# Ion-Beam Plasma Neutralization Interaction Images

Igor D. Kaganovich, Edward Startsev, S. Klasky, and Ronald C. Davidson

***Abstract*—Neutralization of the ion beam charge and current is an important scientific issue for many practical applications. The process of ion beam charge and current neutralization is complex because the excitation of nonlinear plasma waves may occur. Computer simulation images of plasma neutralization of the ion beam pulse are presented.**

***Index Terms*—Particle beam transport, particle beam focusing, plasma application, plasma waves.**

THE PROPAGATION of a high-current finite-length ion beam in a background plasma is of considerable interest for many applications, including heavy ion fusion, plasma lenses, cosmic ray propagation, etc. Many applications rely on the neutralized transport of positively charged particles. Heavy ion fusion considers the ballistic focusing of stripped heavy ions. High-energy physics applications involve the transport of intense positron beams. In these applications, the plasma is preformed by an external source and is independent of the beam characteristics.

A suite of simulation codes has been developed to calculate the degree of charge and current neutralization of an ion beam pulse by the background plasma. The suite consists of two different codes: a fully electromagnetic, relativistic, particle-in-cell (PIC) code, and a nonrelativistic, Darwin fluid model for long beam pulses [1], [2].

In this paper, we present images generated from this suite of codes; the visualization has been performed using the AVS/Express software [3]. Fig. 1 shows the steady-state propagation of the beam through a cold background plasma with uniform density $n_p$. The electrons, attracted by the beam ions, move to neutralize the beam charge on a time scale $1/\omega_p$, where $\omega_p = (4\pi e^2 n_p/m)^{1/2}$ is the electron plasma frequency. Therefore, if the beam half length ($l_b$) is small compared with the neutralization length $V_b/\omega_p$ ($V_b$ is the beam velocity), the electrons do not neutralize the beam charge [Fig. 1(a)]. For long beams, however, the charge neutralization is nearly complete, but large-amplitude plasma waves are excited by the beam front [Fig. 1(d) and (e)]. Fig. 1(a)–(d) were generated using a fluid model, whereas the data in Fig. 1(e) were obtained from a PIC code. The trajectory of electron fluid elements intersect at one point in Fig. 1(e), thus producing a singularity in the fluid solution. Therefore, at sufficiently large beam densities plasma waves cannot be described by a one-fluid approximation.

Nonlinear plasma waves are rather complex phenomena, and the images in Fig. 1(d) and (e) resemble one of the primitive biological organisms called "trilobites" [4]. The similar study has been done by Mission Research Corporation [5].

In conclusion, computer simulation images of beam-plasma interactions have been presented. These images provide important information on the complex physical processes occurring during beam propagation.

Manuscript received June 27, 2001; revised September 17, 2001. This work was supported by the U.S. Department of Energy.

The authors are with the Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543 USA (e-mail: ikaganov@pppl.gov).

Publisher Item Identifier S 0093-3813(02)03068-0.

## REFERENCES

[1] I. D. Kaganovich, G. Shvets, E. Startsev, and R. C. Davidson, "Nonlinear charge and current neutralization of an ion beam pulse in a preformed plasma," *Phys. Plasmas*, vol. 8, pp. 4180–4192, 2001.
[2] ——, Nonlinear charge and current neutralization of an intense ion beam pulse propagating through a background plasma. presented at *Proc. 2001 Particle Accelerator Conf.*. [Online]. Available: http://pacweb-server.fnal.gov/papers/Tuesday/PM_Poster/TPPH317.pdf.
[3] AVS/Express [Online]. Available: http://www.avs.com/software/soft_t/avsxps.html.
[4] Trilobites. [Online]. Available: http://www.trilobites.com.
[5] Mission Research Corporation. [Online]. Available: http://www.mr-cabq.com/Services/Particle/Codes/codes.htm.

