COMPUTER INVESTIGATION OF COAXIAL GYRO-BWO EFFICIENCY DEPENDING ON OSCILLATION FREQUENCY AND LONGITUDINAL WAVEGUIDE DIMENSIONS

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In this article (first part of one) we investigated efficiency dependence of gyro-BWO on oscillation frequencies f=7.7…10 GHz under fixed injection energy of an electron beam γ_0=2. We obtained efficiency increasing of gyro-BWO from ~10 up to ~30% at above mentioned oscillation frequency band f=7.7…10 GHz. Then (second part) we investigated efficiency dependence on longitudinal and transversal waveguide dimensions under the same oscillation frequencies and fixed energy injection of an electron beam. High efficiency η ~ 0.3 still remains the same under fixed distance between radii of coaxial waveguide. High efficiency η takes place too under varying length L of space interaction 60 cm$\geq$L$\geq$30 cm due to form changing like-a-bell guiding magnetic field**.**

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INTRODUCTION

The gyro-BWO is a HF powerful oscillator for cm and mm band of wavelength, where relativistic electrons beam (REB) is used for coupling with a backward wave on normal Doppler effect. The first research of gyro-devices was published in 60th [1]. The state of the art of gyro-BWO program is represented in Ref. [2]. Results of the linear and non-linear analytical investigation of coaxial gyro-BWO operation are presented in Ref. [3], [4]. An electron beam and waveguide support the oscillations with circular frequency ω , which can be described by the expressions for normal Doppler effect, accordingly

$$\omega = k_z V_z + n\Omega_H / \gamma , \qquad (1)$$

$$\omega^2 = c^2 k_\perp^2 + c^2 k_z^2 , \qquad (2)$$

where $\Omega_H = eH_z^g / \mathrm{m}c$ is non-relativistic gyro-frequency of electrons with energy W=$m_0c^2(\gamma\text{-}1)$; H_z^g –guiding magnetic field; γ – relativistic factor; k_z, V_z – longitudinal wave number and velocity correspondingly, n=0,±1,±2… An operating mode for gyro-BWO is near to interception of a straight line (1) and hyperbola (2) in coordinate plane (ω, k_z) (for gyro-BWO the longitudinal wave number k_z <0). An ordinary efficiency value for coaxial gyro-BWO is ~10% for homogenous guiding magnetic field H_z^g .The efficiency of the gyro-BWO is relatively lower than one of other gyro-devices.

1. COMPUTER SIMULATION A

We investigated in first part of our paper efficiency dependence of coaxial gyro-BWO on oscillation frequencies in diapason f=7.7…10 GHz under fixed energy injection of an electron beam γ_0=2 for profiling of guiding magnetic field $H_z^g(z)$ at longitudinal direction z as

$$H_z^g(\xi) = H_{z0}^g (1 + \alpha(\xi / \bar{L}) \cos^m(\pi\xi / 2\bar{L}))^{1/2} \qquad (3)$$

comparatively to homogenous case $H_z^g = H_{z0}^g$, where α is non-homogeneity amplitude, $\xi = z\omega / c$ is normalizing longitudinal coordinate, $\bar{L} = L\omega / c$ is normalizing waveguide length, $\xi / \bar{L} = z / L$, m>0. A corresponding transversal component of magnetic field is

$$H_r^g(z) = -\frac{r}{2}\frac{\partial H_z^g}{\partial z} ,$$

where ***r*** is transversal coordinate.

We considered waveguide exciting mode TE_{01} with components of an electromagnetic field E_φ, H_r, H_z under satisfy conditions (1, 2). For computer simulation we used equations for electrons motion and exciting field TE_{01} from Ref. [3].

