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To cite this version:


HAL Id: jpa-00222570
https://hal.archives-ouvertes.fr/jpa-00222570
Submitted on 1 Jan 1983

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A TWO-DIMENSIONAL THEORY OF PULSE PROPAGATION IN THE FEL OSCILLATOR

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Abstract.

We present an axial symmetric analysis of the free electron laser (FEL) oscillator in the low gain regime. The electron beam consists of short pulses where the axial pulse shape is arbitrary and the transverse profile is Gaussian. The radius of the electron beam is taken to be much smaller than the radius of the radiation beam. We will consider the case where the resonator is designed to operate in the Gaussian $TEM_{00}$ mode. The portion of the stimulated radiation of interest is a superposition of the Gaussian mode, i.e., the vector potential of the radiation pulse can be written as

$$\vec{A}(r,z,t) = \sum (2n+1) \int dk \bar{A}_{00}(k,t) C_{00}(r,k,z) e^{i(k+\omega_0)(z-ct)/c},$$

where $C_{00}(r,k,z)$ is the normalized complex amplitude associated with the $TEM_{00}$ mode and $\omega_0$ is the resonant laser frequency. The equation governing $\bar{A}_{00}$ can be summarized in a rather compact form,

$$\bar{A}_{00}(k,t_N + \tau) = e^{i\int_0^\tau dt \int_\infty h(\Sigma_o)e^{-i\varphi(\Sigma_o,k,z)}} F(k,t',\tau)$$

where $F(k,t,\tau)$ is the self-consistent complex filling factor, $\bar{a}$ is a constant, $h(\Sigma_o)$ is the arbitrary axial electron profile, $\Sigma_o$ is the axial position of the electron relative to the center of the $N$th electron pulse at $t=t_N$, $t_N$ is the time the $N$th electron pulse entered the wiggler, and $F(\Sigma_o,k,t)$ is the phase of the electron.

The particle dynamics of the electrons enter the calculation through the phase $\varphi$. Taking a constant wiggler as an example, the phase equation can be written as

$$\frac{d^2 \varphi(\Sigma_o,k,t)}{dt^2} = c \int_\infty \bar{A}_{00}(k,t_N) g_{00} (0,k,z) \sin[\varphi(\Sigma_o,k,t) + \Phi(\Sigma_o,k,t)]$$

where $\bar{a}_{00} = \bar{a}_{00} e^{i\Phi_{00}}$ and $g_{00} = g_{00} e^{i0_{00}}$, $\varphi_z = ((k\omega_0/c + \omega_0)/c)$ is the axial electron velocity, $z = \int_0^t \nu_z dt$, $\nu_z$ is the axial position of the electron at time $t$, and $\omega_0$ is the resonant laser frequency.

Equations (2) and (3) form a complete set of nonlinear self-consistent equations which govern the dynamics of the radiation pulses in the oscillator.

*This work was supported by DARPA under Contract No. 3817.