2D SIMULATION OF FEL AMPLIFIERS

A. Dipace, A. Renieri, E. Sabia

ENEA, Dip. Sviluppo Tecnologie di Punta, CRE Frascati, P.O.Box 65, 00044 Frascati (Rome) Italy

Abstract

High efficiency FEL amplifiers can be properly designed by tapering the undulator. While the design of the magnetic field profile can be accomplished by 1D codes, higher dimensional effects (synchrotron-betatron resonance, transverse magnetic field variation) which decrease FEL efficiency must be taken into account. Preliminary results of a 2D numerical code for the design and simulation of FEL amplifiers are presented.

High power, high efficiency FELs have applications especially in spectral regions not covered by conventional lasers or microwave tubes (10 μm-1mm and VUV-XUV regions). Therefore they are well suited for heating tokamak plasmas by ECH (electron cyclotron heating), for high gradient accelerators and as drivers for inertial confinement fusion.

First results of a 1D code are reported in [1]. The simulation model was based on the solution of the coupled differential equations for the electrons and the laser field in the self consistent model of [2,3]. The code has also the capability to design the undulator field profile by defining a synchronous particle which is constrained to have no phase variation during its motion

$$\frac{d\psi_r}{dz} = K_u - \frac{K_s}{2\gamma_r^2} \cdot \left[1 + \left(\frac{b_u}{K_u}\right)^2 - \frac{2e_s b_u}{K_u K_s}\cos\psi_r + \left(\frac{e_s}{K_s}\right)^2\right] + \frac{d\Phi}{dz} = 0 \qquad (1)$$

where:

- K_s laser wavenumber
- K_u undulator wavenumber
- $e_s = eE_s/\sqrt{2}\, mc^2$ normalized laser field
- $b_u = eB_u/\sqrt{2}\, mc$ normalized undulator field
- Φ laser field phase
- $\psi = (K_u + K_s) - \omega_s t + \phi$ resonant electron phase

It is well known that a realistic undulator, as well as radiation field, has a not constant transverse profile [4], so that lack of resonance in all radial points leads to electron detrapping and reduction of efficiency. 1D codes clearly overestimate gain and efficiency.

We present here preliminary results of a 2D code which is an improvement of the already existing 1D code.

The main difference is that the laser field equation becomes a partial differential equation

$$\left(2iK_s \frac{\partial}{\partial z} + \nabla^2\right) e_s = - \frac{eZ_0}{2mc^2} \frac{b_u}{K_u} f_B J < \frac{e^{-i\psi}}{\gamma} > \qquad (2)$$

where:

- Z_0 vacuum impedance
- J current density

While finite size of the e-beam is taken into account, no transverse momentum spread is included. The e-beam is simulated at each of 10 radial grid points by 512 electrons, and the electric field is defined on tipically 60 radial grid points. The structure of the code is as follows:

a) Design of the magnetic field profile by the resonant particle approximation [1] at a fixed radial point, for example at a point of maximum electron density.

b) Simulation of the e-beam dynamics at the chosen radial points. Betatron motion is only included in an average way [4]

c) Solution of the 2D azimutally symmetric electric field equation which is reduced to a set of ordinary differential equations by a finite difference technique and then coupled to the equations of motion of an average particle defined at each radial point in the previous step.

As a test case, we choose the following parameters:

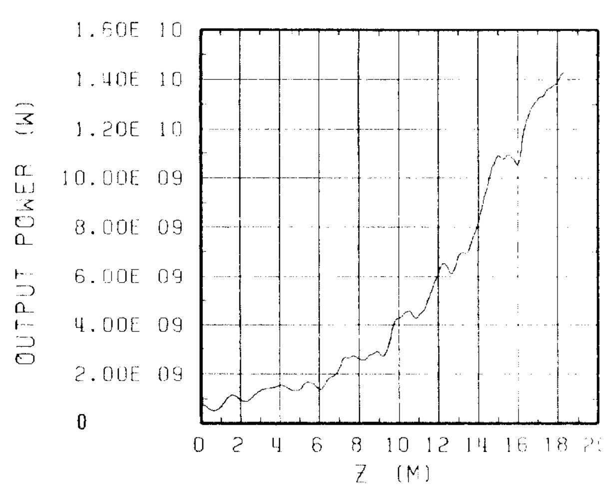

Fig. 1 - Laser power as a function of amplifier length

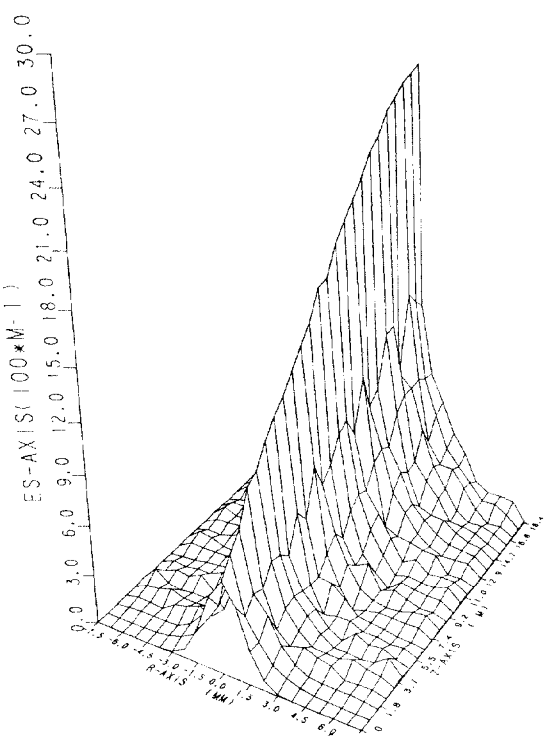

Fig.2 - Laser field as a function of amplifier length and radial position

γ = 100

λ_s = 10.6 μm

λ_u = 8 cm

I = 2 kA

P_o = 800 MW

The agreement with results of ref. [4] seems to be reasonable (see figs. 1, 2). A more realistic version of the code including a finite element solver of field equations and full betatron motion of e-beam is in progress.

References

[1] E. Sabia, A. Dipace, A. Renieri, "Tapered Undulators For FEL", in Proceedings of European Particle Accelerator Conference, Rome, Italy, June 7-11, 1988, pp. 1358-1360.

[2] N.M. Kroll, P.L. Morton, M.R. Rosenbluth, Free Electron Lasers With Variable Parameter Wigglers, IEEE J. Quant. Elec. vol. QE-17, pp. 1436-1468, August (1981).

[3] D. Prosnitz, A. Szoke, V.K. Neil, High-gain Free Electron Laser Amplifiers: Design Considerations and Simulation, Phys. Rew., vol. A24, 1436-1451, Sept. (1981).

[4] E.T. Scharlemann, "Wiggle Plane Focusing In Linear Wigglers", J. Appl. Phys., vol. 58, pp. 2154-2161, Sept. (1985).