Electron Beam Defocusing for the Collector of W-band large power Gyrotron

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Abstract: *The power dissipation of the collector is based on the theory by adding the external coils outside the collector which generates vertical or transverse magnetic field to modify the trajectory of electrons on the collector. In this paper, three power dissipation methods of the thermal loading on the collector for a 94GHz large power gyrotron are described and simulated the trajectory of electrons with CST Particle Studio. The approaches described are the vertical field sweeping system (VFSS), the transverse field sweeping system (TFSS), and the method of synthesis combine VFSS with TFSS, respectively. The results are revealed and discussed though modeling and simulation.*

Keywords: gyrotron; collector; CST; VFSS; TFSS

Introduction

In recent years, the International Thermonuclear Experimental Reactor (ITER) program and the devices and systems have been continuously advanced [1]. Based on such requirements, the gyrotron is rapidly developing toward high frequency, high power, high efficiency, long pulse and even continuous wave. In which, the collector is an important part of the gyrotron that absorbs and releases residual energy and recovers electrons. Collector of the large power gyrotron is exposed to a very strong electron bombardment and thermal loading, so one of the most critical elements for the gyrotron design is collector.

When the collector is hit by particles during the working process, a large amount of heat is generated, which causes the temperature of the collector to rise. It could lead to the desorption of the adsorbed gas on the surface of the material or even evaporation and vaporization of the material itself, which seriously affects the efficiency and stability of the gyrotron. The maximum limit of power loss density at the collector surface for CW-operation is 1000W/cm^2 [2]. It makes the traditional cooling system such as water-cooling cannot meet the requirement in ITER program. The power dissipation in the collector is depending on the distribution of electron beam in the collector. In recent years, a series of expansion methods for the distribution of electron are investigated by the ITER researchers all over the world.

With the improvement of the power and the pulse width, the same problem also appears on the W-band gyrotron. For instance, the improved power of the gyrotron can increase the effective distance of the Active Denial System (ADS), but also lead to the largely increase of the power dissipation in the collector [3]. For this reason, the research on the expansion methods of the electron distribution for 94GHz gyrotron urgently need to be investigated.

In this paper, we firstly model and the simulate the collector power dissipation for 94GHz gyrotron by using CST. Section Ⅰ describes the CST simulation model and analysis the results respectively. Important results are summarized in Section Ⅱ.

Modeling and simulation

It is well known that electrons coming out of the interaction area and hitting the collector are a process of defocusing. Fig.1 is a sectional view of the falling region of the electron without any external magnetic field in the collector. It can be seen from the figure that the electron falls in the range of 1.02 m to 1.25 m, which is a cylinder having a length of about 23 cm.

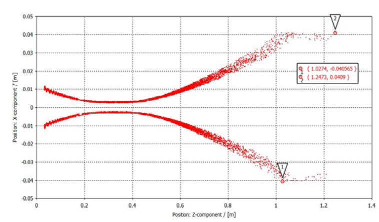


Fig.1 Sectional view of the falling region of the electron without any magnetic field.

Vertical field sweeping system (VFSS): Fig.2 shows the CST model with vertical coil in the collector. The optimized vertical coil position is 900mm to 1100mm in z direction, and the coil turns is 500. Fig.3 (a) and Fig.3 (b) show the falling region of electrons on the collector when an vertical coil capable of generating a vertical magnetic field is applied to the outside of the collector with the -6A and 6A current, respectively.

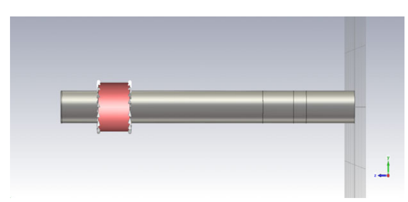
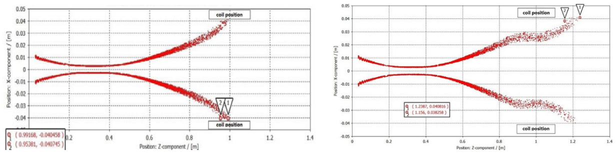


Fig.2 The CST model with vertical coil in the collector.



