HIGH-SPEED GATED CAMERA OBSERVATIONS OF TRANSVERSE BEAM SIZE ALONG BUNCH TRAIN AT THE KEKB B-FACTORY

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Abstract

In order to investigate the single-beam vertical beam-size blow-up observed[1] in the KEKB 3.5 GeV positron ring (LER), we performed beam-size observations using a high-speed gated camera capable of recording the image of a single bunch in the ring. Using this technique, we measured the beam-size dependence on bunch position along a train, and studied the onset of blow-up under various conditions and fill patterns. The method and results are described herein.

1 INTRODUCTION

Vertical beam size blowup has been observed at high currents in the KEKB LER using the synchrotron radiation interferometers since relatively early in commissioning. In addition, it has also often been observed that the lifetime of an LER bunch depends on its position within a bunch train, with the current of the first several bunches at the head of the train decaying away more rapidly than the rest of the train. This led to the supposition that the beam size of the head bunches may be smaller than the rest of the train, with a correspondingly shorter Touschek lifetime. Since the SR interferometer makes measurements integrated over $1/60$ second (about 1667 turns) and cannot resolve bunch-by-bunch size differences, we setup a high-speed gated camera on a branch of the LER SR beamline in order to investigate whether bunch-by-bunch size differences were present.

The gated camera measurements are imaging profile measurements, not interferometric measurements, as the amount of light available from one pass of a single bunch is insufficient to form a usable interferogram under our operating conditions. The image observed with the gated camera is heavily diffraction limited, with a point-spread function size of the same order as the vertical beam spot size.

2 SETUP

The principles of gated camera operation are well covered in a paper on its application to measure the turn-by-turn transverse beam size at the SLC damping rings[3]. The camera used at KEKB is a Hamamatsu C2925, which has been used previously to measure the turn-by-turn emittance at the ATF damping ring[4]. The gate width is adjustable, with a minimum width of $3ns$[5]. A block diagram of the signal path is shown in Figure 1. A free-running 25 Hz trigger signal is generated, which is then synchronized with the revolution signal of the beam. The trigger is then input to a programmable delay module which uses the 508 MHz RF signal as a clock. This enables any bunch within the ring to be selected, though the turn number is determined more-or-less randomly; a kicker timing signal is available in the event we wish to study post-injection turn-by-turn behavior. A pulse generator shapes the trigger signal into a gate pulse of width ≈ 7 ns. The usual bunch spacing in use at KEKB is 8 ns (4 RF buckets), so individual bunches can be observed with no overlap.

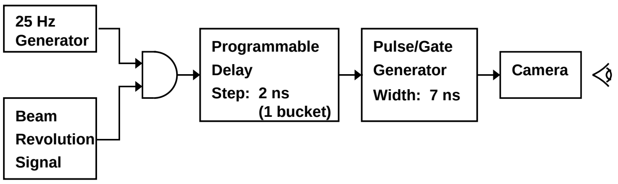


Figure 1: Gated camera setup block diagram.

The optical layout is shown in Figure 2. Light from the synchrotron radiation source magnet follows a 40-meter path to the above-ground optics hutch where the gated camera is installed. Inside the hutch an artificial aperture is set in the path to block regions of distorted wavefront from the edges of the extraction mirror in the tunnel, followed by a focusing objective lens, a bandpass filter (wavelength 550 ± 5 nm), a neutral density filter (as needed), and a polarization filter to select out the σ-polarized component of the synchrotron light. A cylindrical lens is then inserted which focuses in the horizontal direction; this permits the overall magnification ratio to be enlarged for easier observation of the vertical beamsize, without cutting off the ends of the much larger horizontal distribution. Finally a magnifying lens is inserted in front of the gated camera. The output of the camera is in NTSC video format, and is acquired using a commercial frame grabber board.

A commercial image processing package is used to verify that the image frame was grabbed properly, subtract a previously-measured background profile, and project the image along the horizontal axis to extract the vertical intensity profile. A typical example of a bunch profile is shown in Figure 3. Early data sets, including the ones discussed herein, were fitted to a single Gaussian. Due to the presence of wide instrumental tails in the distribution, it has since been found that the profile is best fitted as two

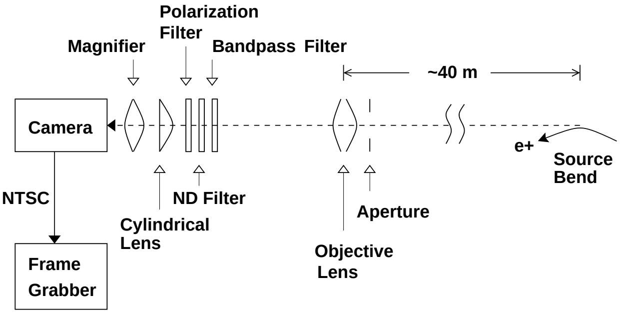


Figure 2: Gated camera optical layout.

overlapping Gaussians with different widths – one wide, low-amplitude component and one narrow, high-amplitude component. However, the narrow component dominates such that a single-Gaussian fit gives a width very close to that of the narrow component in a two-Gaussian fit.

