[IV~12]

Effect of a Gyrating Electron Beam on TE_{011} Cylindrical Cavity in Gyrotron.

박상순, 박긴석
서울대학교 물리교육과 플라즈마 및 전자파 연구실

I. Introduction

High power(0.01-1 MW) electromagnetic wave at high frequency(10-200 GHz) has been realized in gyrotrons for applications of fusion plasma heating and high-resolution radars. The coherent radiation is generated through electron bunching in an electron cyclotron orbit due to a change in the relativistic factor γ. The electron beam affects both the real part and the imaginary part of the impedence of the cavity with which the beam interacts and changes the cavity's characteristics. Therefore, it is important to know the full details of both the change in Q and the frequency shift in order to design practical gyrotron devices. In this paper, the effect of a gyrating electron beam(300 kW, 60 kV) from the magnetron injection gun(MIG) on the TE_{011} cylindrical cavity is considered for a 17.5 GHz gyrotwystron whose bandwidth is greater than 3-5% and whose efficiency is greater than 30%. The expression for change in Q and the frequency shift are obtained for a TE_{011} cylindrical cavity through which a gyrating electron beam passes, using the linearized Vlasov equation. Here, the amount of change in Q and the frequency shift is determined in our operating point, neglecting the velocity spread effects and compared with the MAGIC simulation.

II. Interaction between the electron beam and the field in a TE_{011} cylindrical cavity.

The real and imaginary part of the power transfer can be derived as follows in the case of cold beam, using the linearized Vlasov equation.

$$P_r = -\frac{fI E_0^2 e}{2m\omega^2} F_1(x_0;\alpha_0,\beta_0,\gamma_0) \tag{1}$$

$$P_i = -\frac{fI E_0^2 e}{4m\omega^2} F_2(x_0;\alpha_0,\beta_0,\gamma_0) \tag{2}$$

$$F_1(x_0;\alpha_0,\beta_0,\gamma_0) = (\beta_0 - x_0)\,\alpha_0^2\left\{2\left(x_0+\frac{\beta_0}{\alpha_0^2}\right)G(x_0)+\frac{1}{2}\left[\,x_0^2-\frac{x_0(\beta_0-x_0)(\gamma_0^2-1)}{\alpha_0^2+1}\right]G'(x_0)\right\}$$

$$F_2(x_0;\alpha_0,\beta_0,\gamma_0) = (\beta_0-x_0)^2\left\{K(x_0)-\ \alpha_0^2\beta_0\frac{(x_0^2-1)}{2(\alpha_0^2+1)}K'(x_0)-\frac{(2+\alpha_0^2)M(x_0)}{2(\beta_0-x_0)}+\ \alpha_0^2 x_0 M'(x_0)]\right\}$$

where, $G(x)=\left[\frac{\cos(\pi x/2)}{1-x^2}\right]^2,\ K(x)=\frac{1}{1-x^2}\left(\frac{\pi x}{2}-\frac{\sin\pi x}{1-x^2}\right),\ M(x)=\frac{1}{1-x^2}\left(-\frac{\pi}{2}+\frac{x\sin\pi x}{1-x^2}\right)$

The variables in the above equations are defined as

$$I=NAeu_0,\quad x_0=(\Omega_0-\omega)/k_{\parallel}u_0,\quad \alpha_0=w_0/u_0,\ \beta_0=\Omega_0/k_{\parallel}u_0.$$

Therefore, the change in quality factor and frequency shift is given

$$\Delta\left(\frac{1}{Q}\right)=-\frac{P_r}{\omega U}=\frac{8}{J_0^2(k_\perp a)}\frac{fI}{I_A}\frac{1}{La^2}\left\{\left(\frac{\pi}{L}\right)^2+\left(\frac{3.8317}{a}\right)^2\right\}^{-\frac{3}{2}}F_1(x_0,\alpha_0,\beta_0,\gamma_0) \tag{3}$$

$$\frac{\Delta\omega}{\omega}=\frac{1}{2}\frac{P_i}{\omega U}=\frac{2}{[J_0(k_\perp a)]^2}\frac{fI}{I_A}\frac{1}{La^2}\left\{\left(\frac{\pi}{L}\right)^2+\left(\frac{3.8317}{a}\right)^2\right\}^{-\frac{3}{2}}F_2(x_0,\alpha_0,\beta_0,\gamma_0) \tag{4}$$

where $I_A = 4\pi\varepsilon_0 mc^3/e = 17405\,\mathrm{A}$.

The cavity length L, radius a and cold quality factor are 2.997cm, 1.091cm and 500 respectively. The dimensionless filling factor is chosen to be 0.7. It can be seen that the higher the α is, the more $\Delta(1/Q)$ and $\Delta\omega$ change. When $\Delta(1/Q)$ is positive, net energy transfers from the cavity field to the electron beam. The loaded Q decreases down to 110 at the operating magnetic field of 0.64 T, and the resonant frequency shift is 42 MHz(0.24% of the resonant frequency). Here the beam α is chosen to be 1.2.

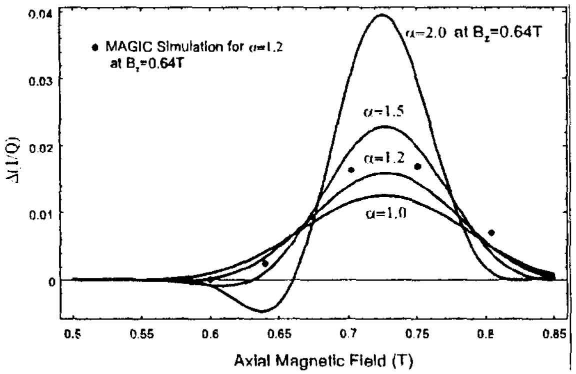

Fig. 1 Change in quality factor as a function of the axial magnetic field for beams having α-values of 1.0, 1.2, 1.5, and 2.0.

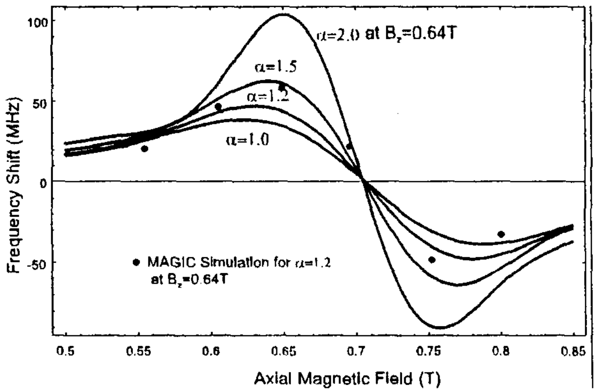

Fig. 2 Frequency shift as a function of the axial magnetic field for beams having α-values of 1.0, 1.2, 1.5, and 2.0.

III. Conclusion

The change in Q and the shift in the resonant frequency due to the interaction between a gyrating electron beam with no velocity spread and the field in a TE_{011} cylindrical cavity was obtained from the linearized Vlasov equation. For a gyrotwystron cavity with a beam voltage of 60 kV and a beam current of 5 A, and a beam α of 1.2, the amount of resonant frequency shifted by 50 MHz, and Q factor decreases from 500 to 110. Also, the amount of change in Q and the frequency shift was obtained from the MAGIC simulation and compared with the linearized theory.