Numerical Analysis of Sampling Streak Camera for Higher Temporal Resolution Operation

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Abstract — To aim to further improvement of the sampling streak camera for higher temporal resolution, numerical simulation method is presented for detail understanding of electron beam dynamics in this measurement device. The numerical code performs self-consistent analysis of electrostatic field and electron beam motion by using Particl-in-Cell method. It is shown from the numerical simulation that higher temporal resolution operation will cause inaccuracy in phase information due to the space charge effects.

I. INTRODUCTION

The streak camera is one of very high temporal resolution measurement devices for luminous phenomena such as in plasma physics, beam physics and semiconductor physics, especially it is a unique possibility for the time range of order of pico-second [1]-[4]. However, the measurement was mainly for only time domain signal and no spatial resolution. For both of temporal and spatial measurements, sampling streak camera was developed for time range of order of 100 pico-second. And also higher temporal resolution of image measurements by using the sampling streak camera is now being developed [5]. Then for the higher temporal resolution of order of pico-second, it is predicted that electron beams behavior will be complicated due to strong space charge effects by stronger electron density. Accordingly numerical simulation will play important role in the detail design of the streak camera system. This paper presents a numerical analysis of the streak camera device by using self-consistent simulation between electron beam and electric field.

II. STREAK CAMERA

Overview of the conventional streak camera system is shown in Fig.1. The incoming measurement signal from luminous phenomena is converted to electron density spatial distribution at the photo cathode. The generated short electron beam is accelerated by the DC electrode up to several keV and travels to scanning electrode via focusing electrode. Then scan pulse voltage is applied on the scanning electrode synchronizing with the arrival of the electron beam at the scanning electrode. The scanning pulse voltage kicks the head of the electron beam to upward direction and the tail to downward. This means that the temporal signal of the electron beam is transformed to vertical intensity distribution. At the most downstream stage, the vertically distributed electron beam is amplified by the multi channel plate (MCP) and recoded by the CCD camera. Accordingly the conventional streak camera can observe at most spatially 1 D image.

For the temporal measurement of 2D image signal, the matrix pinhole array such as Fig.2(a) is used in front of the photo cathode in the sampling streak camera. For the matrix pinhole array, scan images will be obtain individually such as Fig.2(b). To carefully pick-up same phase points from the scanning image and process them, temporal 2D signal image can be reconstructed. In this device, electron beam trajectories are sensitively disturbed by space charge effects especially in the case of high density electron beam. Accordingly numerical analysis is important for detail understanding of the electron beam dynamics in the sampling streak camera.

III. NUMERICAL SIMULATION METHOD

Numerical simulation of the streak camera system consists of two parts, electromagnetic field calculation and charged particle motion. Although the scanning pulse voltage and the electromagnetic fields produced by the electron beam are both time varying, the magnetic field is negligible for the calculation of the electron motion due to comparably small electron velocity of order of several keV. In this case, it is enough to consider only the electrostatic field described by the following Poisson equation,

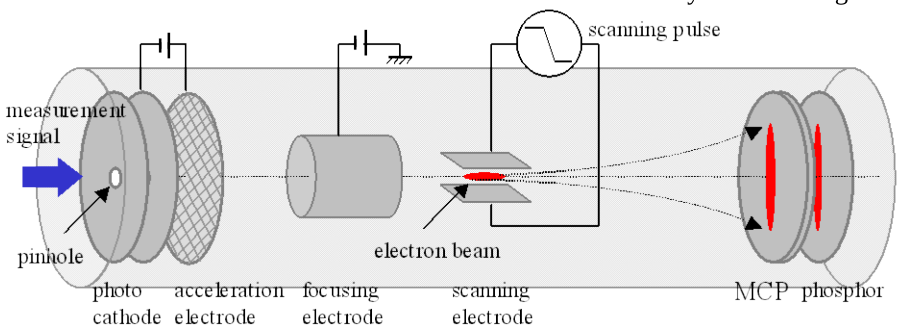
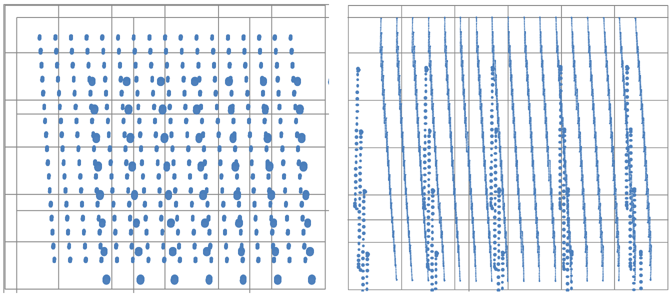


