BUNCH BY BUNCH TRANSVERSE BEAM POSITION OBSERVATION AND ANALYZE DURING INJECTION AT SSRF *

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Abstract

Top-up operation has been performed at SSRF since Dec. 2012. Orbit disturbance every 10 minutes decreased the quality of synchrotron radiation. In order to minimize this disturbance the tilts and the timing of injection kickers need to be tuning carefully based on real beam information. A set of button type pick-up and a scope based IOC were employed to capture the transient beam movement with bunch by bunch rate during injection. Several sets of observation and analyze will be discussed in this paper.

INTRODUCTION

Top-up operation mode is becoming the standard mode of operation in most of the third generation light sources.[1] The basic aim of a top-up operation is to provide practically constant beam current in the storage ring to overcome lifetime limitations and to keep a constant photon flux for a thermal equilibrium at the beamlines.

SSRF officially started top-up operation for user experiments in December 2012.[2] Automatic processes control the timing of the injection and select the bucket in which to inject the single bunch. The bunch index at every injection pulse is determined from a filling pattern monitor and a comparison with the desired bunch pattern. The injection interval is set to 10 min, and 30 bunches with the smallest charges in 500 bunch train are refilled with about 0.08nC each in one injection cycle.

Injection in a storage ring can excite significant transient processes in the refilled bunch as well as perturb stored bunches. It is crucial to suppress the stored beam oscillation during the top-up injection because it modulates the SR intensity and interferes directly with the user experiments.

The SSRF injection scheme consists of four fast kicker magnets placed in a long straight to create a closed beam bump, as shown in Fig. 1.

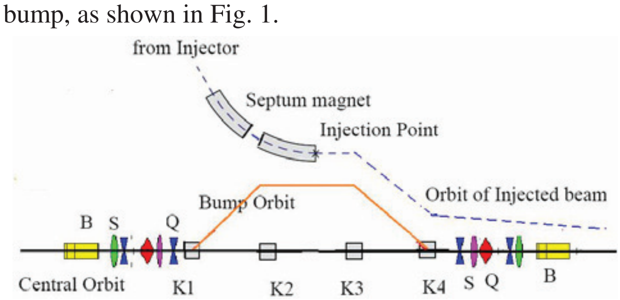

Figure 1: Layout of SSRF ring injection system.

If the current pulses of four kicker magnets perfectly match each in amplitude and phase the local bump will be closed and there will be no injection disturbances for users. However, it is very difficult to provide the complete closed bump because of the magnetic field errors, timing jitters, and nonlinear effects such as from sextupole magnets inside the bump.

Figure 2 shows a measured current waveforms and current deviation of four kickers in SSRF. In this case Top-up injection is not transparent for users. The leaked magnetic field (ΔI_K) will be sensed by all bunches in three turns. Orbit disturbances will be different for each bunch and its amplitude will depend on the bunch index in the train.

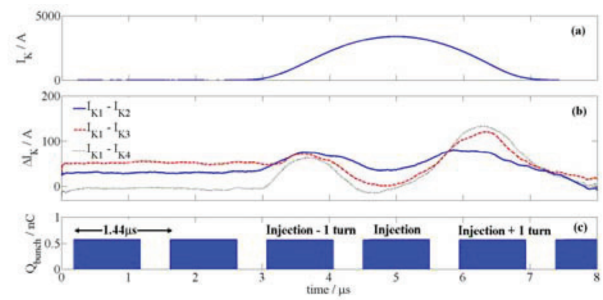

Figure 2: Measured current waveform of injection kickers.

During the past threes years the orbit disturbance as large as mm level due to poor kickers matching had been observed using Libera turn by turn data. However, the bandwidth of Libera is not large enough to retrieve the individual bunch information to analyze and locate leaking sources of magnetic filed. In order to fully understand what happened during injection and guide the optimization of injection system a dedicated broadband diagnostics tool is required. In this paper we present a technique to characterize injection quality in the transverse plane using an digital oscilloscope embedded IOC with capability of bunch-by-bunch position measurement.

DIAGNOSTICS TOOLS

Two kinds of broad band instruments: digital transverse feedback processor and fast gated camera (ICCD) have been widely used to record and study transient behaviour of individual bunch during injection. However, output data of transverse feedback processor is relative position and the sampling rate of ICCD is not truly bunch-by-bunch. These technique shortages define an application limit.

To solve this problem a digital oscilloscope embedded EPICS IOC was developed in SSRF to do transverse position measurement at bunch-by-bunch rate.[3] Broad band beam signals coupled from four button electrodes, passing through a BPF (central frequency 500MHz, BW

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300MHz), are feed into four channels of scope directly. To satisfy bunch-by-bunch analyze requirement an high performance digital oscilloscope, practically Agilent DSO9064A (analogue BW 600MHz, real-time sampling rate 5GHz for 4 channels, and 100M samples/ch onboard buffer), is adopted. Voltage waveforms from four electrodes introduced by passing electron bunches will be recorded simultaneous at 5GHz sampling rate. If the sampling rate or its fraction is equal to machine RF frequency (synchronized sampling) the peak value of raw data can be used to calculate bunch charge and bunch position using Δ over Σ method directly. But for SSRF, RF frequency is usually varying between 499.654MHz and 499.674MHz depending on ground temperature. In this case using raw data will introduce a large sampling phase noise due to difference of RF and sampling frequency.

