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Magnetically Tunable Reflection-Type Oscillator Based on a Gyro-TWT

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Abstract—It is shown that the range of frequency tuning by magnetostatic field in a reflection-type oscillator based on a gyrotron traveling wave tube (gyro-TWT) can be increased to 6–7% with the aid of a four-stage filter, while retaining electronic efficiency on the 30% level typical of the gyro-TWT.

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A conventional gyrotron cannot be used as a magnetically tunable generator, because it is difficult or even impossible to tune its waveguide resonator. At the same time, this is made possible by a gyrotron traveling wave tube (gyro-TWT) in which there is no resonant system. The efficiency of electron beam interaction with a counterpropagating wave in the gyrotron is low because of a nonoptimum field distribution along the working region [1]. In contrast, the field distribution in a gyro-TWT is close to optimum (i.e., the field amplitude increases at the end of the interaction region), which provides a principal gain in the beam–wave interaction efficiency [2].

A gyro-TWT based generator can be implemented by using a counterpropagating wave excited at the end of the interaction region and reflected from the input of this region. This wave provides a positive feedback in the reflection-type oscillator. Reflections can be obtained with the aid of a multistage cathode filter possessing a sufficiently wide stopband. In this band, the reflection-type gyro-TWT can be tuned by varying magnetostatic induction B_0 (i.e., the cyclotron frequency).

The aim of this work was to analyze and optimize a gyro-TWT operation with a four-stage filter. The gyro-TWT was simulated using a Gyro-K program from CEDR software package [3, 4]. The mathematical model of the Gyro-K subsystem is based upon a coordinate transformation method that replaces solution of the problem of irregular waveguide excitation by that for a regular waveguide of unit radius with a variable spatial metric [5]. Using this method, it is possible to reduce a three-dimensional problem to a one-dimensional one, which significantly decreases the computational time as compared to that required in other program packages, such as CST Particle Studio [6] and Karat [7], in which boundary-value problems of electrodynamics are solved by grid techniques.

Numerical calculations were performed for the following parameters of electron flow: $\beta_0 = v/c = 0.436$; $\sigma = \frac{\eta_0\mu_0}{c}I_0 = I_0 \times 0.737 \times 10^{-3}$ (dimensionless current parameter, where I_0 is expressed in amperes); $q = V_\perp/V_z = 0.96$ (pinch factor). The magnetic field was assumed to be constant (homogeneous) along the z axis:

$$F(z) = \frac{eB_z^0(z)}{m\omega_0} = \frac{\omega_n}{\omega_0} = \frac{1.748 \times 10^{11} B_0[T]}{2\pi f_0[\mathrm{Hz}]}$$
$$= \mathrm{const} = 0.996, \quad \omega_n = \frac{eB_0}{m};$$

the leading center radius was

$$r_{\mathrm{lc}} = \frac{2\pi R_{\mathrm{lc}}}{\lambda} = 1.85;$$

and the system (device) length was

$$z = \frac{2\pi L}{\lambda} = 128 \text{ rad}.$$

Figure 1a shows the integral parameters (i.e., characteristics of the ensemble of N particles integrated over period $T_0 = 2\pi/\omega_0$) for the optimum variant of the gyro-TWT with a gyrotron efficiency of 33%. Since the electron beam has a pinch factor $q < 1$, the total

[1] This author has also appeared with an alternate spelling as A.E. Khramov.

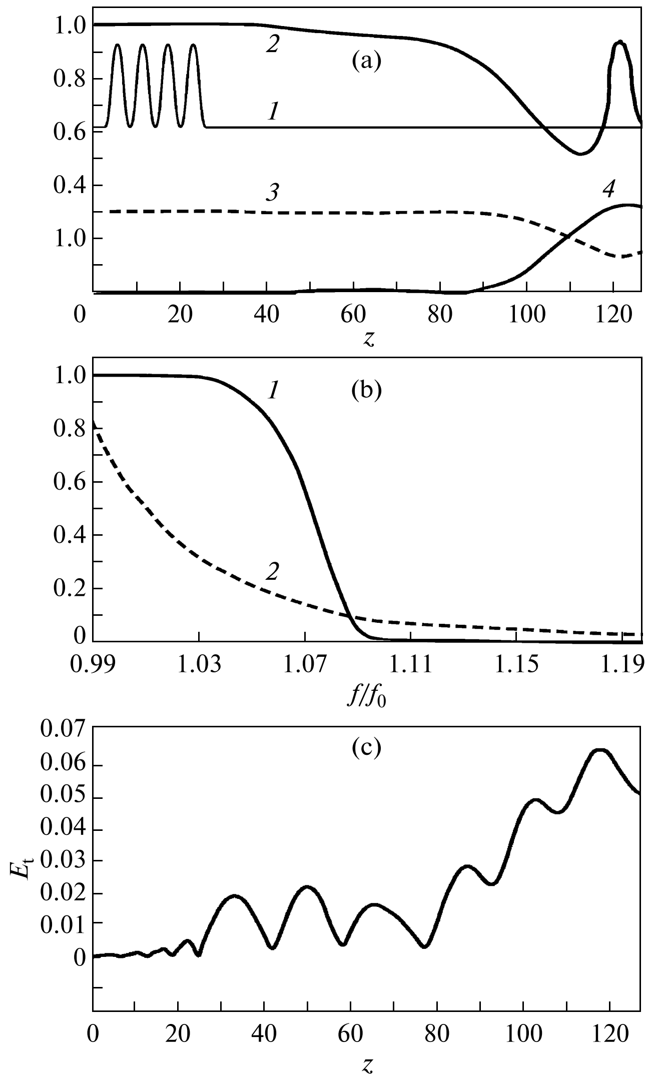

Fig. 1. (a) Integral characteristics of the proposed gyro-TWT: (*1*) R_w/λ (waveguide radius to wavelength ratio), (*2*) F_1, (*3*) $\beta_\perp$ (average transverse electron velocity in the beam), and (*4*) generator efficiency. (b) Frequency characteristics of (*1*) four-stage and (*2*) two-stage filters with respect to reflected power of H_{01} wave. (c) Profile of normalized resultant electric field amplitude E_t in H_{01} wave along the gyro-TWT.

