Frequency Response of Voltage-modulated Gyrotron

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Abstract: For the gyrotron with the triode-gun and the depressed-collector, it is shown that modulation of voltages can be coordinated so that a relatively large frequency shift will be followed with only a small change of the output power. The modulation method is applicable to systems where the fast discrete electron cyclotron wave beam switching will be used in tokamaks to suppress hydrodynamic plasma instabilities.

Keywords: Gyrotron, Tokamaks, voltage-modulated

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In plasma fusion experiments, one of methods to provide the plasma heating and current drive is based on using gyrotrons [1]. When the number of gyrotrons is large, it is expedient to combine a number of generated wave beams into one channel. On the other hand, to suppress hydrodynamic plasma instabilities, the combined wave beam should be adaptively switched from one port to another. The both functions can be realized by multiplexing of radiation from frequency-controlled gyrotrons [2].

The fast control of the gyrotron frequency is convenient to perform by changing voltages at non-current electrodes, for instance (see Fig. 1), by changing the anode-cathode U_{ac} and the cavity-cathode U_{cc} voltages. Correspondingly, shifts of the frequency ω and of the power P are related with shifts of the voltages U_l by formulas

$$\Delta\omega = \sum_i \frac{\partial\omega}{\partial U_i}\Delta U_i, \qquad \Delta P = \sum_i \frac{\partial P}{\partial U_i}\Delta U_i. \tag{1}$$

where $\partial\omega/\partial U_i$ and $\partial P/\partial U_i$ are relevant partial derivatives. By the optimal choice of the primary operation point and the coordinated change of control voltages, the ratio $|\Delta P|/|\Delta\omega|$ can be minimized: the frequency sweep $\Delta\omega$ may be sufficiently wide at a sufficiently small modulation of the RF power.

The Fig. 1 scheme has been successfully realized in a 170 GHz gyrotron by the team lead by K. Sakamoto [3]. The gyrotron operated at the $TE_{31,8}$ mode with 1 MW output power in the following region of parameters: the cavity-cathode voltage was near 80 *kV*, the anode-cathode voltage was near 45 *kV*, the electron beam current was near 30 A.

For a gyrotron with above parameters, we made numerical calculations of modulation characteristics basing on the theory of gyrotrons with self-consistent RF field structure in the cavity [4, 5]. The pitch factor of electron trajectories in the cavity $g = v_{\perp}/v_{\|}$ was calculated by using the adiabatic theory [6]

$$g = \frac{g_0 U_{ac}\sqrt{U_{cc0}}}{\sqrt{\left(1+g_0{}^2\right)U_{ac0}{}^2 U_{cc} - g_0{}^2 U_{ac}{}^2 U_{cc0}}}\,. \tag{2}$$

the primary pitch factor was taken as $g_0 = 1.4$. The calculation results are presented in Fig. 2, where the horizontal axis is the cavity-cathode voltage, the vertical axis is the anode-cathode voltage; at any solid line the output power is constant, at any dash line the radiation frequency is constant.

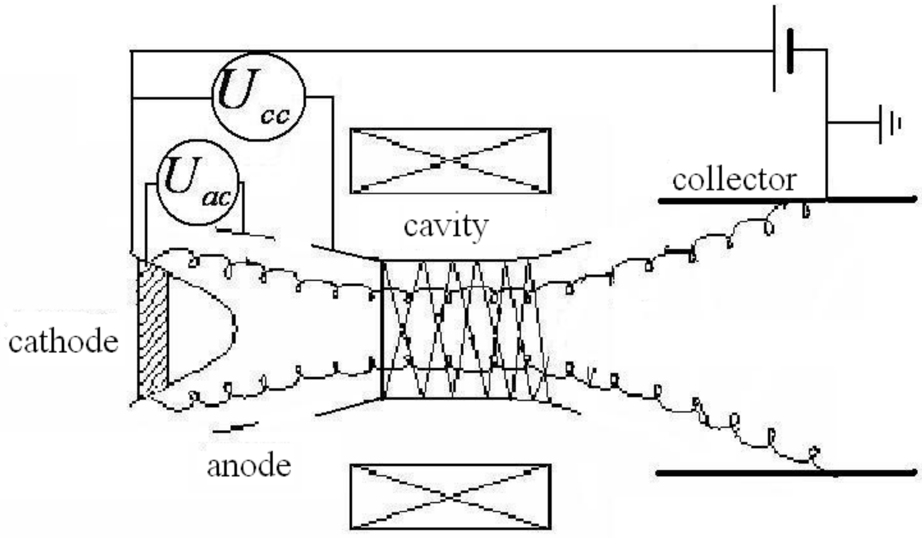

Fig. 1 A scheme of a gyrotron with a triode-type magnetron injection gun and with a depressed collector.

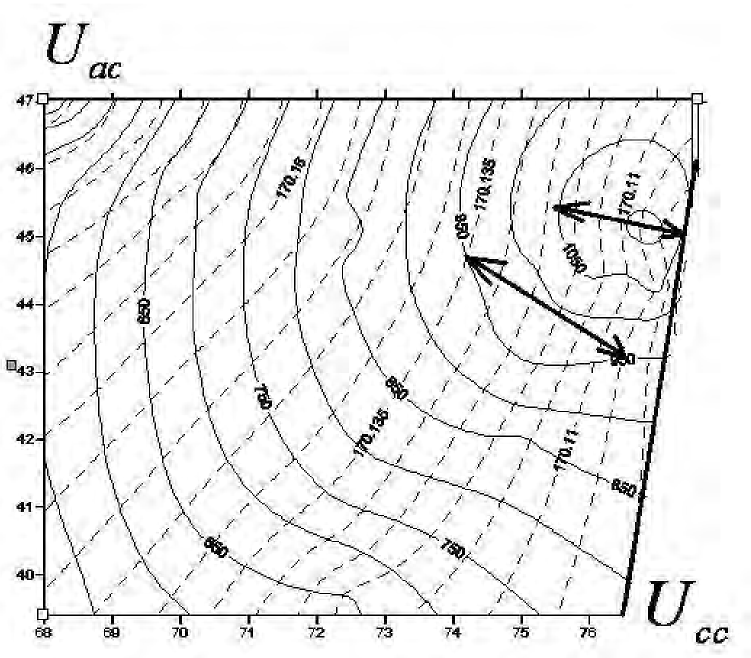

Fig.2 Output power, *kW* (solid lines) and frequency *GHz* (dash lines) vs the cavity-cathode voltage U_{cc}, *kV*, and the anode-cathode voltage U_{ac}, *kV*.

Arrows in the Fig. 2 show two variants of voltage variations:

1) The upper arrow describes a relatively narrow frequency sweep near the highest efficiency point. In this case the frequency modulation can be performed by changing only the cathode-cavity voltage, and the RF power decrease is quadratic relative to the frequency sift:

$$\frac{|\Delta P|}{P_0} = 5{,}7 \cdot 10^6 \left(\frac{\Delta f}{f_0} \right)^2 . \tag{3}$$

2) The down arrow describes a wider frequency sweep provided with comparable changes of the both control voltages: $|\Delta U_{cc}| \sim |\Delta U_{ac}|$; at extreme values of these voltages the output RF powers are equal. The gyrotron efficiency decrease caused by the modulation may be reduced by deceleration of electrons at the depressed collector.

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