Control of the self-modulation and long-bunch hosing instabilities through plasma frequency detuning

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The success of plasma-based acceleration schemes often relies on the ability to manipulate complex beam-plasma interactions. In one of these concepts – the single-stage plasma wakefield accelerator driven by a long, highly energetic particle bunch [1] – the key interactions are two modes (symmetric and asymmetric) of the transverse two-stream instability called self-modulation and hosing, respectively. The self-modulation instability (SMI) [2, 3] can be harnessed to produce high-amplitude wakefields from a very long driver (compared to the plasma skin depth k_p^{-1}), but the fields tend to decay quickly after the instability has saturated. The hosing instability (HI) [4] is undesirable due to its potential disruption of the bunch, and we therefore need ways to mitigate it [5, 6].

During their growth phase, both of these instabilities can be understood as driven harmonic oscillators. In this work we show that it is possible to control their growth rates if the plasma oscillation responding to either the beam radius (SMI) or centroid (HI) perturbation is detuned early enough. The detuning can be achieved by varying the background plasma density, as we demonstrate with particle-in-cell simulations. Using plasma density steps [7], we apply this idea to mitigating the HI and optimizing the amplitude decay of the SMI after saturation. This novel approach to controlling the growth of beam-plasma instabilities could have important implications for plasma-based accelerators.

References

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