Non-Autonomous Regimes in Gyrotrons with Low-Q Resonators

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***Abstract*— Based on the description of wave propagation by a parabolic equation the time-domain theory of non-autonomous operation of gyrotrons with low-Q resonators has been developed. The influence of external signal is taking into account by modification of boundary condition at resonator output. Developed model can be effectively used for simulations of frequency-locking of gyrotron by external signal in soft and hard operation modes, frequency pooling with reflection from remote load, synchronization of several coupling gyrotrons.**

I. INTRODUCTION

Starting from [1], a time-domain self-consistent approach has been effectively used for theoretical analysis of free-running regimes in gyrotrons with low-Q resonators. In the frame of this approach, evolution of electromagnetic field is described based on a non-uniform parabolic equation supplemented by radiative boundary conditions. In this paper we have modified above conditions aiming to take into account an external signal [2]. Formulated universal approach allowed us to consider various non-autonomous regimes of gyrotrons, including frequency-locking in soft and hard operation modes, frequency pooling by reflection from remote load, synchronization of several coupling gyrotrons, etc. Up to now these regimes have been studied basically in the frame of model with fixed field longitudinal profile that corresponds to high-Q resonators [3,4]. For low-Q cavities used in modern powerful gyrotrons, the model with self-consistent field profile looks more preferable and realistic.

II. BASIC MODEL AND RESULTS OF SIMULATIONS

Electron-wave interaction in a gyrotron with low-Q resonators can be described by following system of equations:

$$
\begin{gathered}
i\frac{\partial^2 a}{\partial Z^2}+\frac{\partial a}{\partial \tau}+(i\delta(Z)+\sigma)a=\frac{G}{2\pi}\int_0^{2\pi} p\,d\theta_0, \\
\frac{\partial p}{\partial Z}+\frac{g^2}{4}\frac{\partial p}{\partial \tau}+ip(\Delta-1+|p|^2)=-a,
\end{gathered}
\qquad (1)
$$

where normalized variables and parameters coincide with given in [1]. Under assumption that external signal enters into the system via the output cross-section and taking into account the continuity of the transverse component of the electrical and magnetic field we get boundary condition in the form:

$$
a(L,\tau)+\frac{1}{\sqrt{\pi i}}\int_0^{\tau}\frac{1}{\sqrt{\tau-\tau'}}\frac{\partial a(L,\tau')}{\partial Z}d\tau'=2F(\tau)\,. \qquad (3)
$$

Simulations of frequency-locking regimes of gyrotrons show that external signal $F=f(\tau)\exp(i\Omega\tau)$ can strongly change the field profile in low-Q resonators, that significantly impacts on the process of interaction. In the soft operation mode near the center of the locking band the orbital efficiency is slightly decreases in comparison with the free running regime (see Fig.1, left column). In opposite In hard operation mode efficiency enhancement can be observed (Fig.1, right column, curves A). At the same time in this case multistability takes place, when alongside with frequency-locking there is the regime of regenerative amplification (curves B) with significantly low efficiency.

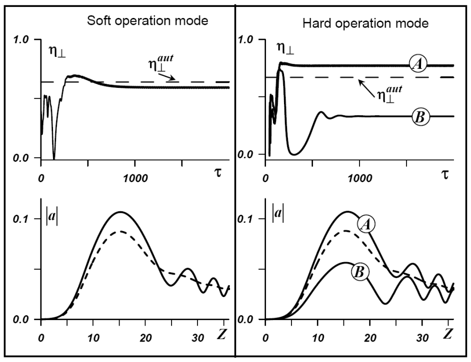

Fig. 1. Frequency locking regimes in a gyrotron with external signal.

Based on developed approach the interaction of two gyrotrons coupling via the common remote load can be analyzed. In fact, gyrotrons mutual influence is described by boundary conditions (2), where $F(\tau)=Ra_{1,2}(\tau-T)$ (T is time of delay, $R=|R|\exp(i\Phi)$ is the transmission coefficient). In Fig.2 the process of transition from beating regime in two coupled gyrotrons to regime of synchronization are presented that are realised due to proper matching of phase shift.

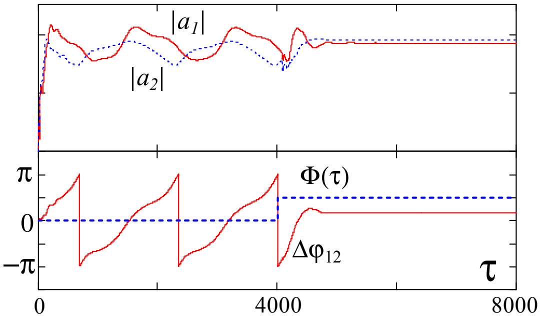

Fig.2 Synchronization of two coupling gyrotrons due to proper matching of phase shift.

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