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Optimal beam loading to 20 GeV through wakefield slope rotation using an evolving electron driver

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The goals of plasma-based acceleration (PBA) are high gradient, high efficient acceleration and high quality beam generation. Various synchronized injection schemes utilizing PBA have been proposed and investigated to generate beams capable of driving a compact x-ray free electron laser (XFEL). In each of these ideas, the main challenge is how to maximize the energy transfer to the injected bunch and minimize its projected energy spread. Using particle-in-cell (PIC) simulations, we demonstrate a new approach to optimal beam loading that relies on wakefield slope rotation triggered by an evolving electron driver. Injection is triggered by self-focusing an electron driver in the nonlinear blowout regime. As the driver loses energy following injection, its evolution alters the shape of the wake and accelerating field loaded by the injected bunch. For high current injected bunches, the slope of the accelerating field can fully rotate from negative to positive over the course of pump depletion so that the average acceleration field has near-zero slope. We also examine beam loading effects at different stages of the acceleration and explain the results using nonlinear theory. PIC simulations using OSIRIS indicate that injection and optimal beam loading can be achieved until the drive beam fully pump depletes. Based on simulation results, the injected beams can be efficiently accelerated with energies up to 20 GeV, projected energy spreads of 0.5%, and peak normalized brightness of $10^{20}\mathrm{A/m^2/rad^2}$.

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