We investigated coaxial gyro-BWO with inner radius of the coaxial waveguide gyro-BWO b=3 cm, outer radius one is a=5 cm, inner beam radius is r_b=3.9 cm, outer beam radius is r_a=4.1 cm, energy of injected electron beam is W_0=511 keV (γ_0=2), an initial ratio transversal momentum to longitudinal one μ=1, length of system is L=60 cm, cut off frequency f_c=7.5 GHz, starting current I_{st}=3.7 A, a limiting vacuum current I_{lim}=6.6 kA for coaxial waveguide. Maximal efficiency η_{max}=0.11 is under input beam current I_b=0.6 kA for homogenous guiding field and cited above gyro-BWO parameters [3].

We investigated dependence time averaged efficiency $\bar{\eta}$ on injection beam I_b under some frequencies: f_1=7.7 GHz; f_2=8.1 GHz; f_3=10 GHz (Fig. 1) for homogenous distribution of guiding magnetic field. Frequency variation is possible due to variation of guiding magnetic field from H_{z0}^g =6.1 kOe to H_{z0}^g =10 kOe.

As follows from Fig.1, when the oscillating frequency varies in the diapason from f_0 = 7.7 GHz to f_0 = 10 GHz maximum efficiency varies from η = 0.11 to η = 0.06 under injection beam current I_b = 0.6 kA correspondingly (for homogenous guiding magnetic field H_z (z) =H^g_{z0}).

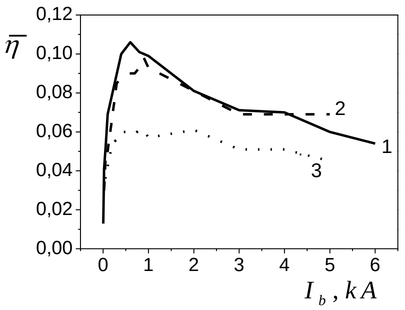

Fig. 1 Dependence time averaged efficiency $\overline{\eta}$ on injection beam I_b under frequencies: 1 – f=7.7 GHz; 2 – f=8.1 GHz; 3 – f=10 GHz (homogenous case $H_z(z) = H^g_{z0}$)

In this paper was investigated dependence efficiency η on above mentioned frequency diapason under profiling guiding magnetic field according to (3) for electron beam current I_b=0.6 kA too. Maximum values of efficiency η_{max} depending on m from (3) present at Tables 1-3 for a given frequency f.

Table 1. (f=7.7 GHz)

m	2	6	8
η_{max}	0.27	0.32	0.27
$H_z(z_0)/H^g_{z0}$	1.2	1.2	1.2

From Table 1 it follows that for the frequency f = 7.7 GHz maximum efficiency is η_{max} = 0.32 for m = 6, relative amplitude of profiling magnetic field $H_z(z_0)/H^g_{z0}$ = 1.2.

Table 2. (f=8.1 GHz)

m	3	4	5	6
η_{max}	0.25	0.27	0.23	0.21
$H_z(z_0)/H^g_{z0}$	1.14	1.14	1.14	1.14

From Table 2 it is seen that for frequency f= 8.1GHz maximum efficiency is η_{max} = 0.27 for m = 4, relative amplitude of profiling fields $H_z(z_0)/H^g_{z0}$ = 1.14.

Table 3. (f=10 GHz)

m	1	2	3
η_{max}	0.22	0.2	0.17
$H_z(z_0)/H^g_{z0}$	1.07	1.07	1.07

From Table 3 it follows that for the frequency f_0 = 10 GHz maximum efficiency is η_{max} = 0.22 for m = 1 and relative field amplitude $H_z(z_0)/H^g_{z0}$ =1.07. Then we obtained dependence of efficiency on injection beam current for profiling guiding magnetic field under different frequencies. That investigation was realized in Fig. 2 for comparing with results in Fig. 1.

From Fig. 2 it follows that for the frequency diapason f = 7.7...10 GHz efficiency increases at least twice compared with the homogeneous case (see Fig. 1). The maximum effect of efficiency increasing 2.5…3 times is observed nearly the given current of injection beam I_b = 0.6 kA .

