INJECTION DIAGNOSTICS USING TRIGGERED BUNCH-BY-BUNCH DATA ACQUISITION *

D. Teytelman†, F.-J. Decker, SLAC, Stanford, USA

Abstract

Quality of injection is very important for reliable and successful operation of colliders and light sources. In this paper we present a technique for real-time monitoring of injection transients in storage rings. We also demonstrate how the data can be used for tuning the injection system. A novel data processing method, coupled with triggered bunch-by-bunch data acquisition system enables one to monitor the effect of adjustments nearly in real time. The acquisition and post-processing technique will be illustrated with the data from PEP-II, DAΦNE, and KEKB.

INTRODUCTION

Injection in a storage ring can excite significant transient processes in the injected bucket as well as perturb stored beam. In the recent years the question of injection quality became more important as colliders and light sources started to adopt top-up (top-off, trickle, continuous) injection mode [1, 2]. In this regime charge is injected into a storage ring during user operation and injection transients directly affect synchrotron light quality or luminosity.

Here we present a technique to characterize injection quality in the transverse plane using a triggered bunch-by-bunch recorder. By automatically extracting the first revolution after injection it serves as a fast diagnostic tool for optimizing kicker amplitudes, relative and absolute timings. This technique can be operated in real-time at 1 Hz update rate serving as an injection quality monitor.

MEASUREMENT TECHNIQUE

A number of high-speed digitizers with appropriate clocking and triggering can be used to capture the beam motion. We have used the data acquisition capabilities of the Gproto bunch-by-bunch feedback system [3].

Data analysis approach presented here makes several assumptions about the ring injection process and the data acquisition. These assumptions are:

- Data acquisition trigger precedes actual injection;
- Between injections the beam is transversely stable;
- Acquired data contains many (10+) betatron cycles;
- All filled buckets are closely matched in charge;
- Injection kicker pulse width is shorter than one turn.

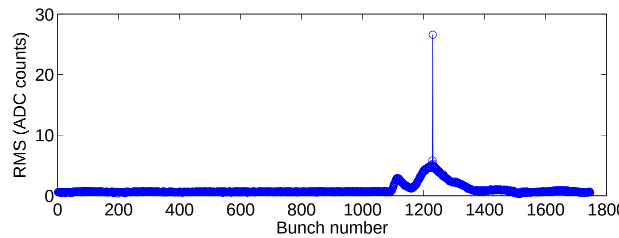


Figure 1: Bunch-by-bunch RMS of a data set from PEP-II HER.

Of these assumptions the last one is not absolutely required — the technique can be easily tailored to longer kicker pulses.

Once the data is acquired we post-process it using a Matlab script. This post-processing extracts what we call the first-turn orbit — transverse beam displacements from nominal positions during the revolution when the injection kicker fires. The first-turn orbit carries an imprint of injection kicker pulse shapes and allows one to extract information on relative and absolute kicker timing as well as amplitude balance (bump closure).

The first step in the post-processing is to perform bunch-by-bunch DC offset removal. This removes static orbit offsets as well as modulations due to uneven bunch currents[1]. In this step we generate data matrix with elements d_{mk} — DC-less signal of bunch m on turn k.

Next we compute the bunch-by-bunch RMS $\sigma_m = \sqrt{\sum_k d_{mk}^2/N}$ where N is the number of recorded revolutions. An example of such an RMS for PEP-II HER is shown in Fig. 1. Note that the RMS of the injected bunch is significantly higher than that of the rest of the beam. From the RMS vector we automatically determine the injected bucket and shift the data samples to place the injected bucket in the middle of the turn.

In the third step we automatically determine the injection turn (first-turn) by computing a turn-by-turn RMS vector $\sigma_k = \sqrt{\sum_m d_{mk}^2/M}$ where M is the number of bunches. For stable operation this RMS value is determined by the noise floor of the ADC and the receiver front-end and is typically below 0.5 counts. As shown in Fig. 2 the turn-by-turn RMS increases dramatically at the moment of the injection. Finding the first data point in this vector to rise above some predetermined threshold, typically taken as $3\min_k(\sigma_k)$, gives us the necessary first turn index (29 for Fig. 2).

