HALO FORMATION IN AN INTENSE CHARGED PARTICLE BEAM

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Abstract

Halo formation is an important issue in intense charged particle beams because the loss of halo particles can lead to radio activation of the accelerator. Halo formation can be described by a particle-core model in a continuous focusing channel. We explore the properties of such halo formation by numerical calculations of the equations of motion and from simulations using the object-oriented particle-in-cell code OOPIC, which was modified to allow for external focusing.

1 INTRODUCTION

The need for high intensity charged particle beams has generated a lot of recent interest in beam halo formation. High current accelerators find applications in heavy ion fusion, nuclear waste treatment, production of tritium and production of radio isotopes for medical use. Beam halos comprise of a low density charged particle distribution surrounding an intense beam core. One of the consequences of the presence of such halos is the production of residual radioactivity in the system. Thus, understanding the physics of halo formation is important for the design of high current accelerators with minimized beam loss.

A common model used for this study is the uniform cylindrical beam with a continuously focusing force that varies linearly with r, the radial distance. Particles lying inside the cylindrical core will experience a net force proportional to r, while the force field outside the core consists of a combination of fields varying directly and inversely with respect to r. An initial mismatch, that is an imbalance in the focusing force and the self charge force which leads to oscillation of the core, causes halo particles. Numerical integration of the particle trajectories[1] have shown that depending upon the initial conditions, particles can remain inside the core, travel in and out of the core or remain outside the core causing the halo. An analytic model proposed by Gluckstern[2] which used an azimuthally symmetric KV core has shown that an interaction between the particles and the core results in a parametric resonance that can cause some particles to acquire large amplitudes in phase space.

In this paper, we show the results of simulations using the object oriented particle-in-cell code, OOPIC. OOPIC is a 2 dimensional relativistic electromagnetic particle-in-cell code[3]. We are in the process of developing this code for simulating halo particles in beams. These are preliminary results for future work. This code was modified to allow external focusing for these simulations. This additional force varies linearly with r and is directed inwards.

2 THE PARTICLE CORE MODEL

The equation of motion of the beam radius, known as the envelope equation is given by

$$\frac{d^2R}{dz^2} + \omega_o^2 R - \frac{K}{R} = 0 \qquad (1)$$

where the second term represents the focusing force and the third term represents the space charge force. For a test particle, the equation of motion is given by

$$\frac{d^2r}{dz^2} + \omega_o^2 x = \begin{cases} Kx/R^2 & : x < R \\ K/x & : x > R \end{cases} \qquad (2)$$

The trajectories in phase space of test particles resulting from solving these equations have been have been classified into three distinct classes[1] (a) Particles initially lying inside the core execute orbits known as the plasma trajectories, (b) particles lying far outside the core trace the betatron trajectories, which are believed to constitute the halo and (c) particles lying outside but near the core trace the hybrid trajectories which is a combination of (a) and (b).

3 RESULTS OF SIMULATIONS

We performed two kinds of simulations in order to observe beam halo formation. All the figures shown represent positions of the particles in phase space in the x direction. The size of the grid was 64×64. The boundaries consisted of conductors. The boundaries were sufficiently far away from the particles and it was verified that the presence of these conductors results in an error of less than 5 percent in the electric field even for the outermost particle. Both the simulations had a Gaussian distribution in velocity space.

Fig. 1 shows an initial particle distribution of a beam with a core and with some stray charge distribution extending to 1.5 times beyond the radius of the core. The density of this stray charge is 1/50 of the density of the core. About 3000 computational particles were used. The focusing force was 1.5 times the space charge force. Fig. 2 shows the same beam after 23 core oscillations. Here, we clearly notice that some particles travel far beyond the core. These resemble the behavior of betatron trajectories. The additional charge distribution beyond the core was necessary to generate these particles. In practice, particles can go outside the core by transport mechanisms not described by the current model. Such particles may acquire hybrid or betatron trajectories. Although we see a very small fraction

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of particles with large amplitudes, this is significant enough because in many applications, the fraction of particles lost must be below 10^5.

Fig.3 shows a Gaussian beam. The grid used was the same as the one used for the particle core model. The focusing force is 3 times the space charge force for a particle at the rms position of the Gaussian. The Gaussian was truncated at 3.5σ. Fig. 4 shows the same beam after 14 core oscillations. Once again, we see that the number of particles acquiring large amplitudes is significant enough. In this distribution, particles always extend up to the tail of the Gaussian, so there are always particles that can acquire high enough amplitudes at a later time.