A specific data processing method we called "virtual re-sampling" technique is employed to solve this problem. With correct sampling frequency (or time interval between two samples) and initial sampling phase (T0 of the first sample), synchronizing sampled data can be calculated using spline interpolation method. Ideal sampling frequency, which is equal to practical RF frequency, can be determined by using zero-padding FFT method which makes the data length 128 times than the raw data. Meanwhile the initial sampling phase can be defined manually based on raw waveform. Fig. 3 shows a pair of scope sampled raw data and virtual re-sampled data.

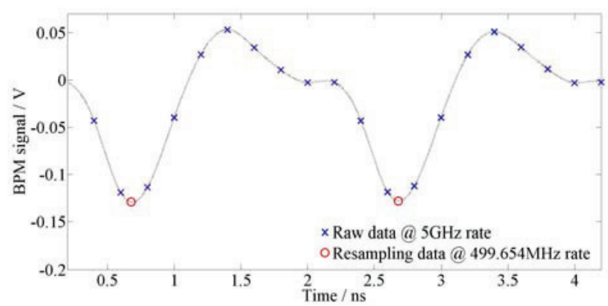

Figure 3: Raw data acquired by digital oscilloscope and virtual re-sampled data using 3rd order spline interpolation method.

After acquiring the peak value of signal waveform for each bunch Δ over Σ calculation can be used to get the bunch charge and absolute postion. The sample size for each bunch is up to 14400 turns due to the large buffer of scope, which makes precise harmonic analyze for individual bunch possible.

Figure 4 shows a set of typical measurements during injection: (a) bunch filling pattern, refilled bunch index can be identified by comparing filling pattern before and after injection, which is 141 in this case; (b) orbit movement of the refilled bunch, which is fixing of betatron oscillation and synchrotron oscillation; (c) orbit movement of a stored bunch, which is almost pure betatron oscillation; (d) correspond FFT of (b) and (c).

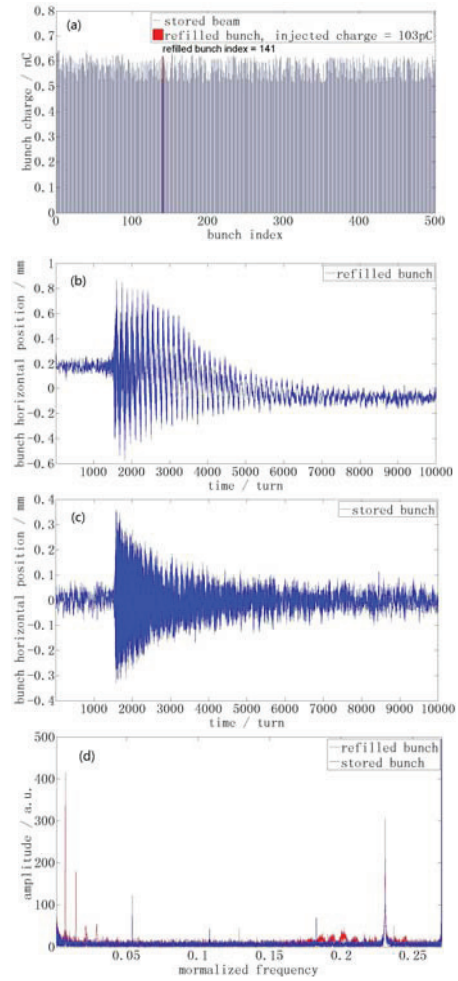

Figure 4: A set of bunch by bunch measurements during injection.

OBSERVATION

Using above diagnostics instrument as large as 14400 turns of triggered bunch charge, absolute transverse position data can be recorded during injection. Time domain and frequency domain analyze of this data are very good tools for injection quality investigation.

Optimization of Injection Kickers

Mismatch of magnetic field of kickers will result residual betatron oscillation in horizontal plane. So comparing orbit movement waveform and oscillation amplitude in time domain will be an easy and direct way to evaluate the performance of injection system.

