USING OF LINEARIZED APPROACH FOR CROSSED-FIELD DEVICES' MODELING

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Abstract — Using of linearized systems describing the crossed–fields devices' operation, taking into account space charge fields, is studied. It allowed simplifying significantly the processes study in crossed-fields devices. It was shown that one of spectrum components coincides with the fundamental mode of magnetron oscillations.

ИСПОЛЬЗОВАНИЕ ЛИНЕАРИЗОВАННОГО ПОДХОДА К МОДЕЛИРОВАНИЮ ПРИБОРОВ СО СКРЕЩЕННЫМИ ПОЛЯМИ

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Аннотация — Рассмотрено использование линеаризованных систем, описывающих работу приборов со скрещенными полями с учетом полей пространственного заряда. Это позволяет значительно упроститьт изучение процессов, протекающих в приборам со скрещенными полями. Показано, что одна из составляющих энергетического спектра совпадает с основной модой колебаний магнетрона.

I. Introduction

Modern science deals with the analysis of complex phenomena and, simplifying them, later studies their rules. Now scientists' attention is directed at complex systems.

Such systems consist of simple elements. Such systems' properties are known and system behavior is not a sum of its components. Such behaviour is named as a cooperative or synergetic effect.

The wideband noise which exceeds flicker noise 5 – 6 times as much, presents in crossed-field devices. However we don't know the nature of noise generation and it is not connected with stochastic oscillations.

The excess noise and azimuth oscillations of space charge in magnetron oscillators are observed in pre-oscillation mode when resonator structure's influence is negligible and the magnetron operates as a magnetron diode.

From the design point of view the modern magnetrons consist of three parts: cathode, anode structure with cavity resonators and RF energy output [1].

These devices have been analyzed with PIC codes [2] and guiding centre theory [3, 4].

Modeling of crossed–field devices operation is based on building and further solving of the most frequent numerical complexes of differential equations. Such models need much computer and time resources.

On the other hand any complex system can be described by means of simpler equations. Our approach uses the linearization of motion equations.

The purpose of this work concerns the use of the linearization approach to motion equations for charged particles in crossed electrical and magnetic fields taking into account the space charge effect.

II. Main Part

We observed and analyzed motion equations for two types of crossed–field devices: a magnetron diode and a magnetron.

For magnetron diode a potential distribution is described by the following expression

$$U(s)=U_a\frac{\ln s}{\ln s_a},$$

where U_a – anode potential; $s_a = r_a/r_c$.

For magnetron a potential distribution is described by [5].

Using above mentioned expressions for potential distribution in crossed–field devices we had described motion equations for magnetron diode as

$$\begin{cases}\dfrac{d^2s}{dt^2}-\left(\dfrac{d\varphi}{dt}\right)^2 s=\eta\dfrac{U_a}{s\ln s_a}-\omega_H s\dfrac{d\varphi}{dt}\\ s\dfrac{d^2\varphi}{dt^2}+2\dfrac{ds}{dt}\dfrac{d\varphi}{dt}=\omega_H\dfrac{ds}{dt}\end{cases}\qquad(1)$$

and for magnetron

$$\begin{cases}\dfrac{d^2s}{dt^2}+\left(1-\dfrac{d\varphi}{dt}\right)\dfrac{d\varphi}{dt}s=\dfrac{\beta}{s}\left(1-2N\ln\dfrac{s_v}{s_a}\sum_{n=1}^{\infty}a_n cors^{Nn}\cos Nn\varphi\right)\\ \dfrac{d^2\varphi}{dt^2}+\dfrac{1}{s}\dfrac{ds}{dt}\left(2\dfrac{d\varphi}{dt}-1\right)=\dfrac{2N\beta}{s}\ln\dfrac{s_v}{s_a}\sum_{n=1}^{\infty}a_n sirs^{Nn}\sin Nn\varphi\end{cases}\qquad(2)$$

where

$$\beta=\frac{\eta U_a}{\dfrac{N\theta}{\pi}\ln\dfrac{s_v}{s_a}+\ln s_a},$$

$$a_n=\frac{\sin Nn\theta}{(Nn\theta+\sin 2Nn\theta)\left(sirs_v^{Nn}-sirs_a^{Nn}\right)+\pi sirs_a^{Nn}}.$$

Considering the relation $r_a/r_c<2$ for modern magnetron-type devices, the dimensionless radius s can be represented as $s=1+x$.