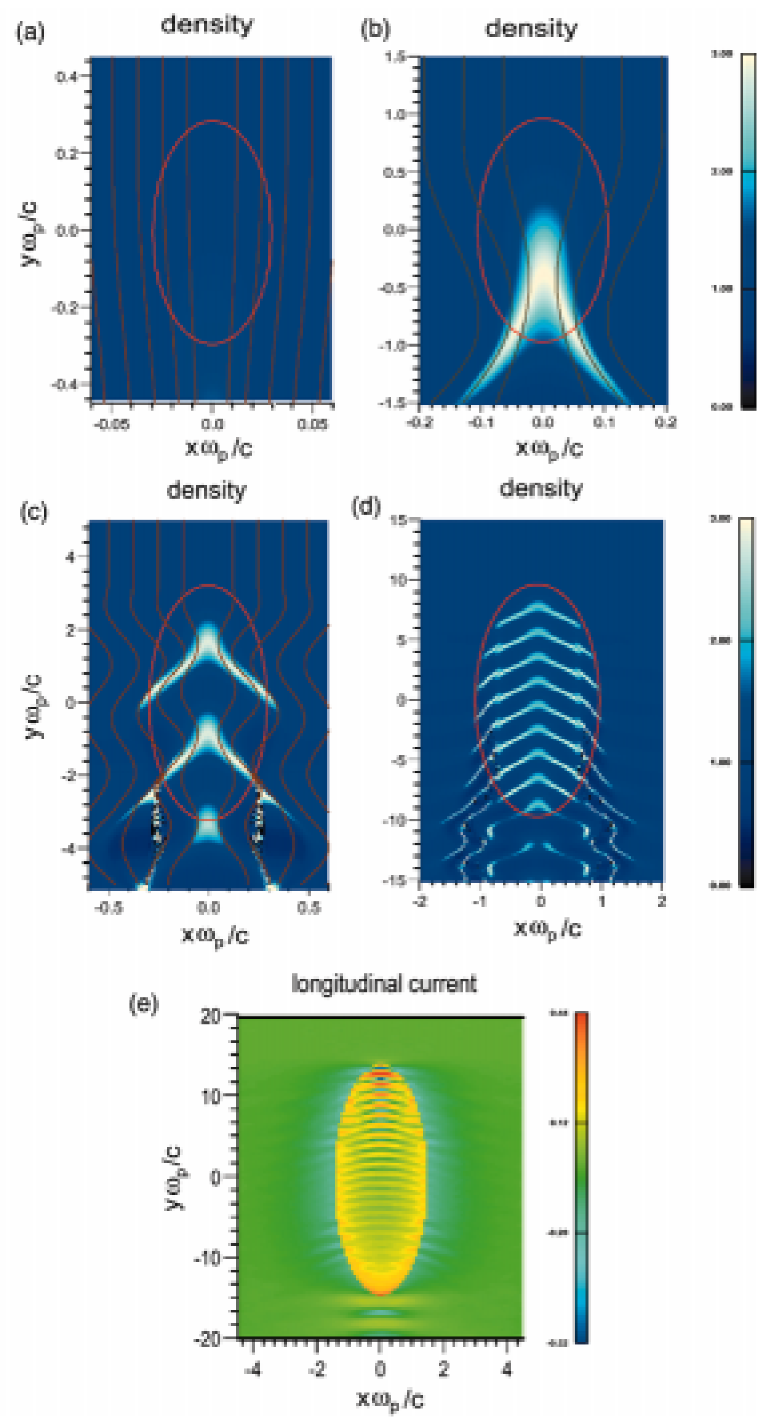


Fig. 1. Neutralization of an ion beam pulse during steady-state propagation of the beam pulse through a cold, uniform, background plasma. The beam propagates along the $y$ axis. The beam density has a flat-top profile, and the red lines show the beam pulse edges. Shown in the figure are contour plots of the normalized electron density $(n_e/n_p)$ and the normalized longitudinal current $(j_z/en_pc)$ in $(x\omega_p/c,\, y\omega_p/c)$ space. The brown contours show the electron trajectories in the beam frame. The beam velocity is $V_b = 0.5c$, and the beam density is $n_b = 0.5n_p$ for Fig. 1(a)–(d), and $n_b = n_p$ for Fig. 1(e). The beam dimensions correspond to (a) $r_b = 0.03c/\omega_p$, $l_b = 0.3c/\omega_p$; (b) $r_b = 0.1c/\omega_p$, $l_b = 1.0c/\omega_p$; (c) $r_b = 0.3c/\omega_p$, $l_b = 3.0c/\omega_p$; (d) $r_b = 1.0c/\omega_p$, $l_b = 10c/\omega_p$; and (e) $r_b = 1.5c/\omega_p$, $l_b = 15c/\omega_p$.