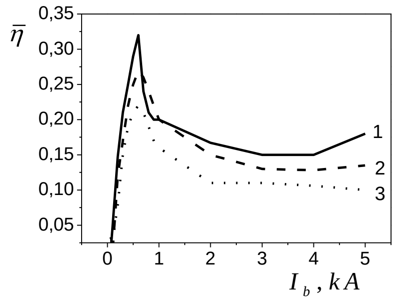

Fig. 2. Dependence time averaged efficiency $\overline{\eta}$ on injection beam I_b under frequencies: 1 – f=7.7 GHz; 2 – f=8.1 GHz; 3 –.f=10 GHz (non-homogeneous guiding magnetic field $H_z(z) \neq H_{z0}$)

2. COMPUTER SIMULATION B

Next part of investigations was involved with variation of geometrical waveguide dimensions comparatively above mentioned a, b, r_a, r_b and L (in "COMPUTER SIMULATION A"). Let consider dependence efficiency η of coaxial gyro-BWO on electron beam I_b with the new following initial geometrical parameters of coaxial waveguide (Fig. 3): inner radius is b=2.5 cm, outer radius a=4.5 cm, the inner radius of the beam r_b=3.4 cm, outer radius of the beam r_a=3.6 cm (curve 1) and (curve 2) coaxial waveguide inner radius is b = 3.5cm, outer radius is a =5.5 cm. Oscillation frequency is f = 7.7 GHz.

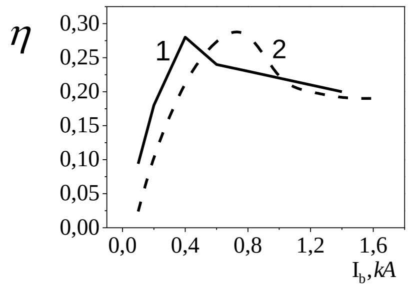

Fig. 3. Dependence efficiency η on electron beam I_b under coaxial waveguide radii: curve 1 – external radius a=4.5 cm, inner radius b=2.5 cm; curve 2 – a=5.5 cm, b=3.5 cm

From a comparison results for the initial geometry of the coaxial waveguide (see Fig. 2, curve 1, b = 2.5 cm, a=4.5 cm) that simultaneous reducing the inner and outer radii of the waveguide without changing the distance between radii (a-b = 2 cm) efficiency decreases slightly (η_{max} = 0.28 for I_b =0.4 kA). Note that in this case the transverse wave number in fact unchanged $k_\perp$ = 1.59 cm^{-1} ($k_\perp$ = 1.586 for the initial geometry), the cutoff frequency is still f_c=7.5 GHz, the amplitude of the magnetic guide field is also unchanged H_{z0}=6.05 kOe (previously H_{z0}=6.1 kOe). Fig. 1 (curve 2) shows the result of efficiency investigation depending on electron beam when the inner and outer radii of the waveguide simultaneously increased by 5 mm (inner radius of the coaxial waveguide gyro- BWO is b = 3.5 cm, outer radius is a = 5.5 cm (a-b=2 cm)).

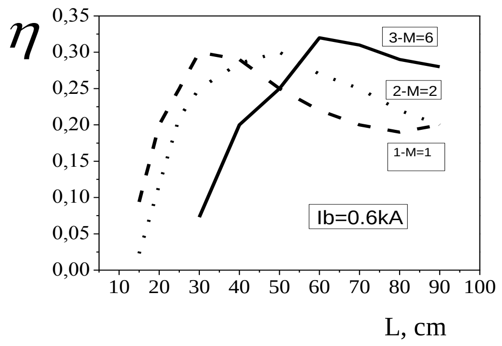

Fig. 4. Dependence efficiency η on oscillator space length interaction L: curve 1 (---) – m=1; curve 2 (. . .) – m=2; curve 3 (——) – m=6 from expression (1)

