ACTUAL STATIONARY STATE FOR PLASMA LENS

Z. Parsa*, Brookhaven National Laboratory,Upton, NY 11973-5000, USA
A. Goncharov, Institute of Physics,46 Prsp. Nauki, 03028 Kiev, Ukraine
V. Zadorozhny†,Institute of Cybernetics, 40 Prsp Glushkov, 03187, Kiev, Ukraine.

Abstract

The electrostatic plasma lens (PL) provides an attractive and unique tool for manipulating and controlling the high-current heavy ion beams. The concept of the PL is based on using the magnetically insulated electrons and equipotentialization of magnetic field lines. Today, the applications of PL are, however limited. The reason is that estimating the behavior of electrons for complicated magnetic fields runs into severe difficulties. We show that there are specific conditions that admit steady-state of a longitudinal motion, and consider the question of its stability. These results are needed to develop an optimized PL with minimal spherical aberration, in part by optimizing the magnetic field configuration in the low-magnetic-field range.

INTRODUCTION

The fundamental concept of the plasma lens (PL) is based on using magnetically insulated electrons and the equipotentialization of magnetic field lines. This plasma-optical concept was first described for example, in [1] and [2]. The electrostatic PL is an axially symmetric plasma-optical device with a set of cylindrical ring electrodes located within the magnetic field region, with magnetic field lines connecting ring electrodes pairs symmetricaly about the lens's midplane. Steady-state electric fields are introduced into the plasma volume to control high-current beams of nonmagnetized ion. Several devices of this kind were developed and demonstrated for various applications.

The electrostatic PL has been investigated for more than half a century. This background work is characterized by a steady increase in the beam current I_b and the beam potential parameter $I_b/4\pi\varepsilon_o V_b$, where ε_o is the permitivity of free space and V_b is the velocity.

Earlier results e.g., in [1] showed that the hydrodynamic model of the PL is described, in a *stationary mode* (steady-state), by a simple equation

$$E = -\frac{1}{c}[v \times H], \quad (1)$$

where E and H are, respectively, electrostatic and magnetic fields of PL, v is a hydrodynamic electron velocity.

It follows from this that electrons will be in motion with a hydrodynamic velocity

$$v \cong \frac{E}{H}$$

In fact, a Larmor radius of electrons and its temperature have got a finite value. For this reason, a different stationary mode may arise such that equation (1) will not be the same. Besides this, the distributive potential is not like that of equation (1). The importance of new research will improve the PL work. Here we present the new approach to this topic.

THE PLASMA LENS MODEL

In the preceding section, we see how the mathematical model can be used to yield a very simple equation to describe the electron motion. We next include the influence of the electron mass in the dynamics of obtainingthe solution. Thus we impose the following assumption:

1. The electron mass $m \neq 0$.
2. There is pressing of electron component $(-\nabla p_e/en)$.

We restrict our model to the following form:

$$m\partial_t v = e\left\{E + [\frac{1}{c}v \times H] - \nabla p_e/en\right\}. \quad (2)$$

Let us introduce into consideration some coordinate systems - current and relative velocity. Then an absolute acceleration can be written as follows

$$\partial_t v = (\partial_t v_c + \partial_t v_r + 2[\Omega[\Omega\rho]])$$

where $2[\Omega[\Omega\rho]]$ is the Coriolis acceleration. If the force generated by this acceleration

$$F = m(\partial_t v_c + \partial_t v_r + 2[\Omega[\Omega\rho]])$$

is zero then we have got a steady-state trajectory. But there is yet another important factor that can degrade the ion beams focusing. This is connected with a drift instability [4] arising in inhomogeneous crossed $E \perp H$ fields in the lens volume. Thus further understanding of instability mechanisms requires studying the nonlinear dynamics of electrons within the plasma lens medium.

* parsa@bnl.gov,supported by US Department of Energy
† zvf@compuserv.com.ua

 0-7803-8859-3/05/$20.00

A nonlinear equation for the distributed electric potential, we can write in the form:

$$m\partial_t v = e\left\{E_d + \frac{1}{c}[v_d \times H_d]\right\} - \mu \nabla H$$

where μ is a magnetic moment, and the symbol d means disturbed.

CONCLUSION

The experimental and theoretical results, and computer simulations described in the literature (in examples, [3, 5], and references therein), indicate good prospects for the permanent-magnet electrostatic plasma lens for focusing high-current, moderate-energy, large-area, heavy ion beams. With a simple design, and robust construction, only a single power supply is needed. A substantial advantage of a lens consists in using permanent magnets rather than current driven coils. At the present stage of investigations, this plasma-optical device could be used, for example, for high-dose ion implantation; in particle-accelerators, in ion beam sputtering, etc. Further experimental and theoretical efforts are needed to develop and optimize plasma lenses, with minimal spherical aberrations, in part by optimizing the magnetic field's configuration in the low-magnetic-field range.

REFERENCES

[1] A. Morosov, Focusing of cold quasi-neutral beams in electromagnetic field, Dokl. Acad. Nauk, vol.163 No 6, 1965, pp1363-1366.

[2] A. Morosov, S. Lebedev, Plasma-optics, in Reviews of Plasma Physics, M. Leontovich, Ed. New York: 1975, pp.247-281

[3] A. Goncharov, I. Brovn, High-Current Heavy Ion Beams in the Electrostatic Plasma Lens. IEEE Transactions on Plasma Science, v. 32, No 1, 2004, pp.80-83

[4] D. Sivuckhin, The Drift Theory of Motion of Charged Particle Beams into Electromagnetic Fields, Plasma Theory Problems, Gosatomizdt 1963, pp.7-182

[5] Z. Parsa, Ed. Book: New modes of Particle Acceleration And Sources, CP No.396 AIP, New York, 1997. For nonlinear dynamics see for example, (articles and references in): Z. Parsa, Ed., Book: Beam Stability and Nonlinear Dynamics CP No. 405 AIP, New York, 1977.