Cross-Beam Energy Transfer: transient behavior and effect of spatial inhomogeneity

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Inertial confinement fusion assisted by laser beams required a large number of laser pulses that ineluctably cross each other through flowing plasmas. In such configuration, cross-beam energy transfer (CBET) may occur, resulting in an energy exchange from one beam to another, hence threatening the initially symmetric heating of the capsule (in the direct-drive approach) and the hohlraum's wall (in the indirect-drive scheme). This phenomenon results from a three-wave coupling between the two electro-magnetic waves and a driven-acoustic wave. More precisely, the coupling of two laser beams produces an interference pattern in the plasma. The latter produces an imprint in the plasma density due to the laser ponderomotive force that pushes the electrons off the high intensity regions. To conserve the local charge, the ions have to follow the electrons hence producing the ion density modulation. In the plasma reference frame, the interference pattern moves at a velocity comparable with the flow. When this flow reaches velocities near the acoustic speed, the interference pattern imprint is resonant with the ion wave: CBET is triggered. As the amount of energy transfer depends on the ion acoustic wave amplitude and its phase shift with the laser interference pattern, an accurate calculation of both quantities is mandatory to obtain a robust energy transfer estimate.

Yet, most of CBET models developed so far assume that the ion wave relaxes to a driven wave, solution of the ion acoustic wave (in fluid or linear kinetic regime) in the plane wave approximation. This approximation greatly simplifies the CBET modeling, at the cost of a strong condition upon the laser intensity profiles. This latter must have weak inhomogeneities, a requirement hardly compatible with the small speckle size present in any laser pulse used in ICF.

By means of Particle-In-Cell (PIC) simulations, we performed a quantitative study of CBET, in the reduced configuration of two speckles interacting in homogeneous plasmas. In particular, we examined the transient behavior, and the time asymptotic energy transfer for different plasma compositions (single and multi species), in the weakly (Z>>1) and strongly (Z=2) Landau damped regimes. We show that the usual plane wave approximation holds true in the strong damping regime. Within this limit, a remarkable agreement is found between a linear kinetic model [1] and the kinetic simulations, over a large range of parameters. The effect of time varying intensity on the transient behavior is also investigated, and all the simulation results are explained with a full analytical solution of the beam energy transfer including the ion acoustic wave response.

References

[1] D. Marion, A. Debayle et al. Phys. Plasmas **23**, 052705 (2016)