(a) (b)

Fig.3 Falling region of electrons when vertical coil is added with -6A current (a) and 6A current (b).

It can be seen from the above two figures that when the current of vertical coil changes from negative to positive alternately, the falling point of the electron on the collector is slowly moved backward, thereby the falling point of the electrons will periodically appear in different positions on the collector.

Transverse field sweeping system (TFSS): In addition to the coil that generates a vertical magnetic field, a coil generating a transverse magnetic field can also can be applied to the collector, which is shown on Fig.4.

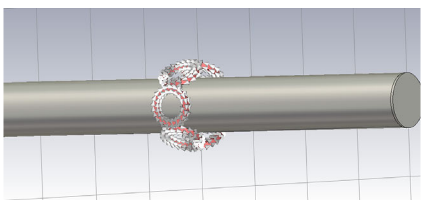


Fig.4 The CST model with six transverse coils in the collector.

In the above figure, a total of three pairs of symmetric transverse magnetic field coils are added, and the AC current added in each coil satisfies the Formula.1, where $\Delta\varphi = \frac{2\pi}{N}$, $i = 0,2,\cdots\cdots N$ is the number of coils.

$$I_i = I_0 \cos\left(\omega t + (i-1)\Delta\varphi\right) \quad (1)$$

When three pairs of coils are selected, the phase of currents on each coil are 0 degrees, 60 degrees, 120 degrees, 180 degrees, 240 degrees, and 300 degrees, respectively. The three pairs of coils produce a dynamic transverse magnetic field that makes a circular motion around the axis. The three pairs of coils located symmetrically around the collector with the phase difference of 60 degrees, which produce transverse rotating time-variant magnetic field. We can give the vector the magnetic field at a certain time and phase as in Fig.5.

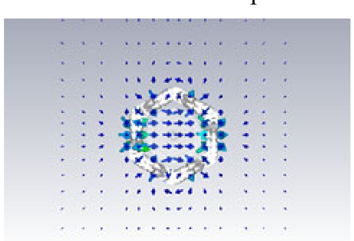


Fig. 5 The vector of the magnetic field with the TFSS

The electrons which enter into collector are centered on the collector axis under the effect of the three pairs of coils, and are scanned on the collector wall in the form of a periodic rotating ellipse. When this ellipse is rotated with the 50Hz alternating current, the falling area of the electrons is significantly increased and uniform, and the heat dissipation efficiency of the collector is improved. Fig.6 and Fig.7 show the falling point of electrons with the transverse coil current of 2A and the trajectory of electrons with transverse coils in CST. It can be seen that the electrons have a falling point of 1 m and 1.27 m, respectively. It can be seen from the cross-section of the electron that the trajectory of the electron is elliptical.

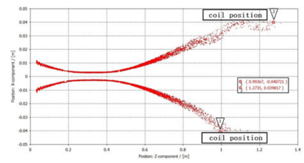


Fig.6 Falling region of electron with six pairs of transverse coils with the transverse coil current of 2A.

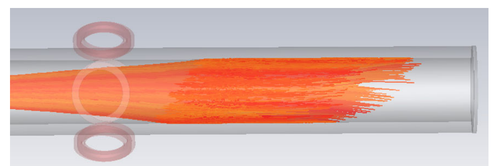


Fig.7 The trajectory of electrons with transverse coils in CST.

Results

The simulation results of the collector of 94GHz gyrotron obtained by CST Particle Studio confirmed that vertical coil and transverse coils outside the collector has enlarged the falling area of electrons hit in the collector wall. The external magnetic field outside the collector is critical to the distribution of electrons in the collector wall. And the combination of VFSS and TFSS further expanding the falling area of electrons, which improves the dispersion region from 23 cm to more than 40 cm.

Acknowledgements

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