Conference Proceedings

2000 International Conference on

MATHEMATICAL METHODS IN ELECTROMAGNETIC THEORY

MMET 2000

Kharkov. Ukraine

September 12-15,2000

SIMULATION OF A NON-LINEAR INTERACTION IN THE COMBINED MAGNETRON

T. I. Frolova, G. I. Churyumov
Kharkov State University of Radio Electronics
14 Lenin Ave., Kharkov, 61166, Ukraine
Tel.: +380 572 409362, Fax: +380 572 409113
Email: frolova@kture.kharkov.ua

ABSTRACT

In the last few years the development of efficient crossed-field tubes is connected with a creation of new non-traditional designs. In this paper a mathematical model of new combined magnetron and the features of modes of its operation are discussed.

INTRODUCTION

An application of new technologies is a promising approach to the problem of development of advanced crossed-field tubes. The development of non-traditional crossed-field tubes is a good example of usage of this approach [1]. Among the possible advantages of non-traditional designs in comparison with the classical designs of tubes (for instant, magnetron), we can mention a suppression of interpulsing spurious oscillations in re-entrant beam, self-modulated CFAs, providing their stable operation in frequency band and the creation of cold cathode, self-modulated, re-entrant beam amplifier [2]. Besides, a considerable advance has been made in studying of new designs of the magnetron oscillators and, in particularly, combined magnetron [3]. However, there is a number of unclear questions concerning non-linear interaction of two electronic beams with electromagnetic wave of the resonant delay line. Their solution cannot be made a priory without theoretical investigations of given interaction mechanism by using self-consistent mathematical models of the tube. The choice of such a mathematical model is determined by a compromise between the list of problems, which have to be solved, and possibilities of a hardware. The application of full-scale simulation allows not only to calculate basic parameters of tubes, and to evaluate their limiting values as well as to explain the possible anomalous physical effects and to point out the ways of their elimination.

In this paper, the features of a mathematical model of combined magnetron are discussed. Mathematical modelling of the electron-wave processes is considered in three-dimensional approximation on one wavelength with usage of the conditions of a quasi-periodicity (quasi-periodical model [4]).The emphasis is on the study of physical regularities governing the electron-wave interaction in the tube and on determination of the optimum performance of its operation.

THEORY

Fig. 1 shows schematically the full classification of crossed field tubes with the azimuthal symmetry. The classical crossed-field tubes with azimuthal symmetry can be considered as electron-wave systems, in which a re-entrant electron beam interacts with a (synchronous) slow electromagnetic wave («the re-entrant electron beam + RF wave» systems). As it has been shown in [1], non-traditional crossed-field tubes are the examples of future advanced technologies, which are connected with the creation of a new design of the tubes. These tubes are defined as electron-wave systems, in which a re-entrant electron beam interacts with two synchronous electromagnetic waves («re-entrant electron beam + two RF waves» systems), or two re-entrant electron beams interact with a synchronous electromagnetic wave («two re-entrant electron beams + RF wave» systems).

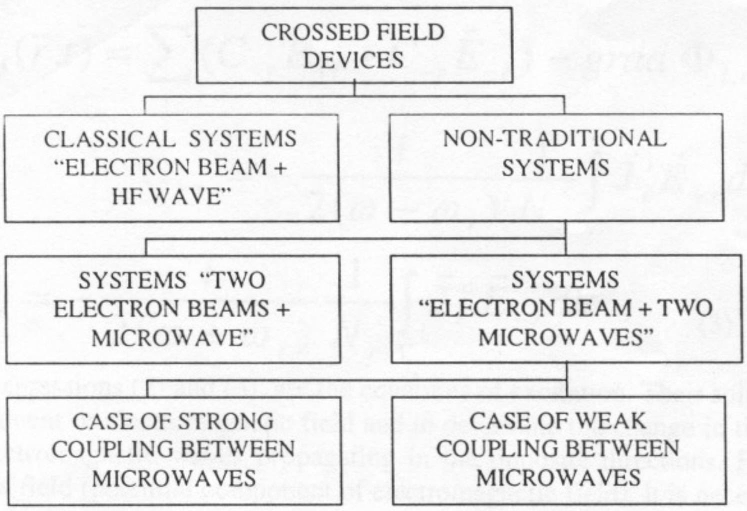

Fig. 1

The angular domain of the interaction space corresponding one wavelength in the combined magnetron, schematically, is shown in Fig. 2. There is an interaction of the inner and outer electronic beams with electromagnetic field of the resonant delay line. A special feature of this interaction is that electron beams have an opposite sense of rotation, i.e. inner beam rotates around internal cathode clockwise and outer one rotates around external cathode anti-clockwise. The average drift velocities of inner (i) and outer (o) beams are $v_e^{i,o} = E_0^{i,o} / B_0^{i,o} \approx U_a^{i,o} / d^{i,o} B_0^{i,o}$, where $U_a^{i,o}$ is the anode voltage;

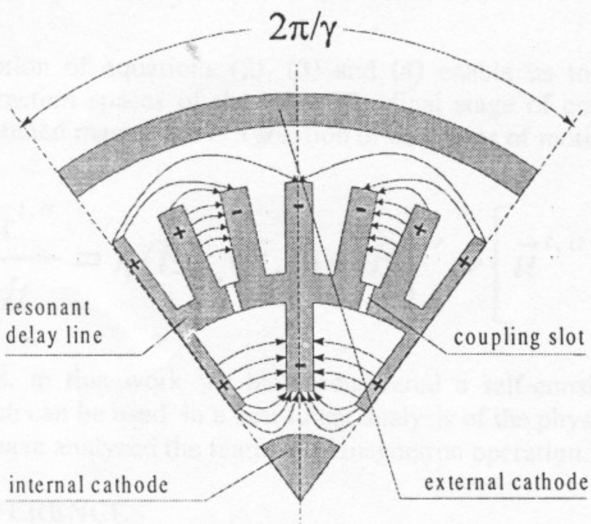

Fig. 2.

