EXTERNALLY EXCITED MILO

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The numerical simulation method was applied to investigate the possibility of controlling the electromagnetic radiation from MILO-type devices using the external excitation by the signal with given characteristics. For this purpose a throttling section in the slow-wave structure of the oscillator is excited. The preliminary results obtained confirm the possibility of constructing a MILO-based externally excited oscillator capable to operate within the wide frequency range and in the broadband radiation mode.

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INTRODUCTION

The Magnetically Insulated Transmission Line Oscillator (MILO) is a cylindrically symmetric coaxial device with an external electrode as an anode and an internal one as a cathode. On the side of the internal anode a slow-wave structure is installed. A voltage source is connected to one end of the line and its other end is shorted, as a rule, with an ohmic resistance. If the electric field intensity in the line exceeds the threshold value, then an explosive electron emission from the cathode surface into the vacuum gap occurs. Further, when the current reaches some minimum required value then in the line a magnetic self-insulation mode is established at which the electron motion is a drift along the longitudinal axis. Such an electron flow, interacting with the wave field of the slow-wave structure can transfer its energy to this field.

Usually, MILO as an oscillator operates in the narrowband radiation mode on π-oscillations. In this case a maximum output radiation power with acceptable efficiency values is provided. However, in some cases it is important to have a possibility of radiation frequency tuning or broadband radiation generation.

In Refs [1 - 3] the authors investigated the possibility of effective generation in such devices of broadband- and multifrequency microwave oscillations due to the use of combined slow-wave structures. The integrated structures under consideration present a combination of two regular combs with different design parameters permitting to generate in MILO the broadband and multifrequency microwave oscillations due to the use of a periodic nonuniformity of electron emission from the cathode surface. It has been shown that there is a possibility to control in the wide ranges the spatial structure of charge-density wave, as well as, to generate with a sufficient efficiency multifrequency microwave oscillations having a frequency band width approximately equal to the octave. As disadvantages of such approaches it should be named an impossibility to control the radiation shape and its spectral characteristics without need to change the device design parameters.

In the present work we investigated the possibilities of MILO use as an oscillator with external signal excitation. The purpose was to investigate possibilities of online controlling the radiation parameters.

1. NUMERICAL SIMULATION MODEL

The investigation method was the numerical simulation by the macroparticle method (PIC-method). Under the assumption of the system axial symmetry in cylindrical coordinates $r,\ \phi,\ z$ two electric field components E_r, E_z and one magnetic field components are taken into account. Electromagnetic fields are found from the solution of the Maxwell equation

$$\begin{aligned}
&\frac{1}{c}\frac{\partial E_z}{\partial t}+\frac{4\pi}{c}\left(j_z+\sigma E_z\right)=\frac{1}{r}\frac{\partial}{\partial r}\left(rB_\phi\right),\\
&\frac{1}{c}\frac{\partial E_r}{\partial t}+\frac{4\pi}{c}\left(j_r+\sigma E_r\right)=-\frac{\partial B_\phi}{\partial z},\\
&\frac{1}{c}\frac{\partial B_\phi}{\partial t}=\frac{\partial E_z}{\partial r}-\frac{\partial E_r}{\partial z}.
\end{aligned}\tag{1}$$

Here, as usually, E_r, E_z, B_φ are the field components, j_r and j_z are the densities of radial and axial electron currents. The medium conductivity σ has a nonzero constant value in the absorber-filled regions. The calculated region can have a boundary of arbitrary configuration. At the region boundaries given are the conditions of ideal conductivity for the tangential component of electric field $E_\tau = 0$. For the difference approximation of the set of equations (1) an explicit scheme is used. A uniform time grid with a step of grid Δt and a uniform spatial grid $\Delta r,\ \Delta z$ are introduced. The electric field is determined in the integer instants of time, and the magnetic field – in the half-integer instants of time. The values of current densities j_z and j_r are calculated by the area weighting method (CIC method) on the uniform rectangular grid. The force exerting an influence upon the particle is determined by the reversed weighting procedure for the grid field values.

