EXCITATION OF BACKWARD WAVES IN THE BEAM TUNNEL OF A HIGH POWER GYROTRON

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***Abstract*— Gyrotrons are an important source of high power coherent radiation in 100 GHz – 200 GHz range. As applications call for higher power, the power in the beam will increase as the danger of spurious oscillations. Competition between operating modes and competing spurious modes in the interaction cavity is a well studied phenomena, with established methods for suppressing the unwanted modes. Spurious modes can also be excited in the beam tunnel, generally in the form of gyro-backward waves. We have made a numerical analysis of the conditions for excitation of backward waves in the beam tunnel of a 170GHz gyrotron. The analysis includes tapering of the wall, variation of the magnetic field in the beam tunnel, and the presence of losses. Our results will be presented in the form of a requirement on the amount of wall loss needed to suppress backward waves for a given beam current.**

I. INTRODUCTION AND BACKGROUND

The efficiency of a gyrotron will be greatly reduced if gyro-backward waves are excited in the beam tunnel connecting the electron gun and the cavity. Generally speaking, these waves can be excited when the cyclotron resonance condition, $\omega - k_z v_z \approx \Omega$, and the waveguide dispersion relation $k_z^2 c^2 = \omega^2 - \omega_{cut}^2$ are simultaneously satisfied. Here ω , (k_z) is the wave frequency (wave number), $\Omega = qB_0 / (mc\gamma)$ is the cyclotron frequency, v_z is the velocity of the electron beam, and $\omega_{cut} = cj_{ln}^{'}/R$ is the cut-off frequency where R is the wall radius and $j_{ln}^{'}$ is the Bessel function root of the TE_{ln} mode. For backward waves the wavenumber and group velocity of the waveguide mode are negative.

To study how to suppress these backward waves we have analyzed the excitation condition based on small signal theory. We use self-consistent equations describing the mode amplitude and perturbed electron momentum and phase, [1-3]. Two different models are considered: one in which only the backward wave solution of the waveguide dispersion relation is included and one in which both the forward and backward waves are included. The model includes profiles of magnetic field and wall radius based on the gyrotron of ref. 4. We also consider the effect of attenuation due to coating of wall the wall with lossy material.

II. RESULTS

For the simple case that there is no tapering of the tunnel radius and constant magnetic field strength, the interaction length needed for the excitation is plotted as a function of the current density of the injected electron beam for different surface impedances are plotted in figure 1. The parameters for this case are: B= 1.7kG, R = 14.25mm, beam radius r_b =9mm beam energy V_{beam}= 80kV, and pitch factor $\alpha = v_\perp / v_z = 1.3$, the mode under consideration is the $TE_{24,6}$, mode.

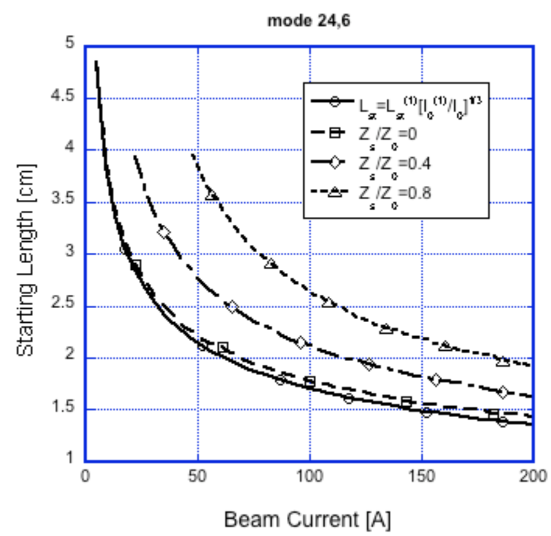

Fig. 1. Start interaction length as function of beam current assuming there is no tapering of the wall and constant magnetic. Z_s is the surface impedance of the wall.

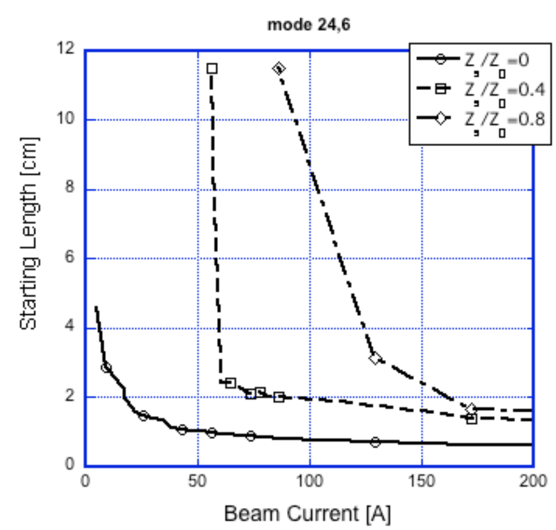

Fig. 2. Start interaction length as function of beam current includes the effect of the wall tapering and varying of magnetic field

The different curves correspond to different values of surface

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impedance on the waveguide wall. Here Z_s / Z_0 is the ratio of the surface impedance of the wall to the impedance of free space. The solid curve shows the expected scaling of start length with beam current, $L_{st} : I^{1/3}$.

In Fig 2, the effects of both tapered wall radius and spatially varying magnetic field strength are included. The wall radius is assumed to be $R[mm] = 14.25 - 0.06 \times z$, z is 0 at the end of the beam tunnel, and the distribution of magnetic field is $B[kG] = 1.7 \times \left(1 - 0.9e^{-6} \times (\omega/c \times z)^2\right)$.

There are several TE modes that could interact with the electron beam. The TE $_{24,6}$ was chosen here, since it can be excited quite close to the cavity, so this kind of mode can have a relative larger interaction length and is more likely to be unstable. From the plots, we see that the larger the injected current density, the more likely the backward wave will be excited. However, excitation can be suppressed by including a lossy material on the wall of the beam tunnel.

We are now considering the situation where both the forward and backward waves can be excited. In this case the wave equation is second order in axial derivatives. Figure 4 shows an example of the excited wave amplitude along axis z for cases with a perfectly conducting wall and with a lossy surface impedance. The parameters are the same as fig. 2. In these plots the presence of a point in z where the mode amplitude goes to zero indicates that the backward wave is unstable. We see that in this case the mode is still unstable in the presence of a lossy wall. A more complete analysis will be presented in the future

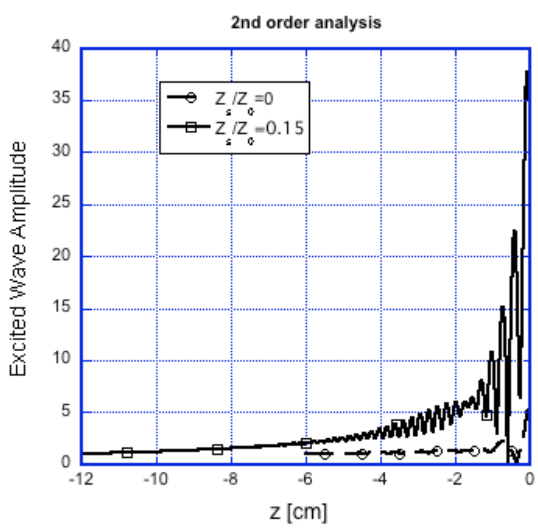

Fig. 1. Excited wave amplitude along axis z for without and with surface impedance.

This analysis will be appropriate to the manufacture of gyrotrons where the beam tunnel wall is smooth [4]. For a specific gyrotron, for which the tunnel length and the current of the injected beam are fixed, we will determine the level of surface impedance needed to suppress backward wave excitation. This work was supported by the US Department of Energy.

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