$B_o^{i,o}$ is magnetic field: $d^{i,o}$ is the distance between cathode and anode. Indices (i) and (o) in the expressions above correspond to the inner and outer interaction spaces of the tube, respectively. It is known that the condition of its efficient operation will be the following: $v_e^i \approx v_e^o \approx v_f^{+,-}$ (synchronism condition), where $v_f^{+,-}$ is the phase velocity of synchronous spatial harmonic, and indices (+) and (-) are associated with its rotation clockwise and anti-clockwise. There are two operating modes in the combined magnetron to satisfy the synchronism condition. In the first case, we have $U_a^i \neq U_a^o$ (two power supplies) and $B_o^i = B_o^o = const$. The second case (when $U_a^i = U_a^o$ and $B_o^i \neq B_o^o$) is preferable as it enables one to use a single (in common) power supply. The possible distribution of the magnetic field in this case can be easily realized using a standard magnet. An example of such distribution is described in [3].

The particle-in-cell (PIC) method was chosen as a basis for computer modelling of the non-linear interaction in combined magnetron. The simulation was carried out in one-wave approximation by using three-dimensional mathematical model. It was suggested that the distribution of electromagnetic field both in the internal and external interaction spaces of the tube corresponded to the π –mode oscillation of the resonant delay line. In this case the resonant electromagnetic field can be presented as a superposition of two traveling waves having equal amplitudes. Total electromagnetic field (both its rotational and potential components) in the inner and outer interaction spaces can be written in the form [5]:

$$\vec{E}_{i,o}(\vec{r}.t) = \sum_r (C_{+r}\vec{E}_{+r} + C_{-r}\vec{E}_{-r}) - grad\ \Phi_{i,o}\ , \quad (1)$$

where $$C_{+r} = -\frac{i}{2(\omega - \omega_r)}\frac{1}{N_r}\int_V \vec{J}^{\,i}_e \vec{E}_{+r} dV \quad ; \quad (2)$$

$$C_{-r} = -\frac{i}{2(\omega + \omega_r)}\frac{1}{N_r}\int_V \vec{J}^{\,o}_e \vec{E}_{-r} dV \quad ; \quad (3)$$

The expressions (2) and (3) are the equations of excitation. Their solution allows to find the rotational component of electromagnetic field and to determine the change in time of the amplitudes and phases of electromagnetic waves propagating in the opposite directions. For the calculation of the space-charge field (potential component of electromagnetic field), it is necessary to solve a Poisson equation in the inner and outer regions of the interaction space.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{\partial \Phi_{i,o}}{\partial r}\right) + \frac{1}{r}\frac{\partial^2 \Phi_{i,o}}{\partial \varphi^2} + \frac{\partial^2 \Phi_{i,o}}{\partial z^2} = \frac{\rho_{i,o}}{\varepsilon_0} \quad . \quad (4)$$

Solution of equations (2), (3) and (4) enable us to calculate a total electromagnetic field in the interaction spaces of the tube. The final stage of computer modelling of the physical processes in combined magnetron is a solution of equations of motion for two (inner and outer) electron beams

$$\frac{d\vec{u}^{\,i,o}}{dt} = \eta(\vec{\tilde{E}}_{i,o}(\vec{r},t) + \vec{E}^{\,i,o}_0 + \left[\vec{u}^{\,i,o} \times \vec{B}^{\,i,o}_0\right]) \quad (5)$$

Thus, in this work we have considered a self-consistent system of integro-differential equations, which can be used in a non-linear analysis of the physical processes in combined magnetron. Besides, we have analyzed the features of magnetron operation.

REFERENCES

[1] Churyumov G.I., Sergeev G.I. New concepts of development of crossed-field microwave devices with azimuthal symmetry. *Proc. 8-th Int. Symp.Non-Linear Electromagnetic Systems (ISEM-97).* 12-14 May, Braunschweig, 1997, p. 295-296.

[2] Churyumov G.I., Sergeev G.I. Simulation and modelling of self-modulated re-entrant beam crossed-field amplifier. *IEEE Trans. Electron Devices*, vol. 46, May 1999, pp. 1063-1069.

[3] Frolova T.I., Churyumov G.I., Sergeev G.I Computer modelling of the electron-wave interaction in combined magnetron. *Proc. 1-st Int. Vacuum Electronics Conference (IVEC'2000).* 2-4 May, Monterey, 2000. pp. 551-554.

[4] Yu S.P., Kooyers G.P., Buneman O. Time-depend computer analysis of electron-wave interection in crossed field, *J. Appl. Physics*, 1965, vol.36, ¹ 8, p.2550-2559.

[5] Vaynshteyn L.A., Solnthev V.A. *Lectures on Microwave Electronics*, Moscow· Sov. Radio, 1973 (in Russian).