In this cause using the linearization method for motion equations (1) we obtain

$$\begin{aligned}&\frac{d^2x}{dt^2}=b-(1+b)x\\ &\frac{d\varphi}{dt}=x\end{aligned}\qquad(3)$$

and motion equations (2)

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$$\frac{d^2x}{dt^2} = \gamma - (1+\gamma)x$$
$$\frac{d\varphi}{dt} = x \quad . \qquad (4)$$

Taking into account the Brillouin flow we have the following form for b

$$b = \frac{\eta}{(\omega_H r_c)^2}\left[\frac{U_a - \frac{\omega_H r_c^3}{2h}\left(s_a + \frac{1}{9s_a^3}\right) + \frac{5\omega_H r_c^3}{9h}}{s \ln s_a} + \frac{\omega_H r_c^3}{2h}\left(1 - \frac{1}{3s^4}\right)\right]$$

and for γ

$$\gamma = \frac{\eta}{(\omega_H r_c)^2}\left[\frac{U_a - \frac{\omega_H r_c^3}{2h}\left(s_a + \frac{1}{9s_a^3}\right) + \frac{5\omega_H r_c^3}{9h}}{s\left(\frac{N\theta}{\pi}\ln\frac{s_v}{s_a} + \ln s_a\right)} + \frac{\omega_H r_c^3}{2h}\left(1 - \frac{1}{3s^4}\right)\right].$$

Solutions of equations (3) can be found in analytical form. Thus, for magnetron diodes we have the following:

$$x(t) = \frac{b}{1+b}\left(1 - \cos\sqrt{1+b}t\right)$$
$$\varphi(t) = \frac{b}{1+b}\left(t - \frac{\sin\sqrt{1+b}t}{\sqrt{1-b}}\right).$$

These solutions show that the charged particle in crossed–fields in magnetron diodes takes part in two kinds of motion: oscillation motion in radial direction and rotation in azimuthal direction.

We have solutions of equations (4) for magnetrons:

$$x(t) = \frac{\beta}{1+\beta}\left(1 - \cos\sqrt{1+\beta}t\right)$$
$$\varphi(t) = \frac{\beta}{1+\beta}\left(t - \frac{\sin\sqrt{1+\beta}t}{\sqrt{1+\beta}}\right).$$

This solution is similar to the interpretation that obtained for magnetron diodes.

These solutions show that the charged particle in magnetron diodes in crossed fields takes part in two kinds of motion: oscillation motion in radial direction and rotation in azimuthal direction.

III. The Research Results

To estimate the excited oscillations we must build an “energetic” spectrum. Here we studied K_u-band magnetron.

Spectral components were shown on Fig. 1, where a magnetron diode is shown on Fig. 1a) and a magnetron on Fig. 1b).

On these figures we can see fundamental and second cycloid harmonics and an undefined component.

For magnetron diodes the second cycloid harmonic coincides with a fundamental mode of K_u-band magnetron.

For magnetron the undefined component coincides with the fundamental mode of K_u-band magnetron.

IV. Conclusions

It is shown that the use of the linearized approach for the study of charged particles’ motion in crossed electric and magnetic fields taking into account the Brillouin flow allowed simplifying the solution of such problems and estimating the rotational motion’s frequency.

Thus using the proposed approach we can analytically investigate behavior of nonlinear dynamical systems "a magnetron diode" and "a magnetron" and prove existence of oscillation and rotation types of motion. It will allow improving the theory of analytic investigation of crossed–field systems.

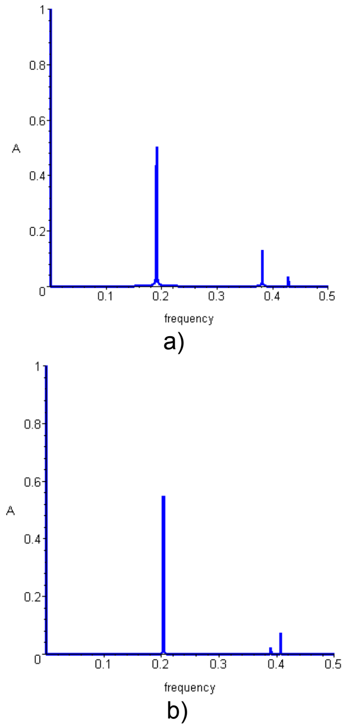

Fig. 1. Energetic spectrum:
a – magnetron diode; b – magnetron

Рис. 1. Энергетический спектр:
а – магнетронный диод; b – магнетрон

For magnetron diode model the second harmonic of cycloid frequency coincides with fundamental mode of K_u-band magnetron oscillations. For magnetron model the undefined component coincides with fundamental mode of K_u-band magnetron oscillations. Accuracy for magnetron diode is 0.5% and for magnetron is 2.3%.

In future such investigations will be made for magnetrons in other bands.

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