NOVEL AND ADVANCED ACCELERATION TECHNOLOGIES

A STUDY OF THE MICROWAVE AMPLIFICATION IN MILO WITH THE FLAT INTERACTION SPACE

A.M. Gorban', Yu.F. Lonin, G.E. Sarukhanyan
National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine
E-mail: gorban@kipt.kharkov.ua; lonin@kipt.kharkov.ua

The magnetically insulated transmission line oscillator (MILO) is the crossed field device developed for generation of microwave power at gigawatt level. We have used a numerical simulation method to investigate electromagnetic oscillations in MILO where a plane region of interaction between the flow of electrons and the field of the slow-wave structure is installed. The system under study is a segment of the plane transmitting line of an infinite width. The slow-wave structure in the form of a comb is placed on one of the electrodes (anode). The other electrode (cathode) is an explosive electron-emitting source. The line areas on the left and on the right of the slow-wave structure are filled with absorbent to prevent the electromagnetic wave reflection. After the voltage application to the transmission line, an electron flow magnetic self-insulation mode is installed. The slow-wave structure is exited by an external signal. The results obtained for this model were used to calculate the transfer ratio as a function of the exciting signal amplitude and signal frequency detuning with respect to the slow-wave structure principal mode. The spectral characteristics of output signals have been estimated for different excitation modes. The spectral characteristics of output signals have been estimated for different excitation modes.

PACS: 533.9; 538.311

INTRODUCTION

The MILO-type devices are typical models of relativistic oscillators designed for producing very high-power microwave pulses. In that capacity they are constantly studied and developed in the form of experimental setups [1 - 3].

At the same time, to study a possibility of amplification of the radio-wave radiation, including the broadband one, in such devices, is a very important task. In the previous study [4] we have obtained the results showing that it is possible to use the MILO-type devices in the amplification mode. However, the computational model, we have applied, was inconvenient for systematic investigations. Generally, it was because of high requirements to the computer system.

In this connection we have developed a new model requiring a less computation volume and providing a softer control of PC parameters.

1. COMPUTATION MODEL

The calculation spacing (Fig. 1) is a planar diode infinitely extended along the *z* axis and confined along the *y* axis by the cathode and anode planes. In the longitudinal direction (along the *x* axis) it is confined by the regions filled with "ideal" radio absorber. Thus, there are boundaries in the model being opened for microwaves. A slow-wave structure in the form of a comb resonator is placed on the internal surface of the anode. There is a region of an explosion electron-emitting source on the cathode. An external transverse magnetic field is applied (a magnetic bias field) along the *z* axis so that the electron flow coincides with the wave propagation direction. The external excitation of the system is realized by passing modulate current throughout the absorber taking place on the left of the interaction space.

The amplified radiation with increase of phase velocity in the area of a "wedge-shaped" profile of a comb is directed to the area filled with an absorber (on the right in drawing). Thus, we approximately model its output from the system.

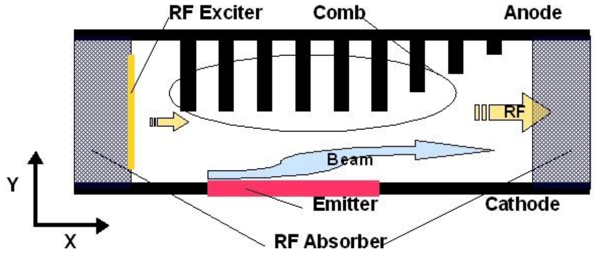


Fig. 1. Schematic representation of the model

As the system is infinitely extended in the direction of axis Z, all fields in this direction are uniform. Therefore, the problem phase space is limited to two coordinates x, y and two components of velocity v_x v_y. Fields have three other than zero components E_x, E_y, H_z and in system may exist TE type electromagnetic oscillations.

