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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

Simulations of the Stanford FIREFLY 1 kW free electron laser

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A modification of Stanford's Superconducting Accelerator Free Electron Laser (SCAFEL) has been proposed to increase its average optical power to about 1 kW. The FIREFLY Free Electron Laser (FEL) would be a factor of 100 increase in output power over the most powerful FEL in operation now and would cost about 1 million dollars. Simulations show the evolution of longitudinal modes over many passes and the development of the trapped-particle instability. Power versus desynchronism is studied for different electron energies.

The simulations use the pendulum equation to describe the electron motion in the undulator and the wave equation to describe the optical field evolution. Dimensionless parameters are used for quantities such as j, the dimensionless electron beam current density, and $|a|$, the dimensionless optical field strength [1]. The electron pulse length $\sigma_z = l_e/N\lambda$ and the desynchronism $d = \Delta L/N\lambda$ are normalized to the slippage distance. Desynchronism is the adjustment of the optical cavity in order to overcome the effects of lethargy [1].

Simulations of the 1 kW FIREFLY FEL use an electron beam energy of 45 MeV to produce light at a wavelength of 7.6 μm. Also simulated were beam energies of 25 MeV and 10 MeV with wavelengths of 24.1 μm and 142 μm, respectively. The peak current was 40 A with a micropulse length $l_e/c = 2.1$ ps, and emittance of 10π mm-mrad (FWHM). The undulator had $N = 25$ periods, wavelength $\lambda_0 = 6$ cm and an rms undulator parameter $K = 1.1$. The cavity length was 12.68 m with a resonator quality factor $Q = 100$ [2].

Fig. 1 shows the results of a longitudinal multimode simulation using an electron beam energy of 45 MeV. The upper plots show the evolution of the optical field amplitude $|a(z, n)|$ and phase $\phi(z, n)$, where z is the longitudinal position and n is the pass number. Also plotted is the

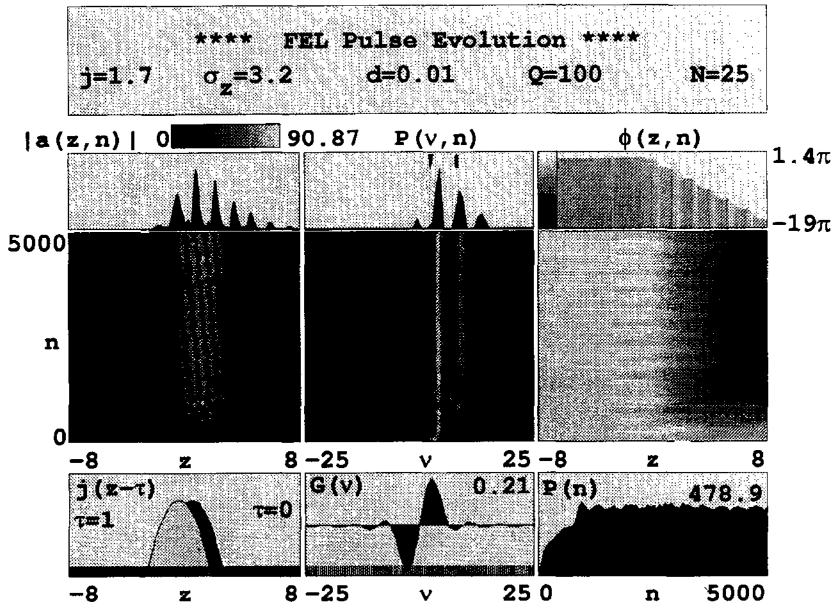

Fig. 1. Longitudinal multimode simulation of FIREFLY.

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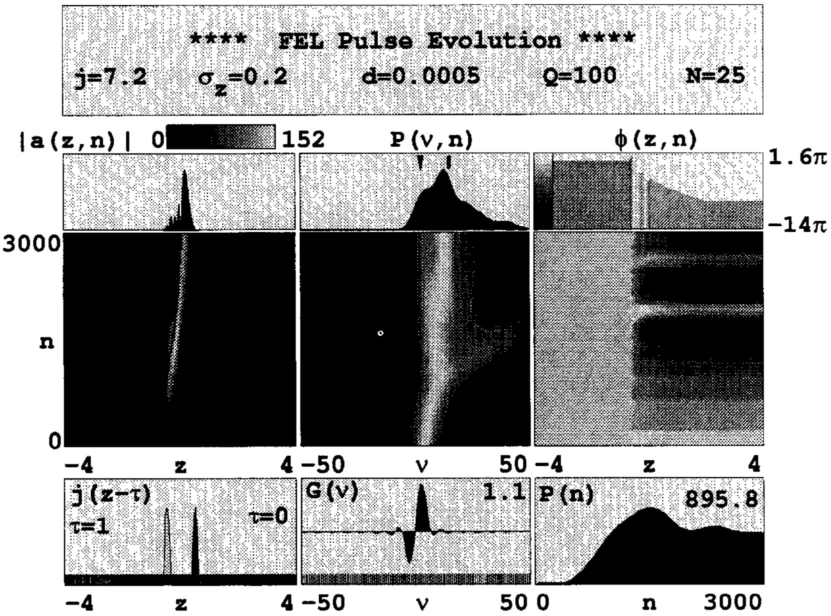

Fig. 2. Longitudinal multimode simulation of FIREFLY.

dimensionless power spectrum $P(\upsilon, n)$, where υ is the phase velocity [1]. The three plots across the bottom of the figure are the electron pulse $j(z)$ shown at the beginning ($\tau = 0$) and end ($\tau = 1$) of the undulator, the weak-field single-mode gain spectrum $G(\upsilon)$, and the dimensionless power evolution $P(n)$. At the wavelength 7.6 μm, the electron pulse length is three times longer than the slippage distance. The trapped-particle instability results in a strong sideband in the power spectrum at steady-state. Note the limit-cycle behavior in the plot of $P(n)$ at lower-right in the figure. The peak power was at a desynchronism of $d = 0.0005$, where the average output power was calculated to be approximately 0.9 kW. Simulations using a 25 MeV electron beam resulted in a peak power at desynchronism $d = 0.003$ where the average output power was 140 W. The goal of 1 kW only applies to the FEL with an electron beam energy of 45 MeV.

Fig. 2 is the result of a simulation using an electron beam with energy 10 MeV and $d = 0.0005$. Because of the long wavelength in this case, the electron pulse length is much smaller than the slippage distance. Lower electron beam energy and pulse slippage effects reduce the output power to 20 W. The light pulse has reached steady-state and is shorter than the slippage distance resulting in a broad optical power spectrum $P(\upsilon)$.

Acknowledgements

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