PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Limiting current in gyrotron coaxial cavities

R. A. Correa

R. A. Correa, "Limiting current in gyrotron coaxial cavities," Proc. SPIE 1929, 17th International Conference on Infrared and Millimeter Waves, 192973 (7 December 2017); doi: 10.1117/12.2298372

Event: 17th International Conference on Infrared and Millimeter Waves, 1992, Pasadena, CA, United States

LIMITING CURRENT IN GYROTRON COAXIAL CAVITIES

R.A. Correa and J.J.Barroso
Instituto Nacional de Pesquisas Espaciais
12201-970 - São José dos Campos, SP - Brasil

Abstract

A study is presented of self-space charge effects of tubular electron beams with gyromotion in coaxial cavities. Analytical expressions for the space charge limited current and voltage depression are obtained. The analysis indicates that the coaxial waveguide appears to be more attractive than the hollow cavity, as the coaxial insert greatly alleviates the design constraints associated with the self-space charge depression of the propagating beam. In particular, it is verified that in a 280 GHz, $TE_{42,7}$ gyrotron cavity the limiting current for a 90 keV electron beam (with an electron velocity ratio of $\alpha = 2.0$) raises from 52A to 143A after introducing into the cavity a 5.7-mm-diameter coaxial conductor, which leaves almost unperturbed the operating $TE_{42,7}$ mode.

Voltage Depression and Limiting Current

We restrict ourselves to the following model (Fig. 1) which permit us to write explicit solutions for the limiting current and voltage depression analytically: i) A tubular electron beam is injected into a cylindrical coaxial conducting guide immersed in a uniform axial magnetic field which is assumed to be sufficiently strong so that the total perpendicular electron momentum is conserved; ii) Far from the injection plane, the electrostatic field is well approximated by that of an infinite beam; iii) The system has reached a steady state and it is further assumed that the beam upon entering the cavity is monoenergetic. Thus the voltage difference between the radial positions R_e and R_w is given by

$$\Delta\Phi = (V_2 - V_1)\frac{ln(R_w/R_e)}{ln(R_w/R_{in})} + \frac{eN_bG}{4\pi\epsilon_0}$$

where $N_b = I/ev_{||0}$ is the axial beam density and the geometrical factor $G(R_e, \Delta R_e)$, where ΔR_e denotes the beam thickness, is defined as

$$G(R_e,\Delta R_e) = \left(1 + 2ln(R_w/R_2) - \frac{2R_1^2}{R_2^2 - R_1^2}ln\left(\frac{R_2}{R_1}\right)\right)\frac{ln(R_e/R_{in})}{ln(R_w/R_{in})} + \frac{2R_1^2}{R_2^2 - R_1^2}ln\left(\frac{R_e}{R_1}\right) - \frac{R_e - \Delta R_e/4}{2R_e}$$

The total beam current flowing down the guide is

$$I = N_bev_{||} = N_bec\left\{1 - \frac{1 - \beta_{||0}^2}{1 - \frac{e}{\gamma_0 m_0 c^2}\left[(V_2 - V_1)\frac{ln(R_e/R_w)}{ln(R_{in}/R_w)} + \frac{eN_bG}{4\pi\epsilon_0}\right]}\right\}^{1/2}$$

Under the condition $\partial I/\partial N_b = 0$, the limiting current I_L can now be obtained:

$$I_L = \frac{G(R_e, 0)}{G(R_e, \Delta R_e)}I_{L0}$$

with

$$I_{L0}(kA) = \frac{17.07\gamma_0}{G(R_e,0)}\left\{1 - \left[(1 - \beta_{||0}^2)\left(1 - \frac{e(V_2 - V_1)}{\gamma_0 m_0 c^2}\frac{ln(R_e/R_w)}{ln(R_{in}/R_w)}\right)\right]^{1/3} - \right.$$

$$\left. - \frac{e(V_2 - V_1)}{\gamma_0 m_0 c^2}\frac{ln(R_e/R_w)}{ln(R_{in}/R_w)}\right\}\left\{1 - \frac{(1 - \beta_{||0}^2)^{1/3}}{\left(1 - \frac{e(V_2 - V_1)}{\gamma_0 m_0 c^2}\frac{ln(R_e/R_w}{ln(R_{in}/R_w}\right)^{2/3}}\right\}^{1/2}$$

where γ_o is the relativistic factor without voltage depression and m_o is the electron rest mass.