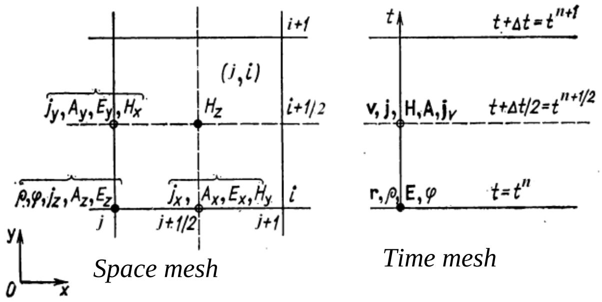
Fields have three components – external electric and magnetic fields, fields of the electromagnetic waves propagating in system and electric field of a volume charge.

The external static magnetic field H_{Z0} is uniform on all area of system. External electric field $\vec{E}_0$ is calculated by integration of the Laplace equation with the boundary conditions determined by the set geometry of the slow-wave structure and value of anode potential (and structures). An integration method – sequential overrelaxation. Momentary values of the electromagnetic wave field are determined by the integration of the Maxwell rotor equations

$$rot\,\vec{E} = -\frac{1}{c}\frac{\partial \vec{H}}{\partial t}; \quad rot\,\vec{H} = \frac{1}{c}\frac{\partial \vec{E}}{\partial t} + \frac{4\pi}{c}\vec{j}\,. \qquad (1)$$

Here we assume that $\mu/\varepsilon = 1$ (vacuum, Gaussian system of units). For the TE waves in the Cartesian coordinates in the mesh (Fig. 2), the difference equations set (Yee [5]) is as follows

$$H_z^{n+1/2}\left(j+1/2,i+1/2\right)=H_z^{n-1/2}\left(j+1/2,i+1/2\right)-\frac{\Delta\tau}{\Delta x}\left[E_y^{\,n}\left(j+1,i+1/2\right)-E_y^{\,n}\left(j,i+1/2\right)\right]$$
$$+\frac{\Delta\tau}{\Delta y}\left[E_x^{\,n}\left(j+1/2,i+1\right)-E_x^{\,n}\left(j+1/2,i\right)\right]; \tag{2}$$
$$E_x^{n+1}\left(j+1/2,i\right)=E_x^{n}\left(j+1/2,i\right)+\frac{\Delta\tau}{\Delta y}\left[H_z^{n+1/2}\left(j+1/2,i+1/2\right)-H_z^{n+1/2}\left(j+1/2,i-1/2\right)\right]-4\pi\cdot\Delta\tau\cdot J_x^{n+1/2}(j+1/2,i);$$
$$E_y^{n+1}\left(j,i+1/2\right)=E_y^{n}\left(j,i+1/2\right)-\frac{\Delta\tau}{\Delta x}\left[H_z^{n+1/2}\left(j+1/2,i+1/2\right)-H_z^{n+1/2}\left(j-1/2,i+1/2\right)\right]-4\pi\cdot\Delta\tau\cdot J_y^{n+1/2}(j,i+1/2).$$



Space mesh *Time mesh*

Fig. 2. Computation mesh

Here $H_z^{n+1/2}\left(j+1/2,i+1/2\right)$ is the transverse magnetic field induction in the displaced node $j+1/2,i+1/2$ at instant of time $t+\Delta\tau/2\ \left(n+1/2\right)$; E_x, E_y – the electric field component; J_x, J_y – the electron current density components (of the excitation source), and $\Delta x, \Delta y$ – are the mesh sizes in the corresponding directions.

When the emission and escape of electrons occur, equations (1) do not provide the fulfillment of a law. Therefore, to determine the complete electric field components it is necessary to make a correction in the right part of (2) for the space charge (Boris's correction [6]) so that

$$\vec{E}^{new}=\vec{E}^{old}-\vec{\nabla}\delta\varphi\,, \tag{3}$$

where $\delta\varphi$ is found from the Poisson equation

$$\Delta\delta\varphi=\vec{\nabla}\cdot\vec{E}-\rho\,, \tag{4}$$

where ρ is the electron flow density. The integral method (4) is the successive overrelaxation.

The mesh values of the charge density ρ and current densities J_x, J_y were calculated by the area weighting method (CIC model). The integration of electron motion equations is performed by the Boris's method [6]. When the particle reaches any of the region boundaries, it is excluded (absorbed) from the calculation.

