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Simulations of a klystron undulator for the SLAC X-ray FEL

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Abstract

The Stanford Linear Accelerator Center (SLAC) linac has been proposed as an electron beam source for a high power X-ray FEL. A klystron design with an enclosed dispersive section allows a shorter undulator to achieve bunching in a weak radiation field. Single-mode phase-space simulations are used to investigate the effectiveness of electron bunching and the onset of saturation. A longitudinal multimode simulation shows the resulting coherence development.

Holography and high resolution imaging of DNA base pairs are potential applications for an X-ray laser [1]. The "water window" , where water becomes transparent, can be explored by soft X-rays in the 20–40 Å wavelength range. The Free Electron Laser (FEL) appears to be a viable source for an X-ray laser due to its ability to create coherent radiation from noise through Self-Amplified Spontaneous Emission (SASE). The X-rays are created by a single pass of electrons through an undulator which eliminates the need for resonator mirrors. A proposed design combines the SLAC linac with an undulator to produce X-rays. Wavelengths are proposed down to the hard X-ray region of a few Angströms [2].

A large portion of the FEL cost is in the production of the undulator; reducing the length of the undulator reduces the FEL cost. A method of reducing the length of the undulator introduces a dispersive section in the undulator making an FEL klystron. A penalty resulting from the klystron design is the onset of saturation at weaker fields than without the klystron.

The FEL klystron can be described by phase-space simulations using classical FEL theory with dimensionless parameters [3]. The phase of the electron with respect to the optical field is $\zeta(t)=(k+k_0)z(t)-\omega t$, where the optical frequency is $\omega = ck$, the undulator wavenumber is $k_0 = 2\pi/\lambda_0$, and the optical wave number $k = 2\pi/\lambda$. The electron phase velocity is $\nu(\tau) = \mathrm{d}\zeta/\mathrm{d}\tau$, where the dimensionless time $\tau = ct/L$, c is the speed of light, and L is the undulator length. The dispersive section shifts the electrons far off-resonance so that the electrons do not interact with the optical field, and there is no change in the phase velocity, ν. The electron phase change, $\Delta\zeta$ is proportional to the velocity modulation in the first undulator section, so that the net effect of the dispersive section is [3]

$$\Delta\zeta = \nu D, \qquad \Delta\nu = 0,$$

where D is the dimensionless dispersive strength of the klystron.

Phase-space simulations are used to study a soft X-ray FEL at 40 Å. The initial radiation field is $a_0 = 0$; the optical field grows from noise as a result of spontaneous emission from 200 000 electrons with random initial phase. An FEL design at $\lambda = 40$ Å has an undulator length of $L = 17$ m, electron beam energy of 5 GeV and a peak current of 5000 A which corresponds to a dimensionless current density [3] of $j = 932$. This FEL was examined without a klystron and then with a klystron. The case without the klystron is shown in Fig. 1. The electron bunch is at a phase where it gives energy to the optical field at the end of the undulator. The dimensionless power P corresponds to a peak power of 15 GW. In Fig. 2, the use of the klystron FEL with the same parameters and D = 0.5 shows that electrons have bunched in the lower half of the

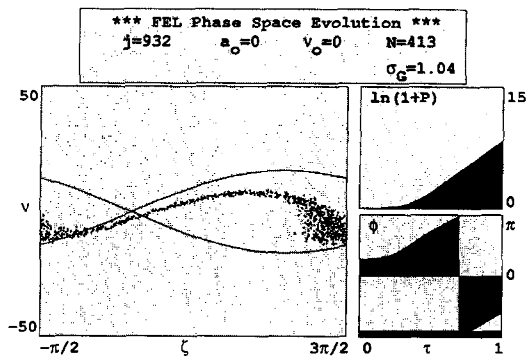

Fig. 1. 40 Å laser, without klystron, single-mode phase-space plot.

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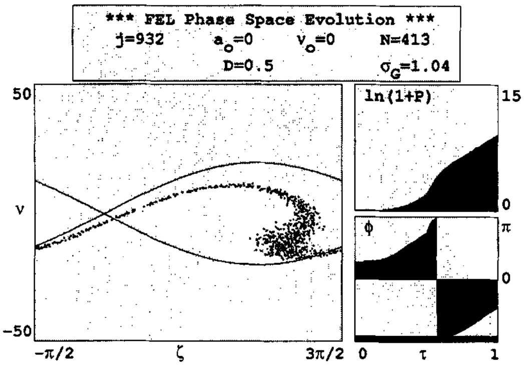

Fig. 2. 40 Å laser, with klystron, single-mode phase-space plot.

separatrix and at the optimal phase relation, $\zeta + \phi = \pi$, for maximum gain. The peak power calculated for the klystron FEL is 51 GW. Saturation occurs earlier than without the klystron reducing the length of the undulator.

Longitudinal multimode simulations with the same parameters study the coherence development of the optical field. Simulations without a klystron and before saturation resulted in an X-ray linewidth of $\Delta\lambda/\lambda = 0.1\%$. Using the klystron and after saturation, simulations resulted in a linewidth of $\Delta\lambda/\lambda = 0.2\%$.

Hard X-ray FELs [2] at 1.5 and 4.5 Å have also been proposed. Single-mode phase-space simulations without a klystron indicate the production of an X-ray beam with undulator lengths of 46 and 45 m, respectively. Simulations show that the use of a klystron with both FELs did not reduce the undulator saturation length. The simulations were run at resonance with various values of dimensionless drift time D. The peak gain may be off-resonance and further research is being performed to determine optimum conditions.

Acknowledgements

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References

[1] Proc. Workshop on Scientific Applications of Short Wavelength Coherent Light Source, SLAC-414, SLAC/SSRL-0007, CONF-9210278 (1993).
[2] LCLS Technical Group Meeting Notes (July 27, 1994).
[3] W.B. Colson and C. Pellegrini, Laser Handbook, Vol. 6 (1990) chap. 5.