Transverse wave number again in fact unchanged $k_\perp$ = 1.58, the amplitude of the magnetic guide field is also in fact unchanged H_{z0} = 6.15 kOe. As can be seen from Fig. 2 the maximum efficiency is η = 0.3 at a beam current I_b = 0.8 kA. Next investigation was realized for efficiency depending on the length of the coaxial waveguide (transversal geometry of the waveguide from "Computer simulation A") for various values of m in expression (1). As can be seen from Fig. 2 for m = 1, the efficiency is maximum (η = 0.3) for corresponding coaxial waveguide length L = 30 cm, for m = 2 the maximum efficiency η = 0.3 is for the length L = 50 cm and, finally, for m = 6 efficiency η = 0.32 for length L = 60 cm. It can be seen that the optimal distribution of guiding magnetic field depending on the length of the interaction region under other fixed geometry and beam parameters of the oscillator. Various values of m from expression (1) correspond to various values of length interaction L as follows from Fig. 4.

CONCLUSIONS

For coaxial gyro-BWO is possible to change the frequency of oscillation in diapason f = 7.7…10 GHz with efficiency η > 0.2 for non-homogenous distribution of guiding magnetic field.

In this report was studied too the possibility of changing the radii of the coaxial waveguide without reducing efficiency for a given profile guiding magnetic field [5]. Maximum efficiency varies a little by under synchronous changing of radii coaxial waveguide for fixed distance between the radii. It was also found that the efficiency remains within η ~ 0.3 when the length L of the coaxial waveguide (in the region of interaction) was changed with a simultaneous corresponding changing value m from expression.

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КОМПЬЮТЕРНОЕ ИССЛЕДОВАНИЕ КПД КОАКСИАЛЬНОЙ ГИРО-ЛОВ ОТ ЧАСТОТЫ КОЛЕБАНИЙ И ПРОДОЛЬНЫХ РАЗМЕРОВ ВОЛНОВОДА

В. Хоружий

Исследовали (первая часть статьи) зависимость КПД гиро-ЛОВ от частоты колебаний в диапазоне F = 7.7…10 ГГц при фиксированной энергии инжекции пучка электронов γ_0 = 2. Получили увеличение КПД гиро-ЛОВ от ~ 10 до ~ 30% для неоднородного распределения ведущего магнитного поля. Исследовали (вторая часть статьи) зависимость КПД от продольных и поперечных размеров волновода в том же диапазоне частот и при фиксированной энергии инжекции электронного пучка. Высокое значение КПД (~ 0,3) не меняется при таком изменении поперечных размеров волновода, при котором расстояние между радиусами коаксиального волновода остается неизменным. Высокое значение КПД имеет место при изменении длины пространства взаимодействия 60 см ≥ L ≥ 30 см в случае соответствующего изменения формы и амплитуды ведущего магнитного поля.

КОМП'ЮТЕРНЕ ДОСЛІДЖЕННЯ ККД КОАКСІАЛЬНОЇ ГІРО-ЛЗХ ВІД ЧАСТОТИ КОЛИВАНЬ І ПОЗДОВЖНІХ РОЗМІРІВ ХВИЛЕВОДУ

В. Хоружий

Досліджували (перша частина статті) залежність ККД гіро-ЛЗХ від частоти коливань у діапазоні F = (7.7…10) ГГц при фіксованій енергії інжекції пучка електронів γ_0 = 2. Отримали збільшення ККД гіро-ЛЗХ від ~ 10 до ~ 30% для неоднорідного розподілу ведучого магнітного поля. Досліджували (друга частина статті) залежність ККД від поздовжніх і поперечних розмірів хвилеводу в тому ж діапазоні частот і при фіксованій енергії інжекції електронного пучка. Високе значення ККД (~ 0,3) не змінюється при такій зміні поперечних розмірів хвилеводу, при якому відстань між радіусами коаксіального хвилеводу залишається незмінною між радіусами коаксіального хвилеводу. Високе значення ККД має місце при зміні довжини простору взаємодії 60 см ≥ L ≥ 30 см у разі відповідної зміни форми і амплітуди ведучого магнітного поля.