Coherent X-Ray emission of a non-degenerated cold electron beam

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Free-Electron Laser (FEL) is a device that can generate high-power coherent radiation. In such scheme, an undulator or wiggler is used to induce a perpendicular wave motion in a relativistic electron beam, in a way that the kinetic beam energy is released into electromagnetic field energy of stimulated radiation, and it obeys the approximate resonance condition, $\lambda_s = \lambda_w/2\gamma^2$, where λ_s is the wavelength of the scattered radiation, λ_w is the the magnetostatic wiggler period, and γ is the normalized beam energy. Alternatively, a counterpropagating laser pulse can work as an electromagnetic wiggler as well. In such a case, the resonance condition changes to $\lambda_s = \lambda_w/4\gamma^2$, where now λ_w is the laser pulse wavelengh. As a laser wavelengh can be much smaller than the usual magnetostatic wiggler period, much smaller radiation output, as x-ray or even gamma-ray, can be obtained.

In our work, by using a quantum fluid model, the linear dispersion relation for FEL pumped by a short wavelength laser wiggler is deduced. Subsequently, a new quantum corrected resonance condition is obtained. It is shown that, in the limit of low energy electron beam and low frequency pump, the quantum recoil effect can be neglected, recovering the classical FEL resonance condition, $k_s = 4k_w\gamma^2$. On the other hand, for short wavelength and high energy electron beam, the quantum recoil effect, which comes from the Bohm potential that appears in the momentum fluid equation for the electron beam, becomes strong and the resonance condition has to be modified. We also show that this quantum potential is important to classify the FEL regime, as it introduces a quantum dispersion in the plasma wave.

At the end, a set of nonlinear coupled differential partial equations, which describes the quantum FEL dynamics, is obtained, being one equation for the plasma oscillation, one for the pump and one for the scattered radiation amplitude. At the end, this set of equations is solved numerically and results are presented.