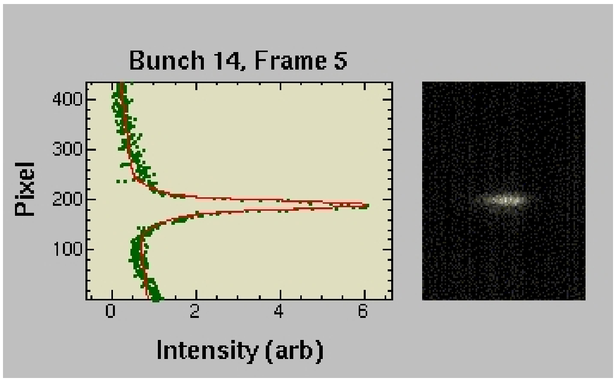


Figure 3: Typical bunch profile with two-component Gaussian fit profile superimposed.

The width of a profile is measured originally in units of camera pixels. To convert the measurement into units of beam size, calibration data is also be taken with the SR interferometer. The width σ_{GC} measured by the gated camera is approximated to be a two-Gaussian convolution of the interferometer-measured beam width σ_{INT} with a diffractive point-spread function caused by aperture restrictions and having a characteristic width σ_{PSF}:

$$\sigma_{GC} = \sqrt{\left[\frac{\sigma_{INT}}{F_{scale}}\right]^2 + \sigma_{PSF}^2},$$

where F_{scale} is the scaling factor from pixels to μm. F_{scale} and σ_{PSF} are not known *a priori*, but can be solved for given two sets of measurements of σ_{GC} and σ_{INT} with the beam at two different beam sizes.

3 OBSERVATIONS

The first set of measurements was made on 13 November 1999. The baseline configuration was a fill pattern of 4 bunch trains of 120 bunches each, with the bunches at a 4-bucket (8-ns) spacing. This 4-bucket spacing has been found to be the most stable one, and is used as the standard fill pattern for physics operation. Bunch profiles were sampled along the first train in the fill, shown in Fig. 4a).

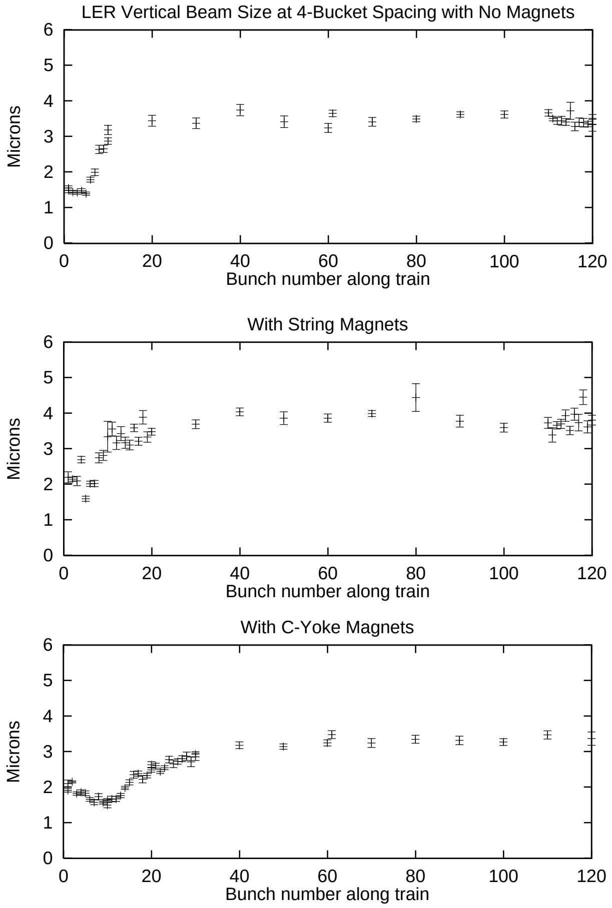


Figure 4: Bunch train profiles for the cases of a) no permanent magnets, b) "string" permanent magnets and c) C-yoke permanent magnets.

The beam current was 150 mA, under which condition the beam was blown up to over twice its normal size as measured by the interferometer. As had been predicted, the first few bunches were found to be smaller than the rest of the train. Comparison with data taken at 50 mA, where the beam was not blown up, shows that the first five bunches were at their non-blown-up beam size of 1.5μm. After that the beam rapidly increased in size until it saturated at about 3.5μm by around the 12th bunch.

The data in Figure 4b) were taken on 21 November, after an experimental linear array of permanent magnets ("string magnets") was affixed to the outer wall of the LER beam pipe in an attempt to reduce the photo-electron build-up that is thought to be responsible for the blow-up. As is seen from the gated camera data, the string magnets had no noticeable effect on the structure of the beam blow-up. The next data were taken on 3 December, after the permanent magnets had been re-arranged and attached to C-shaped iron yokes. Figure 4c) shows that the onset and growth of blow-up was somewhat retarded, but not to a very great extent. However, the fact that the magnets did seem to have some, albeit small, effect did serve to indicate that photo-electrons were indeed implicated in the beam blow-up effect. Further magnet re-arrangements have since been tried, but no great improvement has been seen.

