Update on beam-plasma interaction research at PPPL

Igor D. Kaganovich*[1], Anton D. Stepanov[1], Erik P. Gilson[1], Kentaro Hara[1], Edward A. Startsev[1], Johan Carlsson[1]

[1] Princeton Plasma Physics Laboratory, Princeton University, New Jersey 08543, USA
*Corresponding author: ikaganov@pppl.gov

We have performed experimental and theoretical studies of beam neutralization by background plasma. Near-complete space-charge neutralization is required for the transverse compression of high-perveance ion beams for ion-beam-driven warm dense matter experiments and heavy ion fusion. One approach to beam neutralization is to fill the region immediately before the target with sufficiently dense plasma. The plasma provides a charge-neutralizing medium for beam propagation and makes it possible to achieve a high degree of compression beyond the space-charge limit.

Experiments were performed on the Princeton Advanced Test Stand to investigate the degree of charge neutralization for different methods of neutralization [1]. A high-perveance 38 keV Ar^+ beam was propagated in a plasma produced in a Ferroelectric Plasma Source (FEPS) discharge. By comparing the measured beam radius with the envelope model for space-charge expansion, it was determined that a charge neutralization fraction of 98% is attainable with sufficiently dense FEPS plasma and 83% with neutralization by plasma produced from a background gas. The transverse electrostatic potential of the ion beam is reduced from 15 V before neutralization to 0.3 V, implying that the energy of the neutralizing electrons is below 0.3 eV. Measurements of the time-evolution of beam radius show that near-complete charge neutralization is established 5 μs after the driving pulse is applied to the FEPS and can last for 35 μs.

Numerical simulations of effects of the two-stream instability on the propagation of ion beam in background plasma were performed. Development of the two-stream instability between the beam ions and plasma electrons may lead to beam breakup, a slowing down of the beam particles, acceleration of the plasma particles, and transfer of the beam energy to the plasma particles and wave excitations. Making use of the particle-in-cell code LSP, a one-dimensional Vlasov code, the effects of the two-stream instability on beam propagation over a wide range of beam and plasma parameters were simulated. Because of the two-stream instability, the plasma electrons can be accelerated to velocities twice as high as the beam velocity. The resulting return current of the accelerated electrons may completely change the structure of the beam self-magnetic field, thereby changing its effect on the beam from focusing to defocusing. Therefore, previous theories of beam self-electromagnetic fields that did not take into account the effects of the two-stream instability must be significantly modified [2,3]. As a result of the two-stream instability, an ion beam pulse can generate an electron beam propagating ahead of the ion beam pulse and perturb plasma ahead of the ion beam pulse [4]. One simple method to avoid two-stream instability is to use tenuous plasma that can well neutralize ion beam space charge provided enough electrons can be supplied to the beam pulse from the plasma volume or chamber sides [5]. The associated change in plasma parameters affects the two-stream instability and causes its decay. This effect can be observed on the National Drift Compression Experiment-II (NDCX-II) facility by measuring the spot size of the extracted beamlet propagating through several meters of plasma.

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