FAST PINHOLE CAMERA FOR OPTIMISATION OF TOP UP INJECTION

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Abstract

Top up is increasingly becoming a standard mode of operation for synchrotron light sources. Although it brings a very stable source in terms of intensity and position, the regular injections potentially perturb the beam. In order to investigate the perturbation of the beam from imperfections of the injection kickers (i.e. non-closure of the bump), we use an X-ray pinhole camera equipped with a fast CMOS-sensor giving a rate of up to 3200 frames per second to monitor the image of the beam. The analysis of the observed beam size as well as position allows quantifying the perturbation from the kickers that can be seen on beamlines. In addition we compare the observed motion to bunch-by-bunch position data recorded in both vertical and horizontal planes, which reveals to be very complementary.

INTRODUCTION

In almost all third generation synchrotron light source like Diamond there are plans to operate the machine in top up mode [1, 2, 3, 4, 5, 6, 7]. This operational mode presents many advantages for the machine and for the users. However, it implies injecting a small amount of charge regularly to compensate for the losses. By doing that, there is a necessity to take into account the perturbation of the stored beam by the injection kickers and their consequences on beamlines activities. In this paper we present a method to measure the perturbation of the stored beam by the kickers from the view point of a beamline. This method consists of using a fast camera, operating from 200 to 3200 frame per second (FPS), in a X-ray pinhole camera setup. We firstly present the system and its performance. Then we show some results obtained at Diamond to finally discuss the potential use of such a system and give some concluding remarks.

INSTRUMENTATION AND PERFORMANCE

The system we use is the X-ray pinhole camera setup that is currently used to measure the beam size, and thus calculate the emittance, the relative energy spread and the coupling emittance of the electron beam [8]. But instead of using our standard CCD camera, we use the Pulnix TM-6740GE from JAI[1]. This camera achieves 200 FPS with full frames of the 640 by 480 CMOS sensor and transmits the image data through Gbit Ethernet. The pinhole has a 25 × 25 μm^2 aperture, and the system pinhole + screen + camera provides a good resolution for the measurement we intend to do, i.e. measuring the centroid and the beam size vs. time. The resolution has been evaluated to $\Delta \approx 16\mu$m when using a 0.5 mm thick CdWO$_4$ screen [9]. The other important parameter of the measurement is the flux reaching the camera in order to have a low noise floor on the images. To this end we used the flux from a stored beam with our nominal two third fill at 125 mA. In this case, the average number of photons on the scintillator screen is of the order of $10^{11}\ s^{-1}$ [8].

The camera software provided by JAI is extremely basic but sufficient to allow us to acquire all the frames desired. We setup the camera to 1200 FPS by selecting a small region of interest, 224 by 160 pixels. Higher rates can be obtained by bining the pixels up to 4x4, which provides rates up to 3200 FPS on the whole sensor size but with 4 times less resolution.

MEASUREMENT OF THE KICKED BEAM

Top up mode requires regular injections of a small amount of charge, either after a fixed period of when the stored current drops below a certain threshold. During injections, the stored beam is kicked through a theoretically closed bumped. In practice, a residual angular kick resulting from the four kicks not adding up to precisely zero, or from leakage field from the septum, will perturb the beam. As the residual kick typically originates from a mismatch in the shapes of the kicker pulses, it shows fast changes within the duration of the pulse. This leads to different kicks seen by individual bunches along the bunch train and causes a damped oscillating motion of varying amplitude along the bunch train. As a result of this, using a beam position monitor with turn by turn acquisition (which averages the position of the beam over one turn) to judge when the bunch motion is minimised is fundamentally flawed, as opposite motion of the head and tail can cancel out.

Recording the position bunch by bunch (see figure 1) will reveal the full extent of the residual kick on the first turns after the injection, but it cannot correctly record the full temporal evolution of the damped oscillation. Decoherence of the electrons inside each bunch leads to the oscillation appearing to damp faster as a beam position monitor is only able to record the centre of mass motion.

The disturbance of the stored beam can best be investigated with our fast pinhole camera setup as it records the beam as seen from a beamline and the perturbation can be quantified. We have been acquiring images at 1200 FPS while kicking the electron beam and followed this with an image by image analysis of the horizontal and vertical centroid, the image beam size and the intensity across a given aperture. The beam size is measured by fitting each image

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[1] www.JAI.com

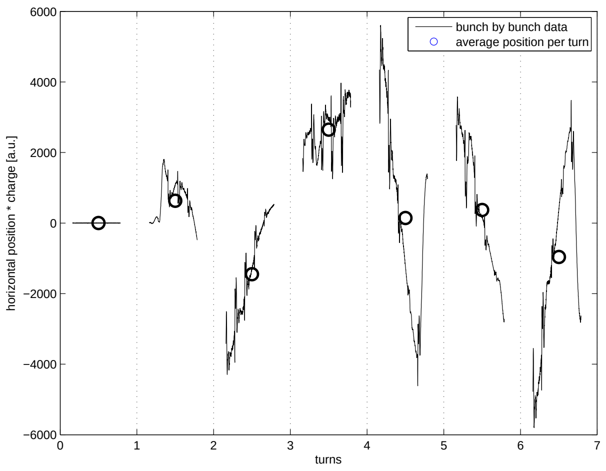

Figure 1: Bunch by bunch data recorded every turn from the injection kick.

