Fast Imaging of Time-dependent Distributions of Intense Beams*

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Abstract

Longitudinal perturbations can be generated in the space-charge dominated regimes in which most beams of interest are born. To study the modification of transverse beam distributions by longitudinal beam dynamics, we have conducted experimental studies using low energy electron beams by taking time resolved images of a beam with longitudinal density perturbations. Two different diagnostics are used: optical transition radiation (OTR) produced from an intercepting silicon based aluminum screen and a fast (<5ns decay time) phosphor screen. It is found that the beam is significantly affected by the perturbation. However the OTR signal is very weak and requires over 45 minutes of frame integration. The fast phosphor screen has much better sensitivity (~1000 times enhancement). In this paper, we also report on the time resolved measurement of a parabolic beam, showing interesting correlations between transverse and longitudinal distributions of the beam.

INTRODUCTION

Much interest has recently been generated in intense beams for applications such as accelerator-driven high-energy-density physics (HEDP) [1], pulsed neutron source [2], or x-ray free electron lasers [3]. Successful operation of such machines requires more detailed knowledge and understanding of the physics of high intensity beams in which space-charge forces play a much more important role than in conventional accelerators. At the University of Maryland, we carry out experimental research on space-charge dominated beams utilizing both the University of Maryland Electron Ring (UMER) [4] and a long solenoid experiment (LSE) system [5], which is a linear test stand for UMER. Previous experiments have revealed much about the longitudinal physics of space-charge dominated beams by monitoring the evolution of longitudinal perturbations [5]. Some initial experimental research also indicates the existence of transverse-longitudinal coupling [6]. To address the study on the transverse-longitudinal coupling for highly intense beams, we have developed several techniques for fast transverse imaging of beams. In this paper, we will first introduce the fast imaging experiment with optical transition radiation (OTR) in UMER before discussing another experiment using fast phosphor screen in LSE.

EXPERIMENTAL METHOD

As a new diagnostic technique implemented in UMER, OTR has been demonstrated experimentally to be useful in beam imaging of low energy electron beams. With the advantage of the prompt property of OTR light, one can obtain time sliced images of the beam using a high-sensitivity intensified gated camera with heavy frame-integration. The detailed discussion of the OTR techniques in UMER beam including the diagnostic system setup can be found elsewhere [7]. In order to profile the longitudinal perturbations, we conduct an experiment in UMER and achieve 3-ns slice images of the beam with and without a perturbation by capturing the OTR light. During our experiment, a gun aperture for a nominal beam current of 23 mA is used. One OTR screen is installed in the first injection chamber (IC1) , about 36 cm away to the gun aperture, and at the eighth ring chamber (RC8) in UMER, about 6.4 m downstream. In addition, a fast Bergoz current monitor is right after the IC1. In our experiment, we view the OTR screen at IC1 with the fast photomultiplier tube (PMT) acquiring the optical signal of the OTR light so that we can compare it with the current signal from Bergoz current monitor. In RC8, a gated 16-bit PIMAX2 ICCD camera with a minimum gate width of 3 ns is used to capture the time resolved beam images.

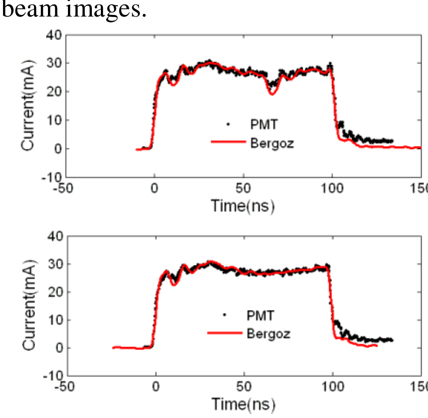

Figure 1: Beam current with perturbation (top) and without perturbation (bottom).

We have several methods for deliberately generating perturbations on the beam including an electrical method [5], illuminating the cathode with a laser [8], and using an induction module [9]. In this experiment, we utilize the electrical method by operating the gridded electron gun in the triode regime so that voltage perturbations between the cathode and grid will be amplified. In the experiment, when the bias voltage is lower than 45 volts, the beam current has a single positive perturbation which is consistent with the shape of the modulated pulse voltage. However, when the bias voltage is increased further, the single perturbation on the current waveform becomes

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negative. A possible explanation for the reduction in beam current is that the beam expands transversely due to the higher space charge during the perturbation, ultimately getting more of the beam intercepted by the aperture. This also suggests the importance of the transverse dynamics on the perturbation's behavior. When the bias voltage is set to 45 volts, the current waveforms of both the perturbed and unperturbed beam measured by Bergoz and PMT are shown in Figure 1, in which the solid lines represent the current profiles measured by the Bergoz current monitor and the dots show the PMT signals. The current profiles derived from both methods agree very well except that the perturbation amplitude of the PMT signal, about 4 mA, is a little smaller than that of the Bergoz signal which is about 6 mA. The measured perturbation width is about 10 ns for both methods. However, with the 3 ns gate width, the light intensity of OTR is so low that we have to wait more than 45 minutes for the frame integrations in order to get one image. To obtain more light than OTR, we test a new type of fast phosphor screen in the LSE system.