efficiency can be increased up to 80%. Here, curve *2* is the plot of

$$F_1 = 1 - \left[\left(\sum_{i=1}^{N_e}\sin(-\arctan(\beta_{xi}/\beta_{yi}) - t_i)\right)^2 + \left(\sum_{i=1}^{N_e}\cos(-\arctan(\beta_{xi}/\beta_{yi}) - t_i)\right)^2\right]$$

which is the depth of the transverse phase bunching of the electron beam at the first harmonic of cyclotron frequency.

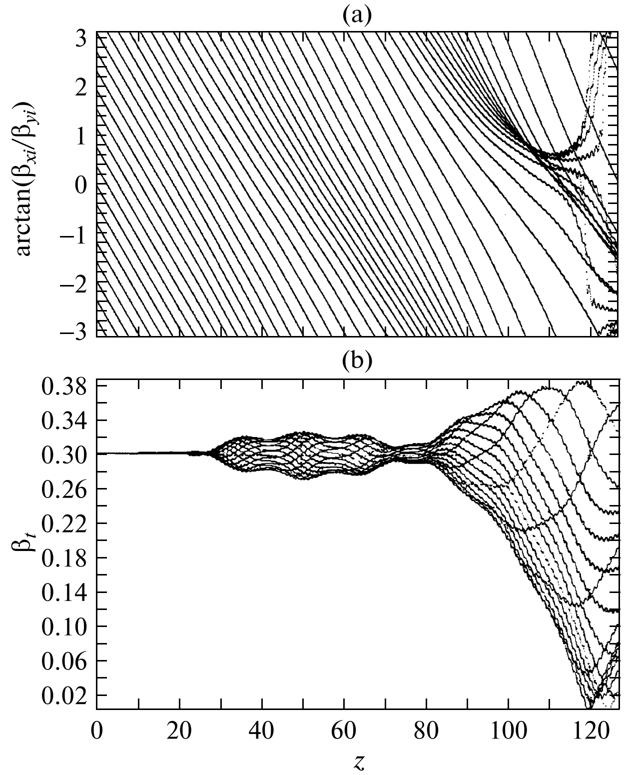

Fig. 2. (a) Phase trajectories and (b) transverse velocity profiles of electrons during transverse bunching in the gyro-TWT.

Figure 1b presents the frequency characteristic of a four-stage filter with a reflection coefficient of 0.998, which is situated at the beginning of the waveguide. As can be seen, the working frequency of the proposed gyro-TWT can be tuned within 6–7% by varying the magnetostatic field.

Figure 1c shows the distribution of the resultant electric field amplitude in a superposition of waves taken into account in the simulation. We have considered eight types of waves, from H_{01} to H_{08}. This distribution is close to optimum for the gyro-resonant interaction [2]. From analysis of Fig. 1, it follows that the field of the H_{01} wave corresponds to a standing wave. This characteristic pattern is created by a counterpropagating wave, which is incident on and reflected from the filter. At the same time, a wave traveling rightward predominates at the output of the working region.

Figure 2a shows the phase trajectories of electrons, which illustrate the process of their transverse bunching in the proposed gyro-TWT. Figure 2b presents the corresponding distributions of transverse electron velocities.

Figure 3 presents the tuning parameters of the gyro-TWT generator as characterized by efficiency and the moralized magnetostatic field *F* as functions of the f/f_0 frequency ratio.

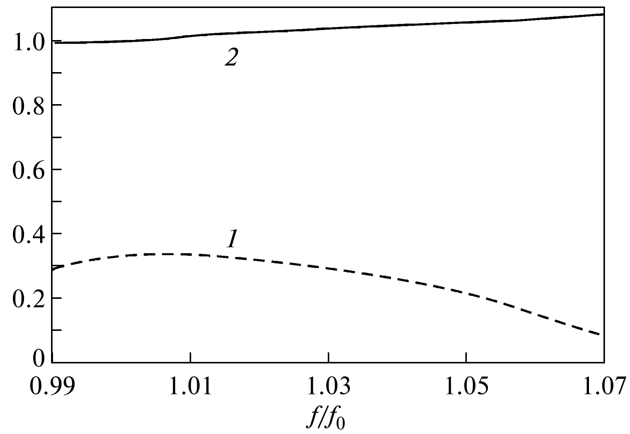

Fig. 3. Plots of (*1*) gyro-TWT generator electronic efficiency and (*2*) normalized magnetostatic field *F* vs. relative frequency f/f_0.

In conclusion, we have demonstrated that gyro-TWT generators with frequency tuning within 6–7% can be created using four-stage reflection filters on an H_{01} wave. The can possess a maximum electronic efficiency of 30% and a total efficiency of up to ~80%.

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