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OPTICAL INSTABILITIES AND COHERENCE IN THE FREE-ELECTRON-LASER\textsuperscript{A}

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Abstract.

We report new theoretical and numerical results in the following areas of FEL physics:

A) Long pulse propagation. Numerical propagation of optical and electron pulses long compared to the slippage has been carried out. The optical pulses break up under condition of moderate saturation into a series of spikes with period and width comparable to the slippage. At higher power one finds further break-up associated with the appearance of spectral features below resonance by approximately the frequency of synchrotron oscillation. Suppression of the break-up has been achieved by spectral filtering of the FEL output at the low-frequency end of the spectrum.

B) Periodic solutions with constant current. By imposing periodic boundary conditions in slow time in an FEL with constant current, we have been able to study the break-up phenomenon in a simpler context than pulse propagation, as well as to calculate the likely behavior of actual constant-current FEL's at moderate power. We find that single-frequency operation is generally stable at low power. At moderate power one instead find that several frequencies mode-lock together to produce a simple periodic waveform. Periods close to the slippage are favored. Under extremely saturating conditions the waveform becomes complex and period doubling is observed.

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C) Injection Locking. We have carried out numerical calculations for a pulsed FEL operating in a ring resonator with an external cw signal injected into the cavity. Detuning between the cw frequency and the cavity modes is an important factor, although zero detuning is not necessarily optimal. Suppression of break-up in short pulses has been obtained with injected power about $10^{-4}$ of the pulse power in the cavity. Only partial suppression of break-up has so far been achieved with pulses long compared to the slippage.

D) Analytical solution for small signal pulse propagation. This exact solution for pulse propagation in the uniform wiggler involves a set of three generalized hypergeometric functions.

E) Shot Noise. A theory incorporating the effects of shot noise on FEL operation is under development. The shot noise is due to the random injection times and transverse positions of individual electrons, and is responsible for starting the lasing process. A three-dimensional theory has been formulated by transforming the Maxwell equation to the frequency domain, where the paraxial approximation can be made. In the case of small filling factor, a one-dimensional theory can be obtained by projecting onto the fundamental Gaussian mode of the resonator at each frequency. The equations can then readily be transformed back to the time domain. After the neglect of certain terms, the small-signal equations can be solved in terms of the generalized hypergeometric functions. Contribution to the field after one pass are found proportional to all powers of the number of electrons. This indicates that coherence is beginning to develop. These contributions unfortunately include infinite self-energy terms.