Amplification Due To The Two-Stream Instability Of Self-Electric And Magnetic Fields Of An Ion And Electron Beam Propagating In Background Plasma

IEPC-2017-525

Presented at the 35th International Electric Propulsion Conference
Georgia Institute of Technology • Atlanta, Georgia • USA
October 8 – 12, 2017

Igor D. Kaganovich, Erinc K. Tokluoglu, Johan Carlsson, Andrew T. Powis, Y. Raitses
Princeton Plasma Physics Laboratory, Princeton, New Jersey, 08543, USA

A. Smolyakov
University of Saskatchewan, Saskatoon, SK, S7N 5E2, Canada

Abstract: Propagation of charged particle beams in background plasma as a method of space charge neutralization has been shown to achieve high degrees of charge and current neutralization and therefore can enable nearly ballistic propagation and focusing of charged particle beams. Correspondingly, use of plasmas for propagation of charged particle beams has important applications for transport and focusing of intense particle beams in electric propulsion, inertial fusion and high energy density laboratory plasma physics. However, the streaming of beam ions through a background plasma can lead to development of the two-stream instability between the beam ions and the plasma electrons. The electric and magnetic self-fields enhanced by the two-stream instability can lead to defocusing of the ion beam and fast scattering of an electron beam. Using particle-in-cell (PIC) simulations, we study the scaling of the instability-driven self-electromagnetic fields and consequent defocusing forces with the background plasma density and beam ion mass. We identify plasma parameters where the defocusing forces can be reduced.

Nomenclature

E	=	Electric field (electric field vector if boldfaced)
B	=	Magnetic field (magnetic field vector if boldfaced)
M	=	Ion mass
n	=	Plasma density
e	=	Charge of electron

I. Introduction

Intense electron or ion beams propagating in plasmas are subject to the two-stream instability, which leads to 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 codes EDIPIC and LSP, we have simulated two-stream instability interactions over a wide range of beam and plasma parameters. Typically, the instability saturates due to nonlinear wave-trapping effects of either the beam particles or plasma electrons. The saturation due to nonlinear wave-trapping effects limits the “mixing” in phase-space and may produce coherent structures in the electron velocity distribution function. For the case of an electron beam, simulations show that the two-stream instability is intermittent, with quiet and active periods. During the active periods of the two-stream instability, the beam interacts with the plasma most intensively at locations where the global frequency of the instability matches the local electron plasma frequency.

Further details of the studies of effects of two-stream instability on the ion beam are described in Refs.[1,2].

For electron beam interaction with in a finite size plasma between two conducting walls, boundary conditions are important and change the behavior of two stream instability drastically. The growth rate is much smaller than for infinite plasma or "textbook" example of plasma with periodic boundary conditions. Further details of the studies of effects of two-stream instability on the electron beam are described in Refs.[3-5].

If ion beam is injected into a plasma it can excite ion acoustic waves. In bounded plasma the instability develops due to coupling of negative and positive energy modes mediated by reflections from the boundary, and was studied analytically and the results are compared with direct, initial value numerical simulations in Ref.[6].

In presence of magnetic field, ion beam interacts with the low-hybrid waves[7]. In this work we investigate how unstable eigen functions described in Ref. 7 are modified in nonlinear regime. For this, the nonlinear simulations were performed with BOUT++ plasma fluid simulation framework[8].

Acknowledgments

This work was supported by the Air Force Office of Scientific Research. This research used resources of the National Energy Research Scientific Computing Center, a DOE Office of Science User Facility supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

References

[1] Erinc Tokluoglu and Igor Kaganovich, "Defocusing of an ion beam propagating in background plasma due to two-stream instability", *Physics of Plasmas* Vol. 22, 2015, 040701.

[2] Erinc K. Tokluoglu, Igor D. Kaganovich, Johan A. Carlsson, Edward A. Startsev, Kentaro Hara, submitted to Physics of Plasmas (2017).

[3] D. Sydorenko, Igor D. Kaganovich, and Peter LG Vetzek, "Excitation of a global plasma mode by an intense electron beam in a dc discharge", accepted to Phys. Plasmas (2017).

[4] D. Sydorenko, Igor D. Kaganovich, and Peter LG Vetzek, "Effect of collisions on the two-stream instability in a finite length plasma" arXiv:1608.01080 (2016), *Physics of Plasmas* Vol.23, 2016, 122119.

[5] I. D. Kaganovich, D. Sydorenko, "Band Structure of the Growth Rate of the Two-Stream Instability of an Electron Beam Propagating in a Bounded Plasma", arXiv:1503.04695; *Physics of Plasmas*, Vol.23, 2016, 122111.

[6] O. Koshkarov, A. I. Smolyakov, I. D. Kaganovich, and V. I. Ilgisonis, ""Ion sound instability driven by ion beam", *Physics of Plasmas*, Vol.22, 2015, 052113.

[7] A. Kapulkin and E. Behar," Ion beam instability in Hall thrusters", *IEEE Transactions on Plasma Science*, Vol. 43, No 1, 2015, pp.64.

[8] B. D. Dudson, M. V. Umansky, X. Q. Xu, P. B. Snyder, and H. R. Wilson, "BOUT++: A framework for parallel plasma fluid simulations", *Computer Physics Communications*, Vol.180, No 9, 2009, pp.1467.