084	0.035	0.015	0.058
	Fourth	0.0057	0.0029	0.0096	0.054	0.023	0.088

TABLE 3. MAXIMUM DEFORMATIONS OF COPPER ELECTRODES IN MDC AT DIFFERENT AMBIENT TEMPERATURE

Condition	**Electrode**	**Maximum Radial Displacement (in mm)**			**Maximum Axial Displacement (in mm)**		
		at 25^{0}c	***at -25^{0}c***	***at 80^{0}c***	***at 25^{0}c***	***at -25^{0}c***	***at 80^{0}c***
RF (Graphite)	First	0.0128	0.0080	0.0201	0.051	0.029	0.0525
	Second	0.0072	0.0046	0.089	0.038	0.017	0.0396
	Third	0.0078	0.0048	0.0093	0.074	0.045	0.0768
	Fourth	0.0081	0.0051	0.0113	0.091	0.054	0.0922

CONCLUSIONS

To study practical feasibility of MDC, thermal analysis has been carried out and observed that temperature distribution is much better than the conventional MDC (under development) using different material at variable ambient conditions. It has also observed that the structural deformation or expansion of the electrodes under hot condition do not show any short circuit among the electrodes and to the ground. Stresses at different braze joint are also studied. In fact, simulation presented here are based on a practical TWT under development (under rigorous qualification). Estimation of deformation is also done and maximum expansion of collector electrodes achieved which is quite acceptable. On the basis of above study it ~~is~~ has been concluded that Copper material is most suitable for electrodes of high efficiency MDCs in reliability point of view.

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