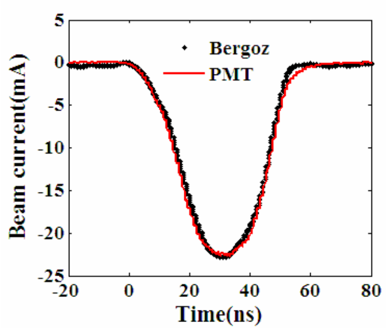

Figure 2: Current waveforms measured by Bergoz (dots) and PMT (the solid line).

The fast phosphor screen, installed in the first chamber of LSE, is a ZnO:Ga deposited quartz plate with thin aluminum coating and has a peak light emitting wavelength of 390 nm. Inside the diagnostic chamber, about 45 cm from the gun aperture plate, we also have a high resolution energy analyzer that can measure the longitudinal mean energy profile of the beam [10]. The beam from the gun is about 50 ns wide with an imperfect parabolic longitudinal current distribution and has a nominal energy of 5 keV. From the gun aperture to the chamber, the beam is focused by two short solenoids, between which a Bergoz current monitor is used to monitor current profiles. Similar to the OTR experiment in UMER, here a PMT and a PIMAX2 ICCD camera are also used for obtaining the optical signal emitted by the fast phosphor screen. The comparison between the Bergoz signal and the PMT signal of the phosphor light is presented in Figure 2. The results indicate that the light signal from the phosphor responds nearly as fast as the Bergoz signal except for a relatively slow tail from 20% of the maximum amplitude to zero. Furthermore, the good fit of the pulse shapes for both signals also proves that the fast phosphor has a linear response to the charge impinging on it. Given all these features, the fast phosphor signal is reliable for diagnostic purpose on the beam. However, more issues such as life time and the maximum charge density tolerance of the screen will still require more experimental investigation.

RESULTS

In this section, we will show the results of time sliced imaging using both OTR and the fast phosphor screen respectively. In addition, the mean energy profile of the parabolic beam in LSE will also be presented.

Using OTR in UMER

In the RC8 of UMER, we try various gate widths of the ICCD camera in taking the sliced images of the perturbation shown in Figure 1. It is found that, to get a clear image of the perturbation, the gate window needs to be reduced to 3 ns. Our results are quite interesting as shown in Figure 3 in which images on the left are color coded and shown on the right side. The 3-ns second slice inside the perturbation exhibits a substantial change when the perturbation is turned off. Another interesting observation is that the perturbation affects the size and profile of the beam core, but not the halo.

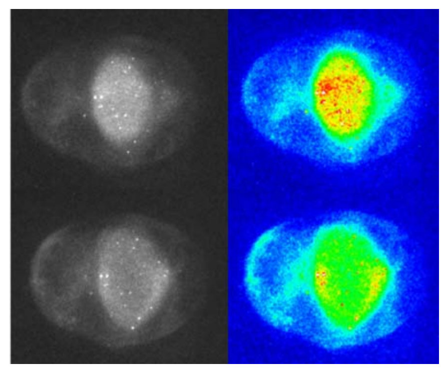

Figure 3: 3 ns sliced images in RC8 with (top) and without (bottom) perturbations.

Using the Fast Phosphor Screen in LSE

Figure 4 shows a series of 3-ns sliced beam images taken progressively along the beam whose profile is shown in Figure 2. Since the observed light intensity from the fast phosphor is much higher than from OTR, it only takes seconds to get one clear image. The dynamic range of the 16-bit camera is so wide that we can capture the 3-ns sliced beam image with a current as low as 0.19 mA that can not be detected by our oscilloscope. Some interesting correlations between transverse and longitudinal dynamics are shown in Figure 4. Both the beam size and transverse distributions are changing all the time along the beam affected by the parabolic longitudinal current distribution. Some interesting structures indicating an exotic particle distribution come and go for the high current parts of the beam. In Figure 5, we show a tilted longitudinal mean energy distribution measured by an energy analyzer at the same location as the phosphor screen. We believe that the tilted mean energy is due to the self electric field inside the imperfect parabolic beam. However, the reason for the beam head having a lower