On 26 December a measurement was made to determine what the minimum clearing gap might be, in which an observer bunch was placed 84 buckets behind a bunch train, and the size of the observer bunch monitored while gradually injecting new bunches to lengthen the train and shorten the gap. The bunch currents were all ~ 0.5 mA, above the blow-up threshold for bunches in a train at 4-bucket spacing. The results, shown in Figure 5, indicate that the observer doesn't blow up until the gap shortens to 12 buckets or less. Unfortunately, as discussed in Reference [1], this gap alone is not sufficient to fully clear the photo-electrons; bunches following the observer blow up more rapidly with a short gap than with a longer one.

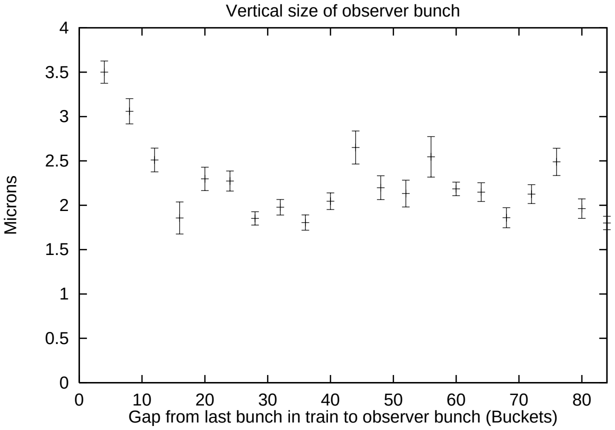
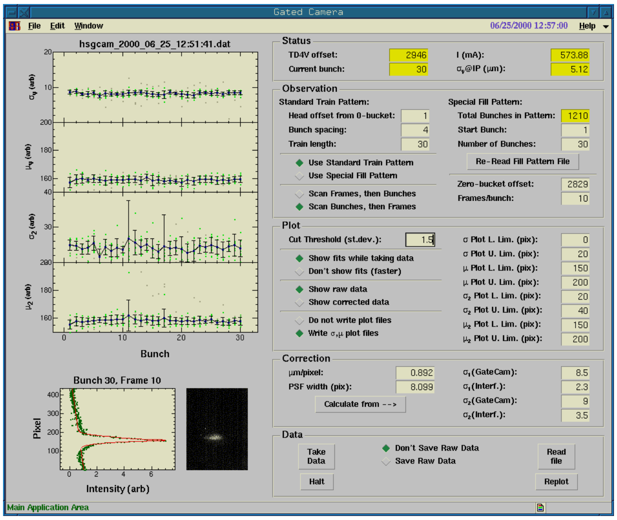


Figure 5: Dependence of size of trailing observer bunch size on distance to leading train.

Other studies have been carried out as well, some discussed in Reference [1]. The gated camera is now installed as a regularly available monitor, accessible from the control room for beam studies. The control panel for the camera is shown in Figure 6, with an example of data taken during collision. Unlike in the single beam data seen before, during collision the beam profile does not appear to vary with position along the train. Although the beam still blows up in collision at high currents, the effect is more evenly distributed across the train. The reason for this is not well understood.

4 CONCLUSION

A high-speed gated camera has been used to measure beam profiles along a bunch train, confirming the effect of photo-electrons on the LER beam size. Diagnostics with it will continue in further beam studies.



Status
TD4V offset: 2946
Current bunch: 30
I (mA): 573.88
σ_y@IP (μm): 5.12

Observation
Standard Train Pattern:
Head offset from 0-bucket: 1
Bunch spacing: 4
Train length: 30
◆ Use Standard Train Pattern
◇ Use Special Fill Pattern
◇ Scan Frames, then Bunches
◆ Scan Bunches, then Frames
Special Fill Pattern:
Total Bunches in Pattern: 1210
Start Bunch: 1
Number of Bunches: 30
Zero-bucket offset: 2829
Frames/bunch: 10

Plot
Cut Threshold (st.dev.): 1.5
◆ Show fits while taking data
◇ Don't show fits (faster)
◆ Show raw data
◇ Show corrected data
◇ Do not write plot files
◆ Write σ,μ plot files
σ Plot L. Lim. (pix): 0
σ Plot U. Lim. (pix): 20
μ Plot L. Lim. (pix): 150
μ Plot U. Lim. (pix): 200
σ_2 Plot L. Lim. (pix): 20
σ_2 Plot U. Lim. (pix): 40
μ_2 Plot L. Lim. (pix): 150
μ_2 Plot U. Lim. (pix): 200

Correction
μm/pixel: 0.892
PSF width (pix): 8.099
σ_1(GateCam): 8.5
σ_1(Interf.): 2.3
σ_2(GateCam): 9
σ_2(Interf.): 3.5

Data
◆ Don't Save Raw Data
◇ Save Raw Data

Figure 6: Observation of bunch size during collision.

ACKNOWLEDGMENT

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