EVOLUTION OF LASER INDUCED PERTURBATION AND EXPERIMENTAL OBSERVATION OF SPACE CHARGE WAVES IN THE UNIVERSITY OF MARYLAND ELECTRON RING (UMER)*

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Abstract

The University of Maryland Electron Ring (UMER) is a scaled model to investigate the transverse and longitudinal physics of space charge dominated beams. It uses a 10-keV electron beam along with other scaled beam parameters that model the larger machines but at a lower cost. Understanding collective behavior of intense, charged particle beams due to their space charge effects is crucial for advanced accelerator research and applications. This paper presents an experimental study of longitudinal dynamics of an initial density modulation on a space-charge dominated beam. A novel experimental technique of producing a perturbation using a laser is discussed.Using a laser to produce a perturbation provides the ability to launch a pure density modulation and to have better control over the amount of perturbation introduced. Collective effects like space charge waves and their propagation over long distances in a quadrupole channel are studied.A one dimensional cold fluid model is used for theoretical analysis and simulations are carried out in WARP-RZ.

INTRODUCTION

Next generation advanced accelerators demand both high current operation and high beam quality [1, 2, 3].Space charge effects will dominate the dynamics in generating such high brightness beams. The nonlinear longitudinal space charge will impact bunch lengthening and distortion of the longitudinal phase space[4]. This, in turn, will lead to emittance growth and hence degradation of beam quality. Such collective effects limit the beam quality achievable in intense beams.One of the collective effects of space charge that needs to be understood is the physics of perturbations on space charge dominated beams[5].These perturbations can be caused by fluctuations in beam current, fluctuations in the laser in case of a photoinjector, or mis-focussing in longitudinal focussing systems[6]. Introducing perturbations on a space charge dominated beam deliberately and observing their evolution will help in understanding the effect of space charge on beam fluctuations[7, 8].

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(UMER)[9, 10] is an experimental facility to investigate space-charge phenomena of highly intense beams. By using a 10-keV electron beam along with other scaled beam parameters, UMER models the larger machines but at a lower cost.So, UMER provides a platform to study the effect of perturbations on space charge dominated beams. In this work, a perturbation is introduced in the beam using a laser and the evolution of space charge waves is observed.

THEORY: ONE DIMENSIONAL COLD FLUID THEORY

The linear theory of space charge waves is based on a cold-fluid model[5]. In this model, a small initial perturbation is assumed and then both momentum and continuity equations are solved. The solution shows that the perturbations propagate along the beam in the form of waves. One of them has a phase velocity greater than the beam velocity called as a fast space-charge wave, while the other one has a phase velocity smaller than the beam velocity and hence called a slow space-charge wave.

The "sound speed" $C_s = \sqrt{\frac{qg\Lambda_0}{4\pi\varepsilon_0 m\gamma^5}}$ is the velocity of the space charge waves in the beam frame, in analogy to the propagation of sound in gas, where $g = 2\ln\frac{b}{a}$; b is the beam pipe radius and a transverse beam radius. It should be noted that the space charge waves have the same shape as that of the initial perturbation but their amplitude and polarity are dependent on the strength of the initial perturbation and initial conditions.The same conclusion can also be arrived by constructing the dispersion relation for the space charge waves[5, 11]. The group velocity is equal to the phase velocity of the waves and hence they are dispersion free. In other words, the perturbation travels unaffected.

EXPERIMENTAL SETUP

A Minilite II Q-switched Nd: YAG laser from Continuum forms the source of optical power. The full-width half-maximum of the laser (FWHM) is around 5 ns. By using the proper nonlinear crystals, light at either 355nm or 266nm can be produced. In these experiments, the third harmonic at 355nm was used. After the UV light is reflected by suitalbe dielectric mirrors, the light passes through a quartz window and is reflected by another mirror installed inside the chamber (IC1) and hits the cathode [7, 8]

