The Verification of the Expression of the Interaction Impedance and Ohmic Losses of the Nonuniform-grating-based Slow Wave Structure

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***Abstract*:** *The expression of the interaction impedance of the nonuniform-grating-based slow wave structure (SWS) is given in this paper. The verification of the expression of the interaction impedance and Ohmic losses of the non-dielectric-loaded (NDL) SWS and partially dielectric-loaded (PDL) SWS is verified by simulations.*

Keywords: ***Nonuniform grating, Interaction impedance, Ohmic losses, Slow wave structure***

Introduction

The nonuniform grating has been used in the backward wave oscillators (BWOs) and clinotrons to increase the output power and efficiency and to reduce the starting current[1,2]. The high-frequency characteristics are important to the study of the PDL nonuniform-grating-based SWS. The dispersion curve and small signal gain have been discussed in [3]. The expression of the interaction impedance of the PDL SWS is derived and the expression of the interaction impedance and Ohmic losses is verified in this paper.

Model and Formula

The interaction impedance and Ohmic losses are important parameters in the traveling wave tubes (TWTs), BWOs and clinotrons. The expression of the electromagnetic fields have been derived in [3] and the simple expression of the interaction impedance and Ohmic losses have been shown in [3]. The specific expressions of the interaction impedance is not given in [3] due to the space limitation. In this paper, the specific expression of the interaction impedance are shown as follows with the parameters which are the same as the parameters in [3].

$$\overline{K_{cn}}(\Omega)=\begin{cases} K_{cn}^{1}\times\left(-Y_{21}-\dfrac{K_{cn}^{2}}{4\tau_{yn}}\right) & k_x^2+\beta_n^2-k_0^2>0 \\ K_{cn}^{1}\times\left(Y_{21}+\dfrac{K_{cn}^{3}}{4\tau_{yn}}\right) & k_x^2+\beta_n^2-k_0^2<0 \end{cases} \quad (1)$$

$$K_{cn}^{1}=\frac{\omega^2\mu^2\tau_{yn}^2A_nA_n^*\left\{X_{21}+\dfrac{X_{s21}}{4k_x}\right\}}{2(x_2-x_1)(y_2-y_1)\beta_n^2P} \quad (2)$$

$$X_{21}=\frac{1}{2}(x_2-x_1) \quad (3)$$

$$Y_{21}=\frac{1}{2}(y_2-y_1) \quad (4)$$

$$X_{s21}=\sin(2k_xx_1)-\sin(2k_xx_2) \quad (5)$$

$$K_{cn}^{2}=\sinh\left(2\tau_{yn}(y_1-D)\right)-\sinh\left(2\tau_{yn}(y_2-D)\right) \quad (6)$$

$$K_{cn}^{3}=\sin\left(2\tau_{yn}(y_1-D)\right)-\sin\left(2\tau_{yn}(y_2-D)\right) \quad (7)$$

$$P_n=\begin{cases} \mathrm{Re}\left[P_n^1\times\left(2D+P_n^2\right)\times P_n^4\right] & k_x^2+\beta_n^2-k_0^2>0 \\ \mathrm{Re}\left[P_n^1\times\left(2D+P_n^3\right)\times P_n^4\right] & k_x^2+\beta_n^2-k_0^2<0 \end{cases} \quad (8)$$

$$P_n^1=\frac{1}{8}\omega\mu\beta_n\left(k_0^2-k_x^2\right)A_nA_n^* \quad (9)$$

$$P_n^2=\frac{\sinh\left(2\tau_{yn}D\right)}{\tau_{yn}} \quad (10)$$

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$$P_n^3 = \frac{\sin\left(2\tau_{yn} D\right)}{\tau_{yn}} \tag{11}$$