Figure 5 and Fig. 6 show the comparison of average orbit movement in different stages of SSRF. In the early stage (Dec. 14, 2011) the matching of four kickers was quite poor. Horizontal residual betatron oscillation was as large as 6.8mm peak to peak. Tilts error of kickers also introduced a large residual oscillation (0.4mm) in vertical plane. During Summer shutdown of 2012 injection system had been upgraded. Four remotely controllable platforms were added to adjust the tilts of four kickers independently. Delay line between pulsed PSs and current

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waveform were tuned based on beam experiments. After that (Jan. 14, 2013) horizontal residual betatron oscillation decreased down to 0.85mm and vertical residual oscillation is smaller than 0.08mm. With very careful tuning of injection kickers (Jul. 15, 2013) both horizontal and vertical residual oscillation can be decrease again (0.43mm H / 0.04mm V) but almost reach the baseline.

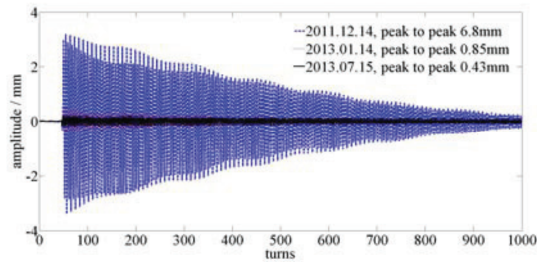

Figure 5: Measured horizontal orbit oscillation by injection kick, which reflects the amplitude and phase mismatch of kicker current waveforms.

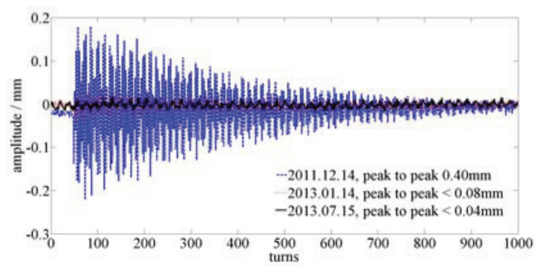

Figure 6: Measured vertical orbit oscillation by injection kick, which reflects the tilts error of kickers.

Energy Mismatch of Refilled Bunch

Large synchrotron oscillation can be easily observed with refilled bunch (Fig. 3). It is highly possible due to energy mismatch between fresh beam and the storage ring. If it is true oscillation amplitude should be linear related to refilled charge. 23 samples in a week had been analyzed to confirm this assumption, which is shown in Fig. 7. Energy oscillation amplitude is acquired by FFT analyze of refilled bunch position data.

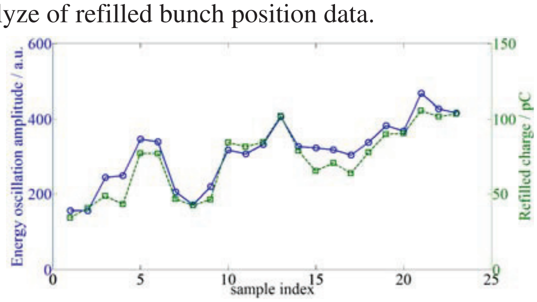

Figure 7: Energy oscillation amplitude of refilled bunch and corresponding refilled charge.

It is obvious that synchrotron oscillation amplitude strongly correlates with refilled bunch charge as we expected. Radio of oscillation amplitude over refilled bunch charge, which reflects the mismatch degree of fresh bunch and the storage ring, can be used as a flag to help injector optimization.

Repeatability and Stability of Injection

A stable and repeatable injection procedure is the fundamental condition for any further improving effort to minimize orbit disturbance. So stability and repeatability of injection procedure need to be evaluated. Harmonic analyze of each bunch position data and waterfall plot are selected as investigation tools. Horizontal position spectrum data in a week has been put together shown in Fig. 8.

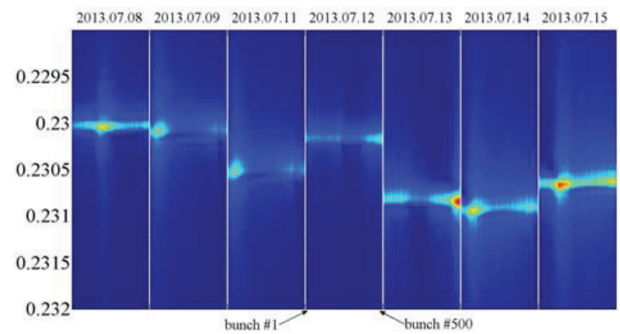

Figure 8: Waterfall displays of horizontal position spectrum during injection in a week.

Comparing the amplitude distribution pattern of betatron oscillation we can easily find that stability and repeatability of injection procedure are not good as we expected. During in this investigation period beam behaviour can be classified into three groups. Group one includes day 2, 3 and 6. Group two include day 4, 5. And group three includes day 1 and day 7. The differences between three groups look like mainly coming from timing shift of trigger signal of kickers.

CONCLUSION

A bunch-by-bunch position measurement instrument based on commercial digital oscilloscope has been implemented in SSRF to evaluate the injection quality. Tilts error, amplitude and phase mismatch of injection kickers, energy mismatch of fresh beam, and repeatability of injection procedure can be investigated with this tools. Further optimization of injector or injection system can be done based on these investigations.

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