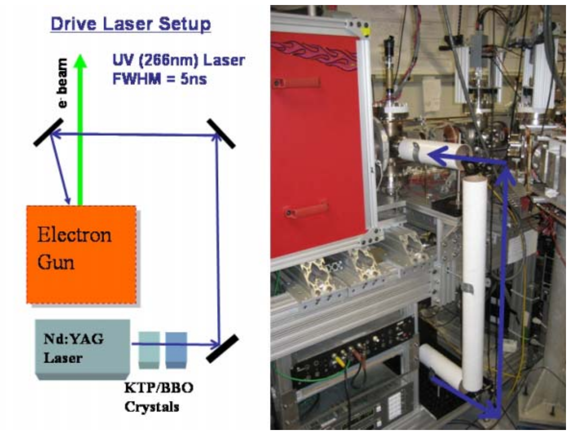

Figure 1: Schematic of the drive laser setup is shown on the left. The actual drive laser setup on UMER is shown on the right. The light path is shown with blue arrows.

EXPERIMENTAL RESULTS

In order to generate a perturbation and observe the space charge waves in UMER, an experiment was set up. The UV laser (355nm) was used to generate a perturbation on a 23mA beam. The current settings on the magnets are set for the main beam pulse current of 23mA and the corresponding steering solution is used.

Fig. 2 below shows the oscilloscope trace of the beam pulse along with the laser induced perturbation.

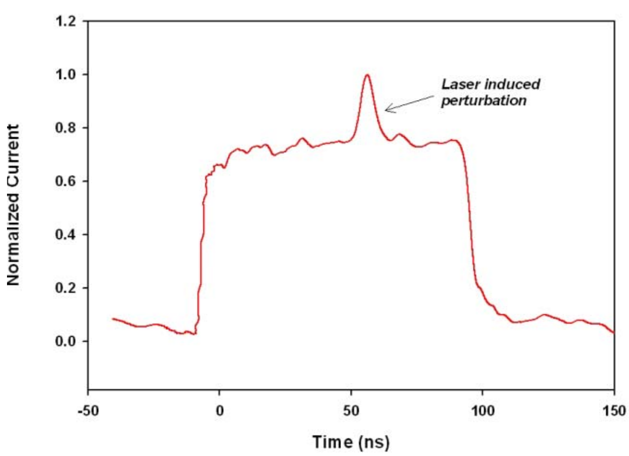

Figure 2: The oscilloscope trace from a Bergoz current monitor showing the perturbation. The main beam current 15mA and the perturbation 15% of main beam current.

The beam pulse is measured at the Bergoz coil which is placed 64 cm from the aperture. After the beam propagates into the ring, the beam current pulse is measured once again at RC6, which is at 5.11m using the BPM channel plates. fig. 3 clearly shows the perturbation in the beam pulse splitting into a fast space-charge wave and a slow space-charge wave.

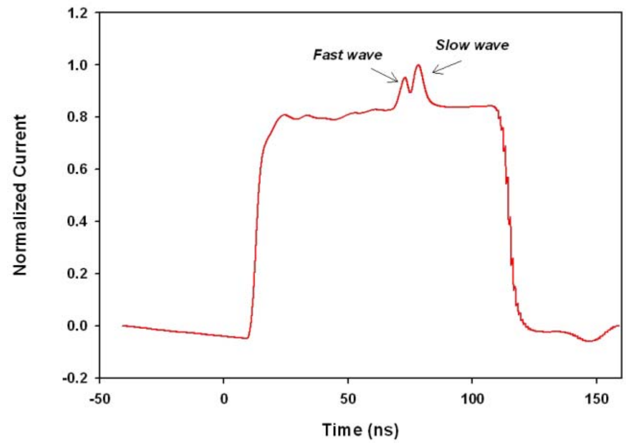

Figure 3: The integrated output trace from a beam position channel plates showing the perturbation splitting into a fast space charge wave and a slow space charge wave.

During the experiment, several interesting phenomena were observed. When the laser power was increased beyond a certain threshold, the perturbation split into multiple sub-pulses. This effect might be due to space charge instabilities and virtual cathode formation [14, 13]. This in turn could be used to study the effect of multiple, periodic perturbations on intense electron beams.