Taking into account the axial system symmetry the phase space of the particle is described by coordinates r, z, p_r and p_z. To calculate the electron motion the relativistic equations of motion in the coordinate-pulse variables are solved.

$$\begin{aligned}
&\frac{d\vec{r}}{dt}=\vec{v},\\
&\frac{d\vec{p}}{dt}=e\cdot\left(\vec{E}+\frac{1}{c}\left[\vec{v},\vec{B}\right]\right),\\
&\vec{v}=\vec{p}/m\gamma,\qquad \gamma=\left(1+p^2/m^2c^2\right),
\end{aligned}\tag{2}$$

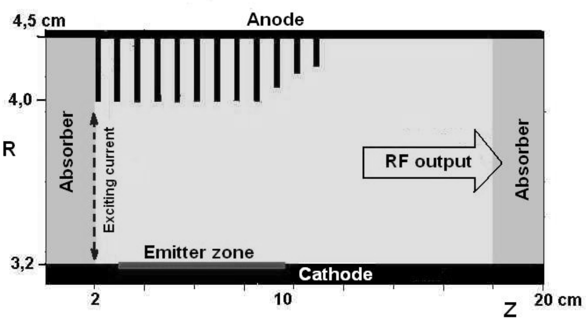
where $\vec{r}=r\cdot\vec{e}_r+z\cdot\vec{e}_z$ and $\vec{v}=v_r\cdot\vec{e}_r+v_z\cdot\vec{e}_z$.

The particle emission from the cathode occurs at every time step in the points where the intensity of transverse field component $\vec{E}$ exceeds the given value. The particle, reaching any region boundary, is absorbed.

2. PROBLEM DEFINITION AND RESULTS

On the potential possibility of using the circuit of a so-called tapered MILO for enhancement of microwave oscillations it has been pointed out for example in [4]. However, in the known articles on MILO with a tapered slow-wave structure a self-excited circuit of the device construction is used. Usually, in this circuit at the beginning of the slow-wave system there is a throttled section – choker, placed on the left of the emitter region. Thus the back wave reflection is provided, as well as, the organization of the internal high-frequency feedback. We have investigated an oscillator model namely of such type. The general layout of the oscillator is presented (without keeping to the scale) in Figure. Its structure and design parameters are close to that described in [5].

The calculations were performed for the following system parameters. The external cathode radius was 3.2 cm. The external slow-wave structure radius was 4.5 cm. The internal radii of structure combs were: 3.8 cm for the first two (chokers), 3.8…4.0 cm for the next seven and 4.1, 4.2, 4.3 cm for the last three combs. The comb period was 0.8 cm. The applied voltage was 400 kV, the total current in the system was from 50 to 100 kA. The operating frequency of the device in the self-oscillation mode was near 9 GHz.



MILO model schematic representation

In the classical circuit of the M-type amplifier with the distributed emission usually an axial terminal of the exciting signal (on the left wall side in Figure) is used. However, to realize such a mode of excitation in the MOILO model is very difficult. Therefore, we used the oscillation excitation in the throttle section of the slow-wave structure. In the model an extraneous radial current flowing along the absorber boundary on the left side (see Figure) was specified.

Preliminary results of numerical calculations have shown a possibility of generated oscillation synchronization by the exciting signal and effective multifrequency signal amplification within the band width equal to the octave. Two variants of the MILO excitation were under consideration. In the first case the “cold” system has been excited by the external signal, and then, after the stationary mode establishing, a high voltage was applied to the anode and electron emission was permitted. In the second variant the exciting signal and the anode voltage were turned on simultaneously. It has been noted that the character of the oscillation establishing process can be essentially dependent on the variant of amplifier excitation.

The preliminary results obtained in our opinion can be regarded as a confirmation for the possibility of a MILO-based externally excited oscillator capable to operate in the wide frequency range and in the broadband radiation mode.

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MILO С ВНЕШНИМ ВОЗБУЖДЕНИЕМ

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Методом численного моделирования исследована возможность управления электромагнитным излучением приборов типа MILO за счет внешнего возбуждения сигналом с заданными характеристиками. С этой целью используется возбуждение дроссельной секции замедляющей структуры генератора. Полученные предварительные результаты подтверждают возможность построения на основе MILO генератора с внешним возбуждением, способного работать в широком диапазоне частот и режиме широкополосного излучения.

MILO З ЗОВНІШНІМ ЗБУДЖЕННЯМ

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Методом чисельного моделювання досліджена можливість управління електромагнітним випромінюванням в приладах типу MILO за рахунок зовнішнього збудження сигналом з заданими характеристиками. Для цього використовується збудження дросельної секції уповільнюючої структури генератора. Отримані попередні результати підтверджують можливість побудови на основі MILO генератора з зовнішнім збудженням, спроможного працювати в широкому діапазоні частот та режимі широкосмугового випромінювання.