The results show that both the models are qualitatively similar, ie, both produce particles with large amplitudes in phase space.

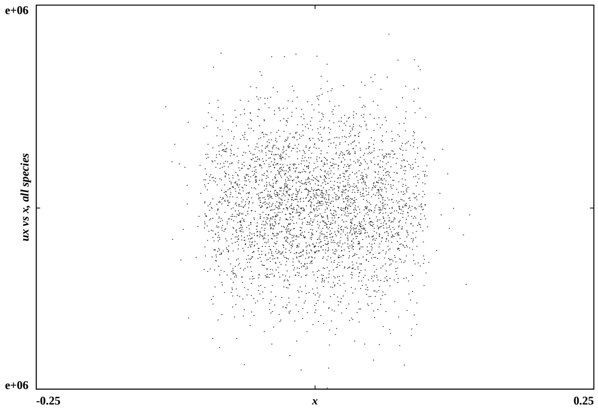

Figure 1: Uniform core with an initial low density charge distribution lying beyond the core

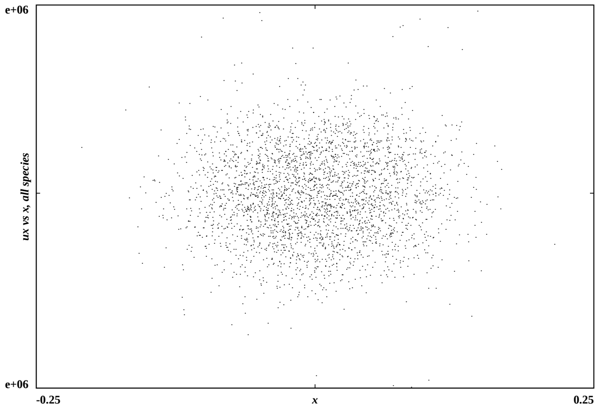

Figure 2: Distribution in fig.1 after 23 core oscillations

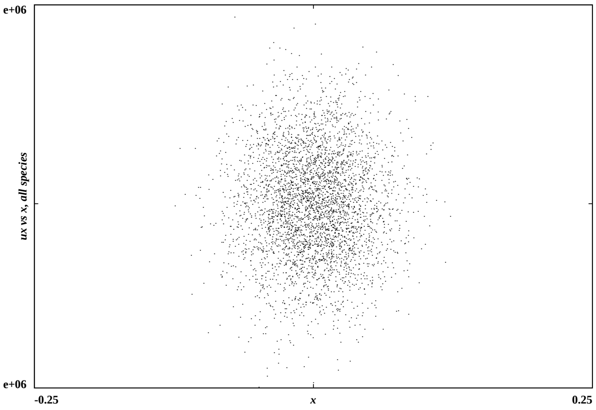

Figure 3: Gaussian distribution

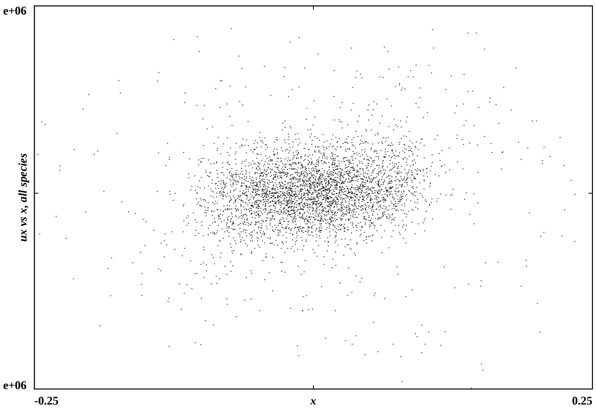

Figure 4: Distribution in fig.3 after 15 core oscillations

4 SUMMARY

We are in the process of developing the capability for the object oriented particle-in-cell code, OOPIC to simulate halo formation of beams. In this paper we have shown some preliminary results of the simulations. The results are consistent with previous results given in ref.[1]. which were obtained by numerically solving the equations of motion of test particles with various initial conditions. In future we wish to study the effect of an alternate gradient focusing instead of continuous focusing. Since this is a 2-dimensional code, we can also study the effect of coupling between the x and y directions.

5 REFERENCES

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