* Work supported by U.S. Department of Energy contract DE-AC02-76SF00515 and by the US-Japan collaboration in High Energy Physics

† dim@slac.stanford.edu

[1] Recorded signal is typically a product of transverse coordinate and bunch current. If bunch-by-bunch current information is available it can be used to improve the measurement accuracy.

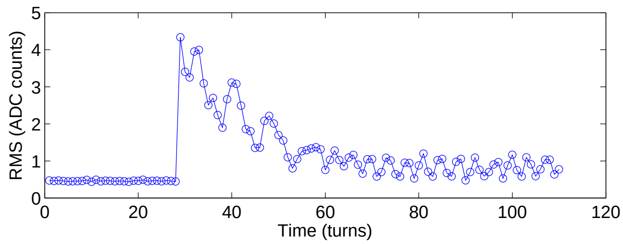
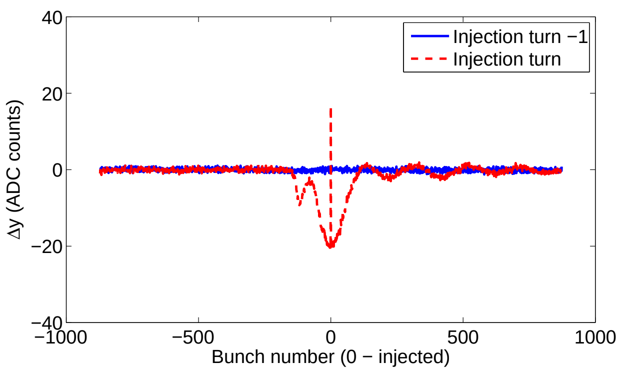
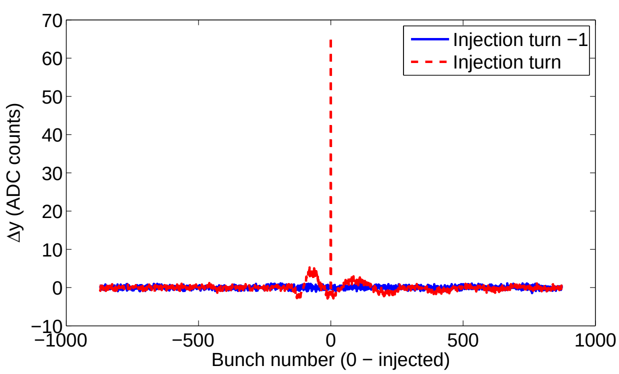


Figure 2: Turn-by-turn RMS of a data set from PEP-II HER.

In order to improve DC orbit rejection we redo offset removal using data only before the injection turn. Finally we plot the extracted first-turn orbit as well as the last turn before injection as shown in Fig. 3(a). Comparing the two vectors we clearly see the injection kicker firing including risetime wiggle due to pulse shape mismatches between kickers. Note that the absolute kicker timing is correct — maximum stored beam bump coincides with the injected bunch. We also observe significant ringing after the pulse. By adjusting relative kicker amplitudes we can improve bump closure as shown in Figure 3(b). In this case stored beam perturbation is reduced from 20 to 5 ADC counts.