17th International Conference on Infrared and Millimeter Waves, edited by Richard J. Temkin, Proc. of SPIE Vol. 1929, 192973 · © (1992) 2017 SPIE · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2298372

Discussion and Conclusion

The consequences of introducing a coaxial insert into a $TE_{42,7}$, 280 GHz gyrotron cavity as conceived at MIT [1] are discussed in Fig. 2. In this figure, $\Delta\Phi/V_{beam}$ and I_L (with $V_1 = V_2 = 0$) are plotted as function of R_{in} for two 90 kV beams; the first, with the design pitch angle factor $\alpha = 1.6$ and the second with a higher $\alpha = 2.0$ value. On calculating I_L, $2R_L$ thick beams, where R_L is the Larmor radius, were considered. We note that I_L increases without limit and $\Delta\Phi$ approaches zero as $R_{in} \rightarrow R_e (= 7.5\,\text{mm})$. We see also that for the beam with $\alpha = 1.6$ the limiting current raises from 87A to 240A when introducing an inner cylindrical condutor of radius $R_{in} = 5.7\,\text{mm}$, which leaves the operating $TE_{42,7}$ mode almost unperturbed [2]. In the presence of the coaxial insert, therefore, higher beam currents could be used realibly to enhance the output power. Alternatively, for the injected beam with $\alpha = 2.0$, whereby an increase in efficiency is to be expected due to the higher α value, we would have, for $R_{in} = 5.7\,\text{mm}$, $I_L = 143A$ that still gives a reasonable small fraction $I/I_L = 0.35$ for the operating current of 50A. In this case, the voltage depression would be below 3%.

In conclusion, we have shown that the presence of the coaxial insert significantly alleviates the design constraints associated with space-charge effects, thus allowing a greater flexibility in selecting the operating parameters of megawatt gyrotrons.

References

[1] Grimm, T.L., Guss, W.C., Kreischer, K.E., and Temkin, R.J., *Bull. Am. Phys. Soc.*, **36**, 2390, 1991.

[2] Barroso, J.J., and Correa, R.A., *Int. J. Infrared Millimeter Waves*, **13**(4), 1992.

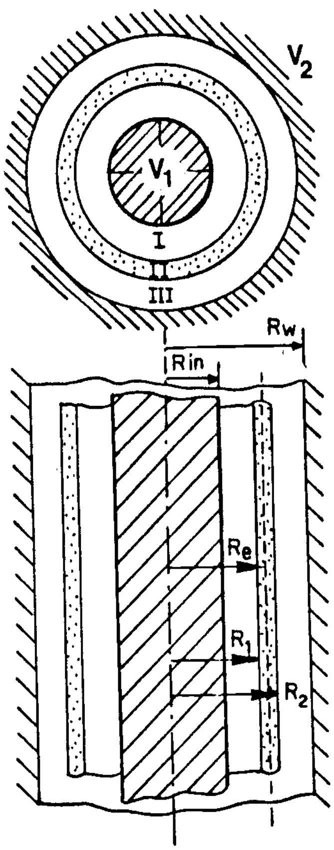

Fig. 1: Electron beam and coaxial guide geometries along with boundary conditions.

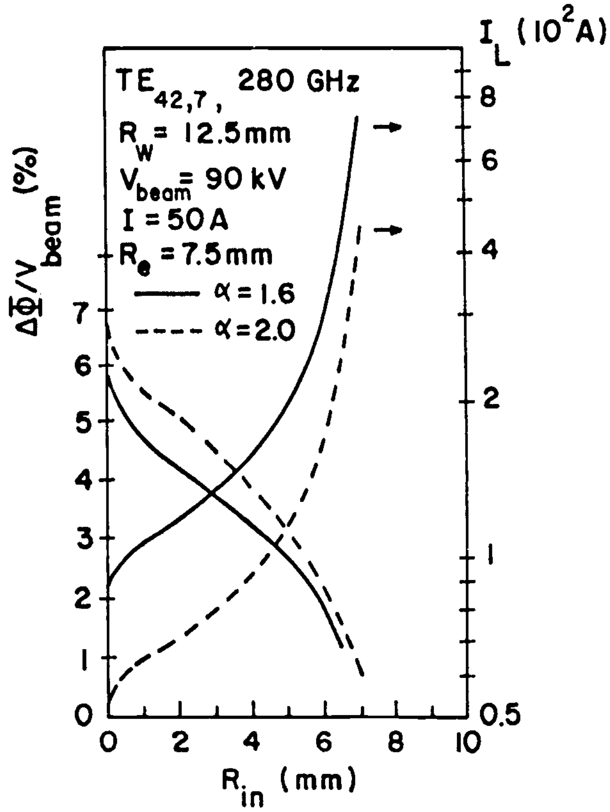

Fig. 2: The normalized voltage depression and limiting current as function of the radius R_{in}.