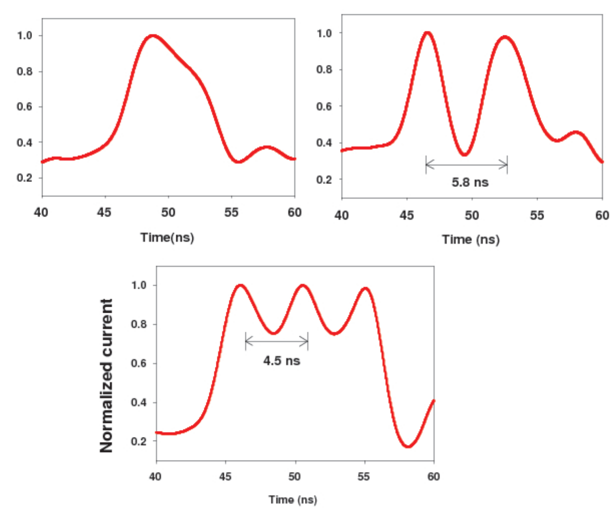

Figure 4: Single perturbation pulse splitting into multiple sub-pulses at (a) Low laser power (b) Medium Laser power(2 mJ) (c) High laser power (2.5mJ). Y-axis is normalized current

SIMULATION

A particle-in-cell code(PIC) WARP[12] is used to simulate the evolution of the perturbation. A uniform focussing channel is used along with longitudinal focussing. It is important to note that the beam line used in the simulation as-

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sumes a conductive wall. The impedance from BPM wall chambers and Y-injection line is ignored.The longitudinal profile of the beam obtained from the Bergoz coil in the injector line is used as the initial distribution.The Bergoz current profile is loaded into PIC simulation code WARP as input. The simulation is ran with a linear,uniform focussing channel. The perturbation splits into a fast wave and a slow wave.fig. 5

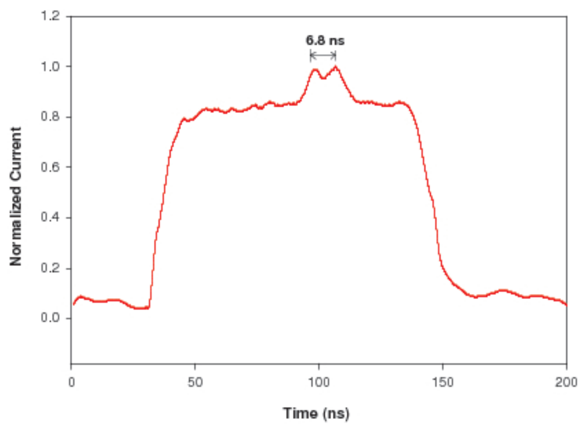

Figure 5: Simulation result: The beam current profile obtained through simulation using PIC code WARP.The splitting of the perturbation into slow and fast wave is observed.

COMPARISON BETWEEN THEORY, SIMULATION AND EXPERIMENT

From linear, one dimensional cold fluid theory, the speed at which the waves travel, called the sound speed, for a 10 keV the electron beam along with other UMER parameters, $a = 4mm$, $b = 2.54cm$, I=15 mA is $C_s = 1.306 \times 10^6 m/s$.

In order to calculate the sound speed from experimental data, let us assume that the waves travel a distance of δz in a time δt in the beam frame. The waves will separate at twice the sound speed from each other. So,the sound speed C_s will be equal to half of $\frac{\delta t \cdot v}{\delta z / v}$. So, $C_s = 0.5 \cdot \frac{\delta t}{\delta z} \cdot (\beta c)^2$. From the data, δt = 6.1 ns and δz =5.75 m (RC7) giving the value of $C_s = 1.544 \times 10^6 m/s$. From WARP simulation the distance between the two peaks is obtained as 6.8 ns.

The value of the sound speed predicted by the 1-D cold fluid theory is less than the observed value. In theory, a small sinusoidal modulation is assumed, but in this experiment the perturbation strength is relatively big(20%) compared to the main beam current. Overall there is good agreement between theory, simulation and experiment.

CONCLUSION

An experimental study of longitudinal dynamics of an intense electron beam using laser generated perturbation has been presented. The perturbation travels in the form of slow and fast space charge waves. The sound speed of the waves were measured experimentally and shows good agreement with 1-D cold fluid theory and simulation.

ACKNOWLEDGMENT

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