Research on the Competition Mode Suppression in Coaxial Extended Interaction Structure

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Abstract: *Extended interaction klystrons operating in high-order mode can establish more sufficient axial electric field than the fundamental mode in a large size cavity. However, this structure suffers greatly from the mode competition because of the combination of axial and transverse modes. This paper presents the mode competition analysis of a coaxial extended cavity operating in* TM_{31} *mode through particle-in-cell (PIC) simulation. Meanwhile, applying dielectric loads in the proper position can effectively suppress the mode competition of this structure, while the* TM_{31} *mode has little interaction with the dielectric loads.*

Keywords: extended-interaction klystron (EIK), high-order mode, particle-in-cell (PIC) simulation, mode suppression

Introduction

Extended interaction klystrons (EIKs) combine the advantages of conventional klystron and coupled-cavity TWT, which is one of the most promising candidates as high-power devices in millimeter-wave and beyond [1]. Conventional EIKs usually choose the fundamental mode as the operating mode. However, the dimensions of a cavity with fundamental mode operation decrease rapidly with increase of the frequency, resulting in a significant reduction in output power [2]. Comparing to the fundamental mode, a high-order mode can support a larger size cavity at the same frequency. Therefore, this approach is expected to break the power limitation at high frequency. Although the advantages discussed above make this structure possess very broad applications, the mode competition is a severe problem for this multigap cavity [3]. This paper presents a high-order mode EIK circuit with coaxial structure. An effective method to suppress competition mode has been proposed.

Mode Competition Analysis

Fig.1(a) shows the structure of a coaxial extended interaction cavity, which consists of three identical coaxial cavities. And six beam tunnels are evenly distributed along the angular direction. This 3-gap cavity is used as the middle cavity of the high-order mode EIK. As shown in Fig.1(b), the TM_{31}-2π mode is chosen as the operating mode, which has six peak electric field in the angular direction.

The corresponding beam parameters of 40kV and overall current 18A (3A×6) was used in this device. The design assumes a center frequency f_0 of 35GHz, and the period p of the slow-wave structure can be derived from

$$p=\frac{\varphi v_e}{2\pi f_0} \qquad (1)$$

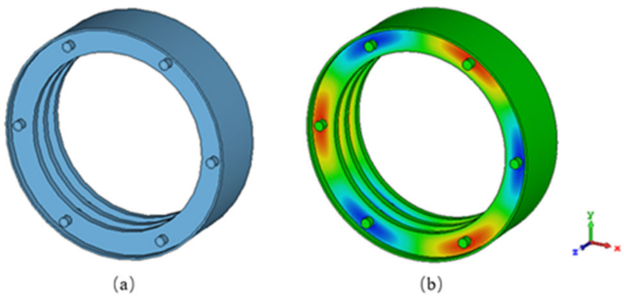


Fig.1. (a)Structure of coaxial extended interaction cavity, and (b) electric field distribution of the TM_{31}-2π mode

Where v_e is the beam velocity, $\varphi=2\pi$ is the axial mode of the electric field.

The simple method to test whether the cavity has oscillation is using the 3-D PIC simulation. The method is that keep the DC beam across the middle cavity and test the gap voltage through the voltage monitor [4]. And the voltage-time signal calculated by CST is shown in Fig. 2(a), the corresponding frequency spectrum is shown in Fig.2(b). Fig. 2(a) shows that the gap voltage reaches 15kV, which is close to the beam voltage. In addition, Fig. 2(b) shows the frequency of the main oscillation mode. From the electric field monitor, the corresponding competition mode is TM_{61}-0.5π mode, as shown in Fig .3.

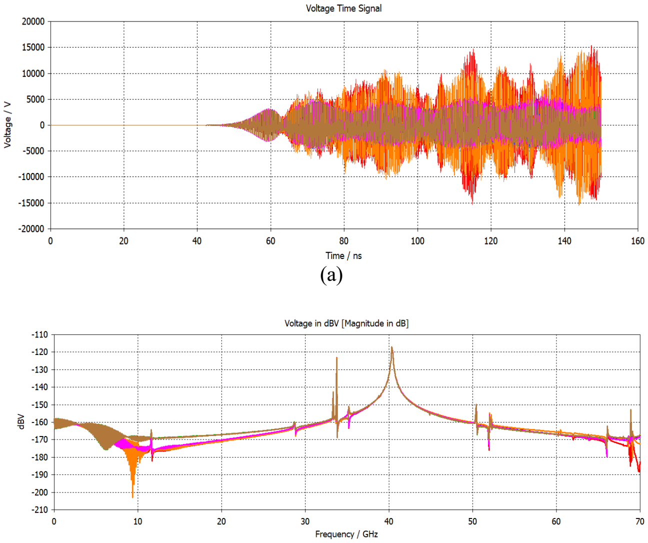


Fig. 2. (a) the voltage signal of the middle cavity, and (b) the frequency spectrum.