2. BASIC RESULTS FOR TWO-FREQUENCY EXCITATION

We have investigated the behavior of the system under the simultaneous action of two harmonic signals for different values of the frequency spacing and their amplitudes. To keep, as long as possible, the system from the π-mode self-oscillation development and change into the saturation condition, the magnetizing field has been set at a rather high level for the electron flow prepression to the cathode. The exciting radiation has been introduced into the system before the explosive emission arising. The results obtained are reduced to the following.

For the effective amplification, the amplitude of the exciting wave should be much higher than the amplitude of noises of the space charge noises at the stage of the electron flow instability development.

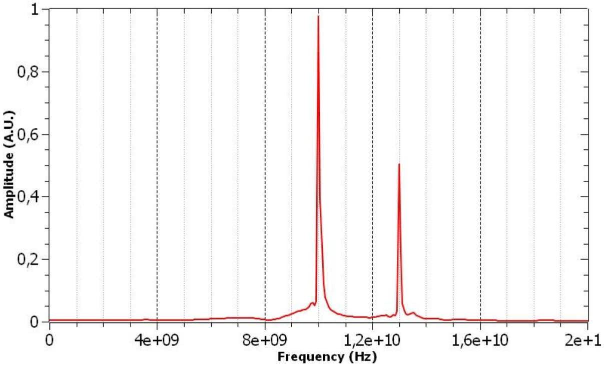


Fig. 3. Cold system. $f_2 = 1.3{\cdot}f_1$

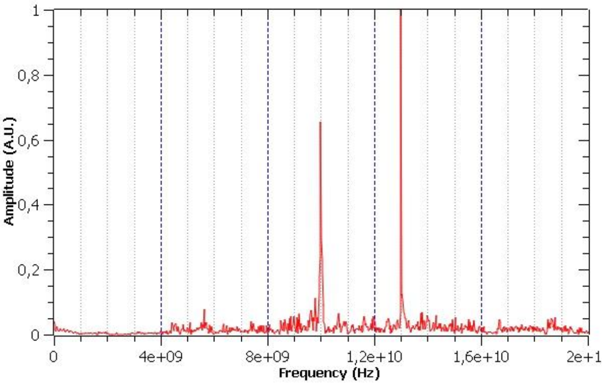


Fig. 4. Warm system. $f_2 = 1.3{\cdot}f_1$

The two-frequency amplification is possible at a relative signal frequency spacing > 0.1. The same concerns the exciting signal frequency from the frequency corresponding to the π-mode of oscillations.

Fig. 2 presents the amplitude spectrum of the cold system oscillations (without emission) under the action of the two-frequency excitation with frequency spacing of 0.3. Here the lower frequency is close to the slow-wave structure eigenfrequency. Fig. 4 presents the effective amplification of the two signals. Different width of peaks in Fig. 4 and in Fig. 3 is explained by different lengths of samples. The ratio of the signal amplitudes in Fig. 4 in respect to Fig. 3 is of about 3 (the same is for Figs. 6 and 5).

Figs. 4 and 5 show the case when the signal frequency spacing is equal to 0.1 (and when the second signal also is close to the slow-wave eigenfrequency). As is seen form Fig. 5 in this case the second wave practically is not amplified.

The presented examples demonstrate complex behavior of the system under two-frequency excitation, which is externally pronounced/defined in the strong dependence of the amplification coefficient on the signal frequency and possibility of suppressing close spaced (by frequency) signals.