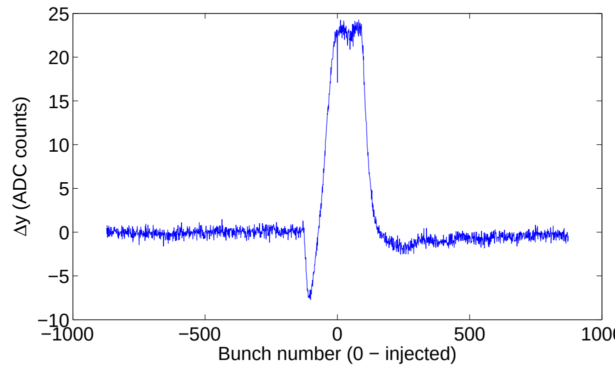


(a) Before kicker amplitude adjustment

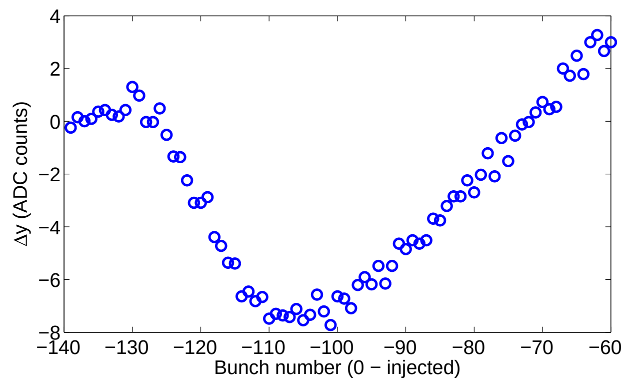


(b) After kicker amplitude adjustment

Figure 3: Extracted first-turn orbit for the PEP-II HER injection



(a) Full one turn



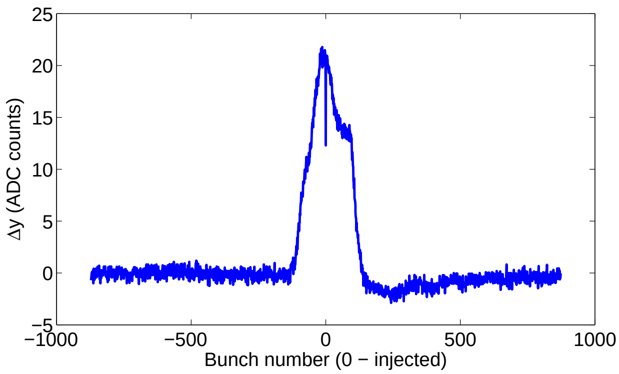
(b) Zoom around kicker rise

Figure 4: First-turn orbit in PEP-II LER before injection kicker tuning.

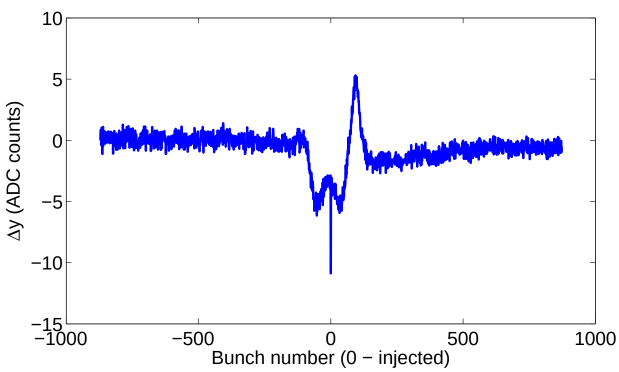
EXPERIMENTAL RESULTS

First we present analysis and tuning of injection into PEP-II LER. In this case the tuning procedure was performed parasitically while the collider was delivering luminosity and was limited to adjusting injection kicker timing and amplitudes. Figure 4(a) shows the initial first-turn orbit before any adjustment. From this plot we can draw several conclusions. First of all, there is a relative timing error between the two injection kickers, since the bunches from -130 to -70 are deflected in the negative direction while the main pulse shows positive deflection. By zooming in in that region as shown in Fig. 4(b) we can estimate the timing error. Around bunch -130 the first kicker starts rising. Around -110 the rising edge of the second kicker stops the deflection increase. Thus the error is around 20 bunches or 84 ns. In order to center the bump on the injected bunch we need to shift the second kicker earlier.

First-turn orbit taken after this adjustment is shown in Fig. 5(a). At this point the injection takes place very close to the peak of the injection kicker pulse. Next we can adjust the amplitude balance for better bump closure. Figure 5(b) shows the injection orbit after one of the adjustments. Clearly the amplitude has been overcompensated creating displacement with the opposite sign. Final adjustment of the kickers has to take into account not only stored



(a) After timing adjustment



(b) After amplitude adjustment

Figure 5: First-turn orbits in PEP-II LER during injection kicker tuning.

beam perturbation but also the detector backgrounds generated by the injected bunch. Leaving in some amount of orbit bumping is typically used to find an injection ”sweet” spot with respect to backgrounds.