$$P_n^4 = \frac{a}{2} - \frac{\sin\left(2k_x a\right)}{4k_x} \tag{12}$$

Theoretical Calculation

The expression of the interaction impedance and Ohmic losses are verified by simulations in this part. The interaction impedance and Ohmic losses of the −1st spatial harmonic of the TE_{10} mode and TE_{11} mode are calculated. The case of the NDL ($\varepsilon_p = 1$) nonuniform-grating-based SWS and the case of the PDL ($\varepsilon_p = 3$) nonuniform-grating-based SWS are calculated. The beam-grating distance is $b = 10$ μm, the thickness of the beam is $y_2 - y_1 = 70$ μm, and the width of the beam is $x_2 - x_1 = 0.66$ mm. The expressions of the electromagnetic fields of the hybrid wave are difficult to obtain. Therefore, only the interaction impedance and Ohmic losses of the part of the pure mode of the TE_{11} mode are calculated.

The theoretical results and simulation results of the interaction impedance of the TE_{10} mode and TE_{11} mode are shown in Fig. 1. It shows that the theoretical results are in good agreement with the simulation results. The maximum relative discrepancy is 10.5%, which appears in the TE_{11} mode of the PDL nonuniform-grating-based SWS.

The simulation results of the Ohmic losses are obtained by[4]

$$\alpha = 8.686\pi f / \left(v_g Q\right) \tag{13}$$

where v_g is the group velocity corresponding frequency f and Q is the unloaded quality factor of the resonator. f and Q can be obtained by simulation.

The theoretical results and simulation results of the Ohmic losses of the TE_{10} mode and TE_{11} mode are shown in Fig. 2. It shows that the trend of the theoretical results are in good agreement with the trend of the simulation results. The relative discrepancy is larger. The dispersion curves of the upper cutoff frequencies of the TE_{10} mode and the dispersion curve of the lower cutoff frequencies of the TE_{11} mode are flatter and the group velocities of those frequencies are smaller. Therefore, the simulation results of the group velocities are prone to larger errors.

Conclusion

In this paper, the detailed expression of the interaction impedance of the nonuniform-grating-based SWS is given. The expression of the interaction impedance and Ohmic losses are verified by simulations. The maximum relative discrepancy of the interaction impedance is 10.5%. The relative discrepancy of the Ohmic losses is larger because of the inaccurate simulation value of the group velocity.

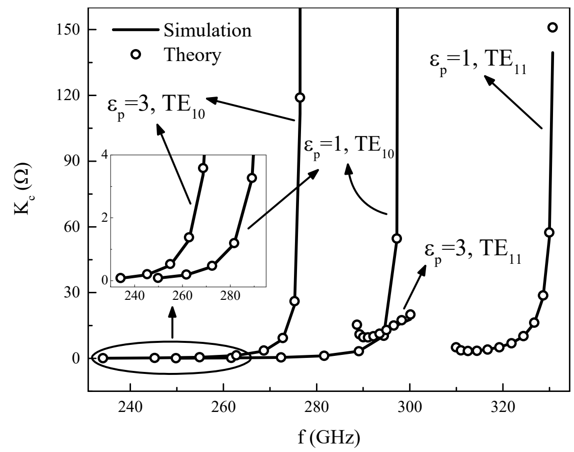

Fig. 1. The theoretical results and simulation results of the interaction impedance of the −1st spatial harmonic of the different modes.

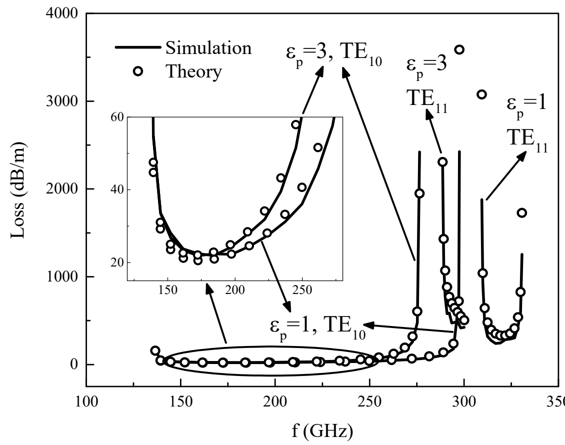

Fig. 2. The theoretical results and simulation results of the Ohmic losses of the −1st spatial harmonic of the different modes.

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