Fig. 1. Overview of streak camera system



(a) (b)

Fig. 2. Matrix pinhole array (a) and corresponding scanning image

$$\nabla^2 \phi(\mathbf{x}) = -\frac{\rho(\mathbf{x})}{\varepsilon}, \ \mathbf{E}(\mathbf{x}) = -\nabla \phi(\mathbf{x}) \qquad (1)$$

Then, the charged particle equation of motion under the static electric field is as follows,

$$\frac{d\mathbf{p}(t)}{dt} = e\mathbf{E}(\mathbf{x}(t)), \ \mathbf{p}(t) = \frac{m\mathbf{v}(t)}{\sqrt{1-\left(\frac{v(t)}{c}\right)^2}}. \qquad (2)$$

Due to the electron energy of order of keV, we need to use the relativistic formulation (2) in the particle simulation.

During the numerical integration of the equation of electron motion (2), the electrostatic field varies in every time step due to the scanning pulse voltage at the scanning electrode and space charge effects cased by the electron beam motion. To save the computer memory and calculation time, we here employ Particle-in-Cell (PIC) scheme for the calculation of the charge particle density in (1) which is caused by the electron beam. The simulation flow of the streak camera is shown in Fig.3. It is necessary to re-calculate the electrostatic field in each time step, and heavy calculation is required.

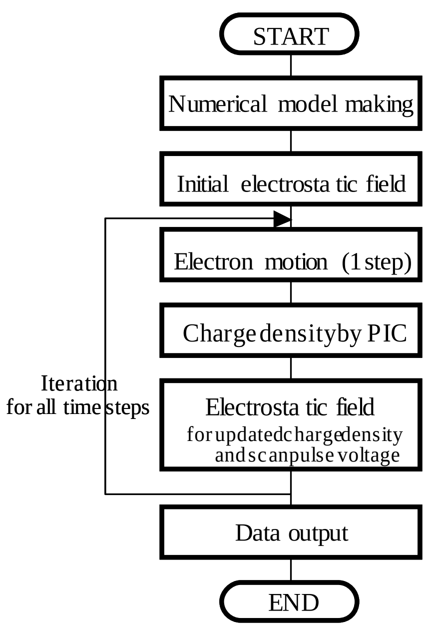


Fig. 3. Calculation flow of streak camera simulation

IV. NUMERICAL EXAMPLE

The temporal resolution of the existing sampling streak camera is of order of nano-second [5]. Numerical simulation for this time range shows normal scanning images such as Fig.2(b). The figure 4 shows final scanning image in the case of 10 pico-second (3mm) longitudinal length uniform electron beam. It is shown from the simulation Fig.4 that the scanning images are no more uniform, especially the scanning images corresponding to edge pinhole result in curved lines. For very short electron beam, the charge density is much higher than the existing device. Due to the dense electron beam, space charge effects my strongly affect to the beam dynamics and lead to this curved scanning images. In the curved scanning images, phase information is no more uniform, the temporal information may be inaccurate.

V. CONCLUSION

This paper has presented a numerical analysis of the sampling streak camera by the self-consistent simulation between the electrostatic field and charged particle motion. It is shown that the scanning image for the next generation higher temporal resolution device may face to inaccuracy in the phase information of the temporal signal and one have to do carefull processing of the scanning images to obtain the original measurement signal.

VI. REFERENCES

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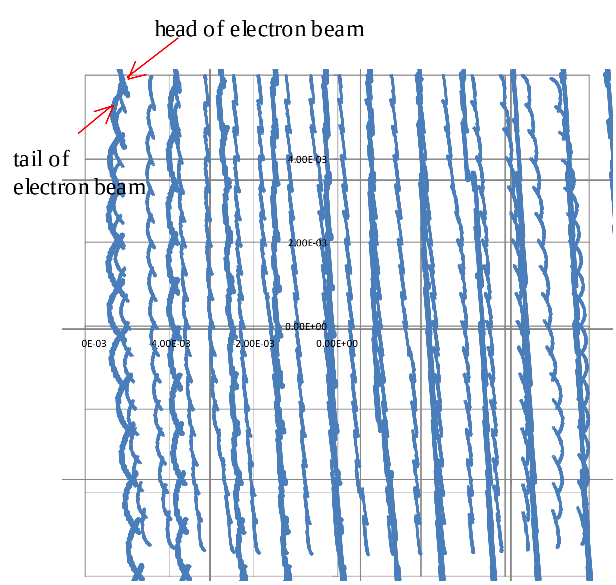

Fig. 4. Scanning images for 10 pico-second electron beam