A Thermal Analysis Method for Dielectric Supported Ring-bar Meander Line Slow Wave Structure

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Abstract: *The thermal characteristics are important for the proper operation of the high-power traveling wave tube (TWT). And they are affected by internal thermal losses, which mainly come from high-frequency loss and electron interception loss. The high-frequency loss can be calculated by setting the material of the slow wave structure (SWS) as PEC and lossy, respectively, and combining the power flow curve. Taking the thermal loss as heat source and processing the SWS in sections, the temperature distribution of the SWS can be obtained by thermal simulation, in which the thermal contact conductance has a greater influence on the maximum temperature.*

Keywords: thermal characteristics; slow wave structure; high-frequency loss; power flow curve.

Introduction

The traveling wave tube has important applications in many communication fields, such as space communication [1]. As the operating frequency increases, the size of the slow wave structure decreases, and heat dissipation of the structure becomes particularly important. If the thermal loss generated during the work makes the local temperature too high, which will cause thermal deformation and affect the normal work of the SWS. Therefore, we need to perform thermal analysis on the SWS to evaluate the heat dissipation performance.

In general, the thermal loss that causes the temperature of the SWS to rise is mainly composed of high-frequency loss and electron interception loss. There are some calculation methods for high-frequency loss. For example, the slow wave system is segmented first, and the insertion loss of each segment is calculated by S_{21} and the average output power of each segment [2]. In this paper, another method is proposed. First, the output power flow curves of the SWS of non-destructive and lossy materials are obtained respectively. Second, segmenting the slow wave system and getting the average output power of each segment. Then subtract the non-destructive and lossy power of each segment to obtain the high-frequency loss of each segment.

Thermal loss calculation

The dielectric supported meander line is taken as the slow wave structure of the TWT, which is shown in Fig.1, and it mainly includes input and output parts, slow wave line with 117 periods, dielectric supported rods and shell. In CST, the material of the slow wave line is set as PEC and oxygen-free high-conductivity copper (OFHC), respectively, and the electron beam voltage is 19kV and beam current is 0.2A.

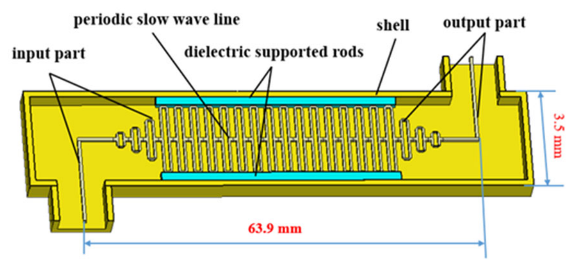

Figure 1. The model of dielectric supported ring-bar SWS

A field monitor is set at the center line of the slow wave line, and the power flow curve along the line is obtained. The entire slow wave system is divided into 31 segments, the first segment is 3.2mm in length, the last segment is 2.7mm, and each segment in the middle is 2mm for 4 periods. In order to obtain the average power of each segment, the maximum value of the power flow curve is equivalent to the output power of the SWS, and then the average value of each segment in the power flow curve is equivalent to the average power of each segment, as shown in Fig.2. Finally, the average power of each segment of PEC and OFHC is subtracted to obtain the high-frequency loss of each segment.

Dividing the entire slow wave system into 31 segments, the total loss obtained is 26.04 W, and it is close to the value of direct subtraction of PEC and OFHC output power, which is 25.3 W. When the segment is reduced, the total loss will decrease, and when the segment is increased, the total loss will increase. Therefore, reasonable segmentation is important for the accuracy of thermal analysis.