with a 2-dimensional Gaussian. When the electron beam has been kicked, it is oscillating in both dimensions, at least due to the coupling between the two planes when the injection kick is only horizontal. The image seen by the camera is the integration of this motion over 800 μs. Therefore, the distribution seen by the camera is not always Gaussian during the kick. After the kick the centroid of the beam undergoes a parametric curve described as a Lissajous curve. As a consequence, the image at the kick shows a more rectangular beam, shown in the figure 2.

In order to simulate the impact of this temporary beam blow-up for a beamline, we integrate the intensity over a 'virtual aperture' of $\pm 3\sigma$, i.e. 110×50 pixels at the center of the camera. The effect of the kick is then seen as a temporary drop in intensity (see figure 2). Finally, figure 3 shows the temporal evolution of the transverse beam dimensions as well as the contours of the line 50% intensity from the maximum at different times before and after the kick. The beam size seen by the camera grows to more than 2.5 times the unperturbed beam size. The analysis of the decay is fitted well with a single exponential decay of $\tau \approx 9$ ms in the vertical plane. In the horizontal plane, the data cannot be fitted well with a single decay, there appear to be a faster decay mechanism with $\tau_1 \approx 1$ ms and a slower with $\tau_2 \approx 9$ ms. In both planes, it takes about 35 ms for the beam to recover its natural size.

DISCUSSION AND CONCLUDING REMARKS

A X-ray pinhole setup equipped with a fast camera can be used for investigation and optimisation of the injection bump. The pinhole camera system provides sufficient accuracy for the beam size and centroid measurement at the ms scale. However, faster camera would imply either a larger flux or a more sensitive camera. Analysis of images permit to quantify the perturbation of stored beam and to assess the perturbation that should be observed on beamlines. We have chosen the normalise the measurement to the beam size as this is generally a stability and quality criteria for beamlines. Most beam beamlines, however, will not have fast enough detectors to observe the transient change of the beam shape, so they will mainly see a brief drop in intensity for typically about 3 transverse damping times. A fast camera with 1200 FPS is well adapted to the measurement as it is fast enough to accurately record the damping of the beam after it has been kicked. The camera sees an integrated motion, which can be a limiting factor for the measurement, but at the same time this is a good diagnostic for investigating the effect to a beamline. Complementary measurement

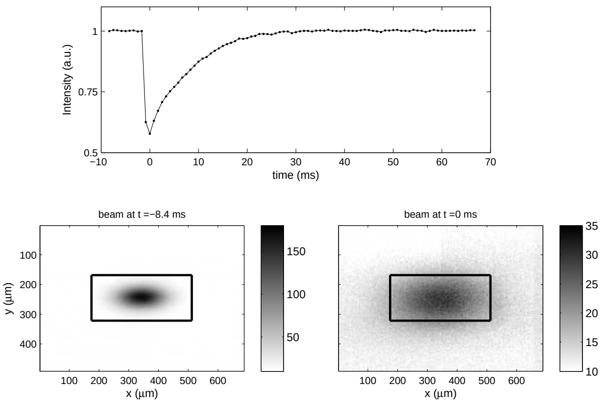

Figure 2: Image of the beam before and at the kick. The square represents an aperture 6 times the r.m.s beam size in both planes. The top graph shows the intensity integrated across the aperture.

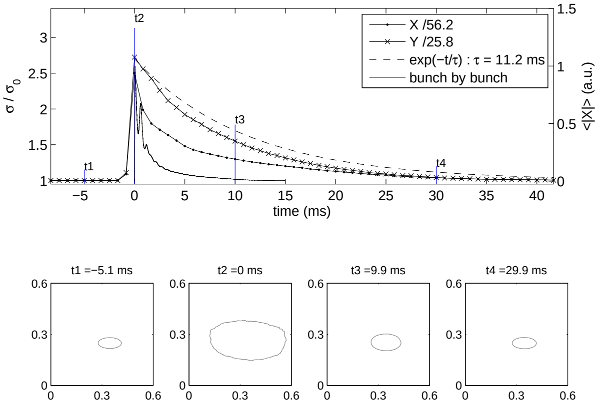

Figure 3: Contour plot showing the FWHM of the beam at several time after a kick. The upper figure shows the beam size, horizontal and vertical (X,Y) after the same kick and the times selected for the contour plots. The theoretical transverse decay is also shown in dash line on the graph. On the right side axis is the decay observed by the bunch by bunch system.

can be done using a bunch by bunch measurement system. Such a system is faster than the camera, and most of the movement can be rebuild with the bunch by bunch data, but at the same time it cannot show the correct decays as the signal is attenuated by decoherence of the beam.

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