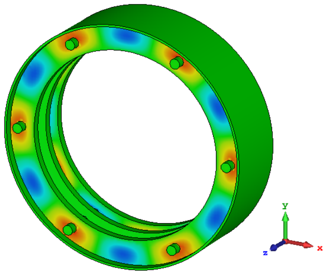


Fig. 3. Electric filed distribution of the competition mode.

Competition Mode Suppression

By comparing Fig. 1(b) and Fig. 3, it can be concluded that the beam tunnels are located at the peak value of the axial electric field of the two modes. However, the axial field of the TM_{31}-2π is almost zero between two adjacent tunnels along the angular direction. While the axial field of the TM_{61}-0.5π mode is still at the peak value. Therefore, applying dielectric loads in these positions can attenuate the TM_{61}-2π mode significantly. While it has very little effect on the TM_{31}-2π mode. Fig. 4 shows the structure of the middle cavity with dielectric loads.

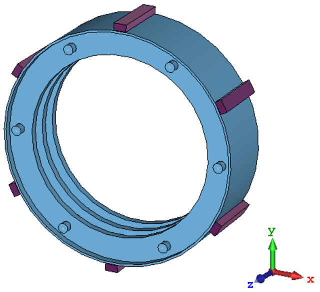


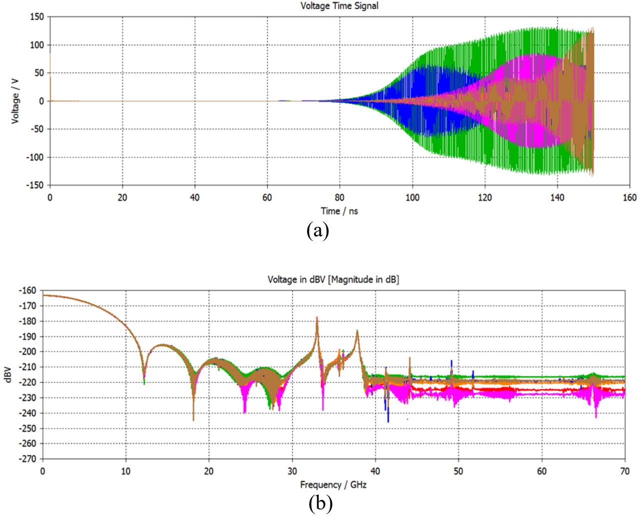
Fig. 4. Structure of coaxial extended interaction cavity with dielectric loading.

The characteristic parameters of the two modes are given in Table I through CST-MWS calculation. The quality factor Q_0 of the competition mode decreases rapidly with dielectric loading, while that of the operating mode is almost unchanged. It means that the method effectively reduces the possibility of the competition mode oscillation.

TABLE I. CHARACTERISTIC PARAMETERS OF THE TWO MODES

mode	Frequency (without the dielectric)/GHz	Frequency (with the dielectric)/GHz	Q_0 (without the dielectric)	Q_0 (with the dielectric)
TM_{31}-2π	35.37	35.25	1355.7	1304.9
TM_{61}-0.5π	40.58	39.31	1470.7	246.6

The 3-D PIC simulation is used to verify the feasibility of this approach. With dielectric loading, the voltage-time signal calculated by CST is shown in Fig. 5(a), the corresponding frequency spectrum is shown in Fig. 5(b). Fig. 5(a) shows that the peak value of the gap voltage is about 130V, which is far less than the beam voltage 40kV. Comparing Fig.2 (b) and Fig.5 (b), the peak value of the competition mode has disappeared in the frequency spectrum. Therefore, it can be concluded from the Fig. 5 that this structure is free from the influence of the mode competition.

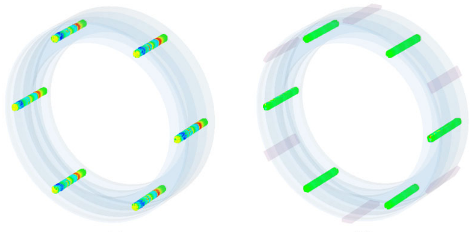


(a)

(b)

Fig. 5 (a)The voltage signal of the middle cavity with dielectric loading, and (b) the frequency spectrum.

Combined with the trajectory of the beam shown in Fig.6, it can be seen that the electron beam has almost no speed modulation after applying dielectric loads. Therefore, the cavity is not excited to oscillate at this time.



(a) (b)

Fig. 6 (a)The trajectory of the beam without dielectric loading, and (b) the trajectory of the beam with dielectric loading.

Summary

In this paper, a high-order mode coaxial 3-gap cavity is presented, which is used as the middle cavity of the EIK. The mode competition of this structure is simulated though CST calculation. A method of mode suppression is proposed, which can greatly improve system stability without attenuating the operating mode. Our next step is to design the whole EIK operating in the high-order mode.

References

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