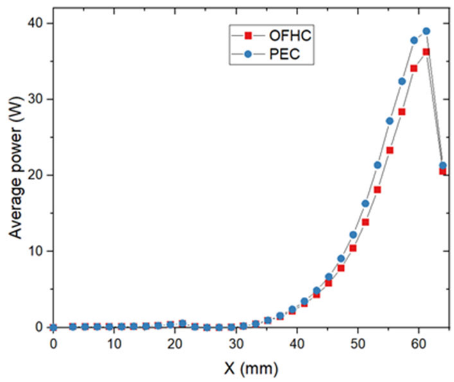

Figure 2. Average power per segment of PEC and OFHC

Thermal analysis

Assuming the electron beam focused perfectly, no electron is intercepted by the SWS. We use ANSYS for thermal simulation of this structure. The materials of the shell and the slow wave line are copper, and the material of the dielectric supported rods are BN. Their thermal conductivity is 401W/(m•K) and 41 W/(m•K) respectively. Setting the thermal contact conductance (TCC) between the shell and the dielectric rods and between the dielectric rods and the slow wave line to 0.4 W/mm^2•°C. The surface of the shell is set as convection, and its coefficient is 0.005 W/mm^2•°C.

The temperature distribution of the slow wave structure is shown in Fig.3. It can be seen that the maximum temperature is distributed in the output part, because the part does not directly contact the dielectric rod, which results in poor heat dissipation. And the maximum temperature is 422.17 °C, the temperature of the dielectric rods and the shell are below 200 °C, and the temperature of the slow wave structure in the latter segments is about 250 °C.

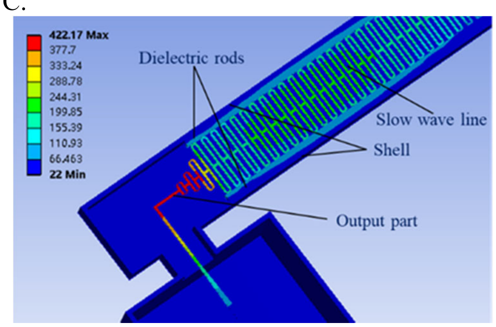

Figure 3. The temperature distribution of the slow wave structure

Through thermal analysis, it is found that the heat dissipation of the output part is not well. Heat dissipation is performed on the output part by adding dielectric rods, and the result is shown in Fig.4. It can be seen that the maximum temperature (236.25 °C) is distributed in the later segments, and the heat dissipation performance of the output part is improved.

In order to study the effect of thermal contact conductance on the maximum temperature of this structure, the contact thermal conductance of the slow wave line with heat dissipation part is set to 0.1-0.8 respectively. The result is shown in Fig.4, it can be found that TCC and maximum temperature are in the form of an exponential decay function.

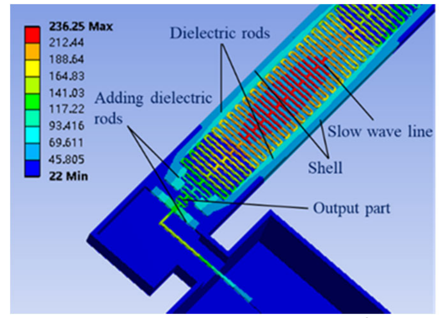

Figure 4. The temperature distribution of the slow wave structure with heat dissipation part

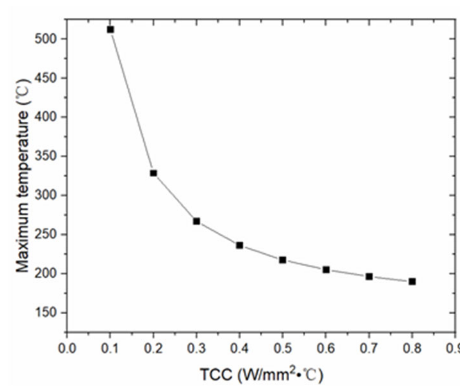

Figure 5. Effect of TCC on the maximum temperature

Conclusion

In this paper, a method for calculating high-frequency losses using PEC and OFHC power flow curves is proposed. The thermal analysis is performed on the dielectric supported ring-bar meander line slow wave structure, where segmentation will affect the accuracy of the thermal analysis. And TCC has a large influence on the heat dissipation of the slow wave structure.

Acknowledgements

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