Abstracts of MMA2009, May 27 - 30, 2009, Daugavpils, Latvia
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SOME ASPECTS OF NUMERICAL INVESTIGATION OF VOLUME FREE ELECTRON LASER NONLINEAR STAGE

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The main principle of vacuum electronic devices such as travelling wave tubes (TWT), backward wave tubes (BWT), free electron lasers (FEL) is based on radiation of bunches of charged particles moving over the surface or through the slow-wave system (resonator). Volume Free Electron Lasers (VFEL) are new electronic devices that are more effective on many parameters than other ones.

VFEL operates as follows. An electron beam with electron velocity u passes through a photonic crystal (resonator) of the length L. Under diffraction conditions two strong electromagnetic waves can be excited in the resonator. If simultaneously electrons are under synchronism condition, they emit electromagnetic radiation in directions depending on diffraction conditions. None of other electronic devices uses principles of dynamical diffraction of electromagnetic radiation in resonator. The system of nonlinear equations used for VFEL lasing dynamics modelling was obtained from Maxwell equations in the slowly-varying envelope approximation. Electron beam dynamics is described using method of averaging over initial phases of electrons. In the common case this system is the following:

$$\frac{\partial E}{\partial t} + a_1 \frac{\partial E}{\partial z} + b_{11} E + b_{12} E_\tau = I, \frac{\partial E_\tau}{\partial t} + a_2 \frac{\partial E_\tau}{\partial z} + b_{21} E + b_{22} E_\tau = 0,$$

$$I = \Phi \int_0^{2\pi} \frac{2\pi - p}{8\pi^2} \left(\exp(-i\Theta(t,z,p) + \exp(-i\Theta(t,z,-p)\right) dp,$$

$$\frac{d^2\Theta(t,z,p)}{dz^2} = \Psi \left(k - \frac{d\Theta(t,z,p)}{dz} \right)^3 \mathrm{Re}\left(E(t - z/u, z) \exp(i\Theta(t,z,p)\right),$$

$$E|_{z=0} = E_0, \quad E_\tau|_{z=L} = E_1, \quad E|_{t=0} = 0, \quad E_\tau|_{t=0} = 0, \quad \Theta(t,0,p) = p, \quad \frac{d\Theta(t,0,p)}{dz} = k - \omega/u,$$

where $t > 0$, $z \in [0, L]$, $p \in [-2\pi, 2\pi]$. Amplitudes of electromagnetic fields are denoted as $E(t,z)$, $E_\tau(t,z)$. Function $\Theta(t,z,p)$ describes phase of electron beam relative to electromagnetic wave. k is a projection of wave vector on axis z. ω is a field frequency. Equation describing phase of electron beam is more complicated than usually used in simulation of different electronic devices because we take into consideration as initial phase of an electron not only the moment of time t_0 of an electron entrance in resonator at $z = 0$ (as usual) but also transverse spatial coordinate in this moment.

In our previous investigations it is shown that VFEL is a dynamical system with multiple bifurcation points and chaotic dynamics. In this work a conservation law for integro-differential system presented here is obtained. VFEL efficiency analysis is proposed. Some steady-state regimes are investigated analytically and numerically.