The technique presented here has been tested in several accelerators in addition to PEP-II. In Fig. 6 the first-turn orbit after injection into KEKB LER is shown. In this machine two bunches with separation of 49 RF buckets are injected simultaneously [4]. On the plot these are placed in locations 0 and 49. KEKB injection kicker is specified to have 1 μs rise and fall times. In Fig. 6 the significant orbit

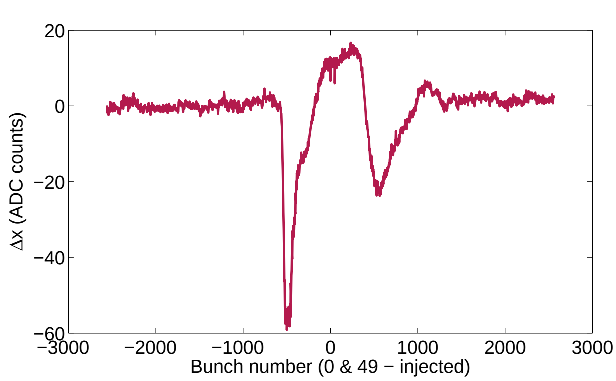


Figure 6: First-turn orbit in KEKB LER.

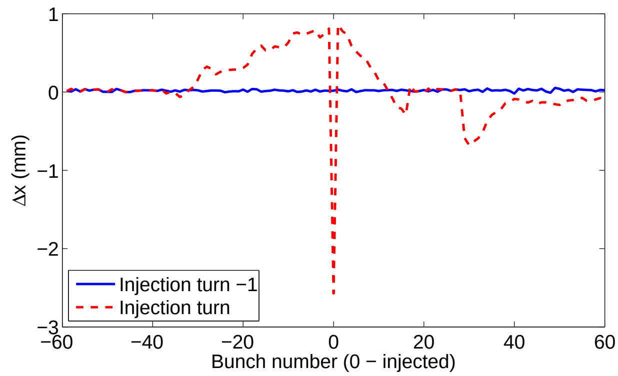


Figure 7: First-turn orbit in DAΦNE positron ring.

perturbations last for roughly 3 μs, suggesting both relative timing and pulse shape errors. At the same time beam perturbation at the center of the pulse is relatively small and suggests good amplitude balance.

It is possible to calibrate the front-end of the data acquisition system by creating an orbit bump at the proper BPM location. For measurements in DAΦNE such calibration has been performed. As a result one can present the first-turn orbit in physical millimeter units as shown in Fig. 7. Relative kicker timing error is evident in the negative deflection of bunches 11-40 (zero-signal region is the 12 bunch fill-pattern gap).

SUMMARY

Triggered bunch-by-bunch data acquisition provides a wealth of beam diagnostic information. Automated post-processing techniques allow one to quickly tune the injection system and to periodically verify the injection quality. Analysis of first-turn orbits provides information on several different types of injection system errors such as amplitude imbalance, relative and absolute timing, and phase advance. Future developments should include calibration to actual beam motion and automated kicker adjustment hinting.

REFERENCES

[1] J. Turner *et al.*, “Trickle-charge: A new operational mode for PEP-II,” in *9th European Particle Accelerator Conference (EPAC 2004)*, pp. 881–883, European Physical Society Accelerator Group, 2004.

[2] A. Lüdeke and M. Muñoz, “Top-up operation experience at the Swiss Light Source,” in *EPAC 2002: proceedings*, pp. 721–723, 2002.

[3] Teytelman *et al.*, “Design and testing of Gproto bunch-by-bunch signal processor,” in *10th European Particle Accelerator Conference (EPAC 2006)*, pp. 3038–3040, European Physical Society Accelerator Group, 2006.

[4] A. Emonoto *et al.*, “Increase of positrons by a high-intensity two-bunch acceleration scheme at the KEKB linac,” in *Proceeding of the 2001 Particle Accelerator Conference*, pp. 3284–3286, IEEE, 2001.