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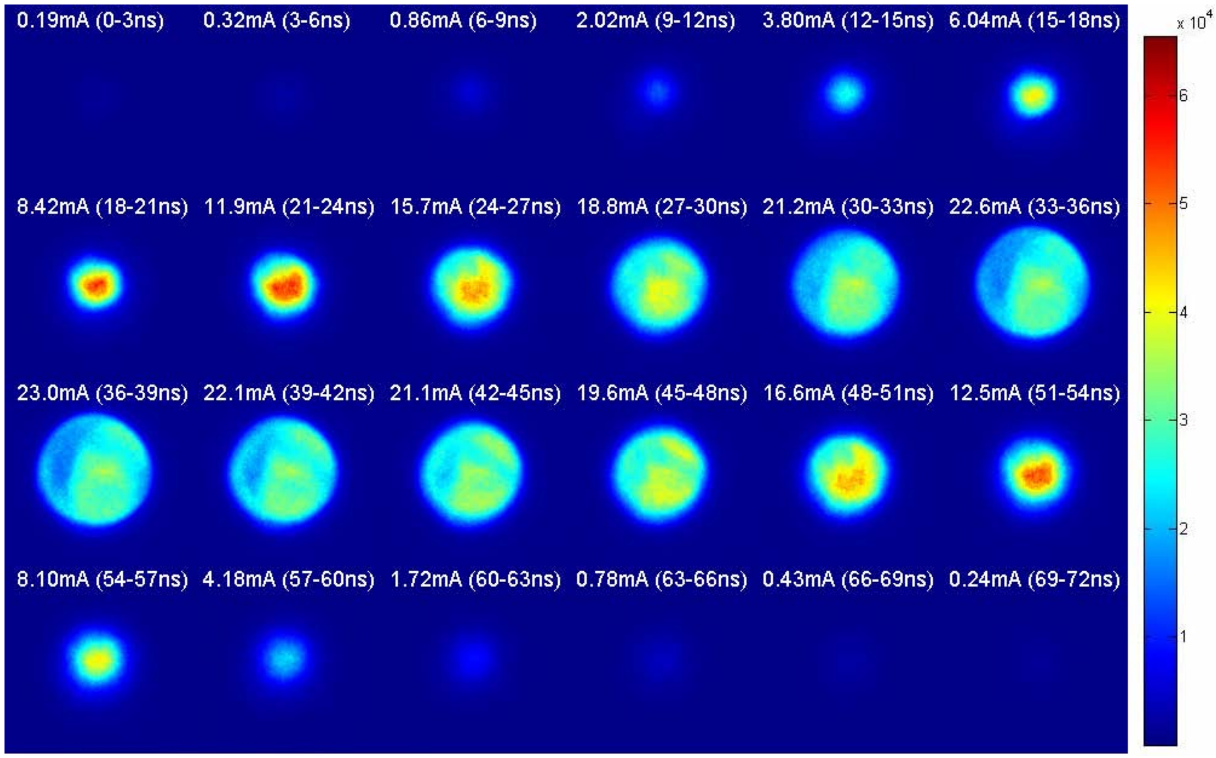

Figure 4: sliced beam images through the whole beam with a 3ns progressive gate on the ICCD camera

mean energy still remains unclear. It is possible that the space-charge forces of the long tail of the beam push the head back and reverse the slope of the mean energy of the beam head [11].

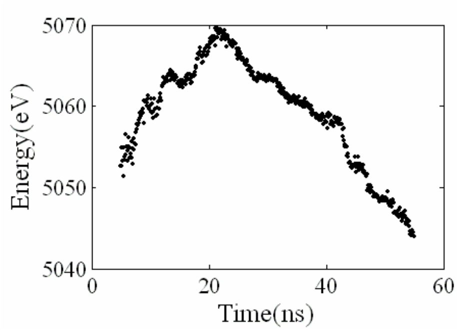

Figure 5: Mean energy profiles of the beam

CONCLUSIONS

Two experiments in time resolved measurement using OTR and a fast phosphor screen have been conducted at the University of Maryland. The results indicate some interesting relationships between longitudinal and transverse beam physics. In the future, we are planning to measure the mean energy of the beam with the energy analyzer in the second chamber of LSE, about 2 m downstream. A longer path length may provide us more information about the longitudinal and transverse coupling.

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