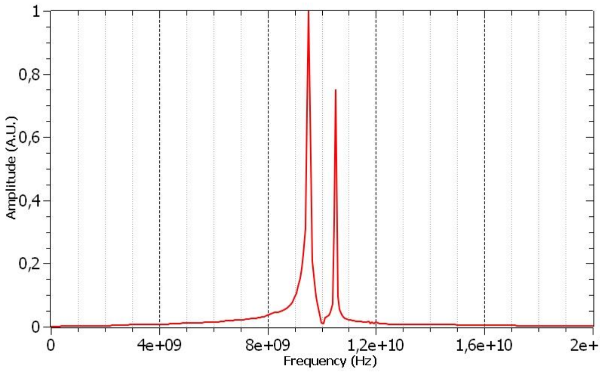


Fig. 5. Cold system. $f_2 = 1.1 \cdot f_1$

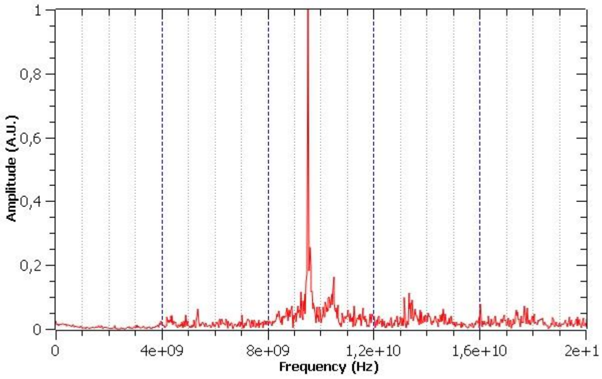


Fig. 6. Warm system. $f_2 = 1.1 \cdot f_1$

To describe in more detail the mechanisms of these phenomena, to all appearance, further more thorough research is required.

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Article received 23.11.2017

ИССЛЕДОВАНИЕ УСИЛЕНИЯ ЭЛЕКТРОМАГНИТНЫХ КОЛЕБАНИЙ В MILO С ПЛОСКОЙ ОБЛАСТЬЮ ВЗАИМОДЕЙСТВИЯ

А.М. Горбань, Ю.Ф. Лонин, Г.Э. Саруханян

Осциллятор на магнитоизолированной передающей линии (MILO) – это устройство на скрещенных полях, разработанное для генерации сверхвысокочастотной мощности гигаваттного уровня. Методом численного моделирования мы исследовали усиление электромагнитных колебаний в MILO с плоской областью взаимодействия электронного потока с полем замедляющей структуры. Исследуемая система представляет собой отрезок плоской передающей линии бесконечной ширины. На одном из электродов (аноде) помещена замедляющая структура в виде гребенки. Другой электрод (катод) является распределенным источником электронов за счет эффекта взрывной эмиссии. Области линии слева и справа от замедляющей структуры заполнены поглотителем для предотвращения отражения электромагнитной волны. После подачи на линию напряжения в ней устанавливается режим магнитной самоизоляции электронного потока. Система может возбуждаться внешним током высокой частоты. По результатам исследования такой модели получены зависимости коэффициента передачи от амплитуды возбуждающего сигнала и параметра расстройки частоты сигнала относительно основной моды замедляющей структуры. Определены спектральные характеристики выходных сигналов для различных режимов возбуждения.

ДОСЛІДЖЕННЯ ПОСИЛЕННЯ ЕЛЕКТРОМАГНІТНИХ КОЛИВАНЬ У MILO З ПЛОСКОЮ ОБЛАСТЮ ВЗАЄМОДІЇ

А.М. Горбань, Ю.Ф. Лонін, Г.Е. Саруханян

Осцилятор на магнітній самоізольованій передавальній лінії (MILO) – це пристрій на схрещених полях, розроблений для генерації надвисокочастотної потужності гігаватного рівня. Методом чисельного моделювання ми досліджували посилення електромагнітних коливань у MILO з плоскою областю взаємодії електронного потоку з полем уповільнюючої структури. Досліджувана система є відрізком плоскої передавальної лінії нескінченної ширини. На одному з електродів (аноді) поміщена уповільнююча структура у вигляді гребінки. Інший електрод (катод) є розподіленим джерелом електронів за рахунок ефекту вибухової емісії. Області лінії ліворуч і праворуч від уповільнюючої структури заповнені поглиначем для відвертання відображення електромагнітної хвилі. Після подання на лінію напруги в ній встановлюється режим магнітної самоізоляції електронного потоку. Система може збуджуватися зовнішнім струмом високої частоти. За результатами дослідження такої моделі отримані залежності коефіцієнта передачі від амплітуди збуджуваного сигналу і параметра розладу частоти сигналу відносно основної моди уповільнюючої структури. Визначені спектральні характеристики вихідних сигналів для різних режимів збудження.