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INJECTION COMPARISON USING BUNCH-BY-BUNCH BEAM SIZE MEASUREMENT SYSTEM AT SSRF*

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Abstract

Injection transient process happens every 5-10 minutes in storage ring during normal top-up operating mode at SSRF, which is a proper window for machine status and injection performance evaluation. In the recent year, a bunch-by-bunch beam size measurement system has been implemented at SSRF, which has the capability to offer transverse bunch-by-bunch position and size information and is a powerful tool for injection study. In this paper, we summarize three injection study results from July 2017 to April 2018, including betatron oscillation amplitude, spectrum, horizontal tune and damping time comparison. The oscillation amplitude and temporal behavior of recent injection are all better than results before contributed to the injection optimization work during maintenance in 2018 winter. In addition, the principal component analysis method is also applied to further study the injection behavior in turn-by-turn or bunch-by-bunch direction to the refilled bucket.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF) is the third generation light source. Since December 2012, a Top-up operation mode has been performed at SSRF [1]. An injection process happens every 5-10 minutes to refill charge to stored bunches for defending particle and energy loss. It is a normal instability disturbance to light source users and also a bottleneck for light source development and diffract-limited storage ring implementation. Hence, it is important to optimize injection transient process, improve injection quality. On the other hand, the injection also provides a proper window for storage ring status evaluation and test environment for fast beam detection system of beam instrumentation.

For fast beam size study during injection transient process and other transverse instabilities, we beam instrumentation group of SSRF developed a bunch-by-bunch beam size measurement system, which could offer bunch-by-bunch position and size information in thousands turns after trigger signal [2]. It is composed of a direct-imaging optical front-end system, a high-speed photon detector based on 16-channels photomultiplier (PMT) array from Hamamatsu Photonics, a signal pick-up and conditioning electronics and high-sampling rate oscilloscope for signal acquisition. In data analysis, the principal component analysis (PCA) method is applied for noise reduction and a Gaussian fitting algorithm is used for position and size calculation based four-channels signal from PMT array detector. An injection transient process had been successfully captured and analyzed using the system, and the behavior of betatron oscillation of position and size from kicker field mismatch and previous bunches wakefield were separated and compared in temporal wave and spectrum [3]. In addition, through the betatron oscillation behavior, we can figure out some transverse machine operation parameters as oscillation amplitude, horizontal tune and damping time. Hence, it is also a powerful tool for machine status and injection performance evaluation.

In this paper, we compare the temporal wave and spectrum of betatron oscillation, horizontal tune and damping time from three captured injection results to evaluate the machine status and injection performance. Furthermore, we analyze the oscillation modes within turn-by-turn or bunch-by-bunch and point out the refilled bucket using PCA method.

INJECTION COMPARISON

SSRF has two long-term maintenances in summer and winter every year. After maintenance, the machine parameters will be slightly changed and some problems will be optimized. Hence, we choose three injection data captured in July 2017, January 2018 and April 2018, which are respectively before 2017 summer maintenance, before 2018 winter maintenance, and after 2018 winter maintenance.

The comparison is composed of initial oscillation amplitude, temporal wave, spectrum and damping time. They will be discussed in following subsections.

Initial Oscillation Amplitude

The peak-to-peak maximum position oscillation amplitude of every bunch in first 10 turns after injection were picked up for initial oscillation amplitude comparison of three injections. Figure 1 showed the initial oscillation amplitude distribution in bunches of the three injections.

From Figure 1, we could figure out that similar distributions in bunches happened in three injections. The maximum oscillation amplitude appeared in the first bunch chain, which is mostly contributed by kicker mismatch, and it decreased from top to end. The minimum oscillation usually was at the second bunch chain, which is mostly contributed by wakefield from previous bunches oscillation. In the next bunch chains, oscillation would raise up close to the first bunch chain.

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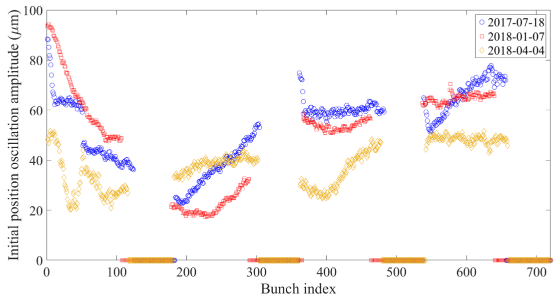

Figure 1: Initial position oscillation amplitude distribution in bunches of three injections.

Comparison with three injections, the amplitude of July 2017 and January 2018 was similar and the maximum amplitude of April 2018 was only about half of the other injections. Hence, we could have a conclusion that injection process had been optimized during 2018 winter maintenance.

Temporal Wave

If we focused on the bunch of maximum position oscillation amplitude, the temporal wave comparison result of position and size was shown in Figure 2 and Figure 3.

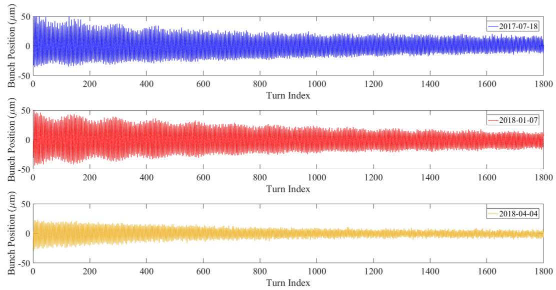

Figure 2: Position temporal wave comparison of maximum amplitude bunch in three injections.

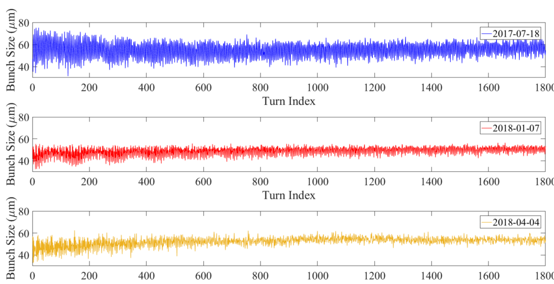

Figure 3: Size temporal wave comparison of maximum amplitude bunch in three injections.

In position temporal wave, the oscillation amplitude of April 2018 was smaller than others, same conclusion as before. In addition, the behavior of synchrotron oscillation sidebands, periodic envelopes along damping, was disappeared in April 2018.

In size wave, the oscillation in July 2017 expanded in both directions, while other two injections only oscillated in diminished direction. It might be the horizontal and vertical coupling effect of the storage ring.

Spectrum

Oscillation amplitude, horizontal tune, synchrotron oscillation sidebands and other information all could be obtained from the spectrum of turn-by-turn position and size behavior. Figure 4 and Figure 5 showed the spectrum of position and size respectively.

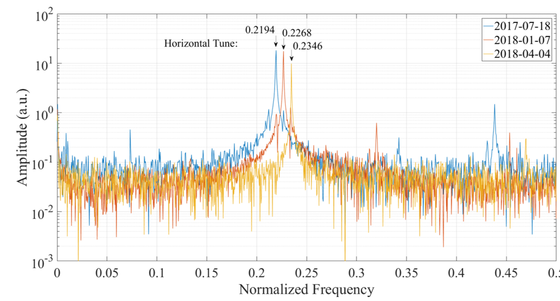

Figure 4: Position spectrum comparison of maximum amplitude bunch in three injections.

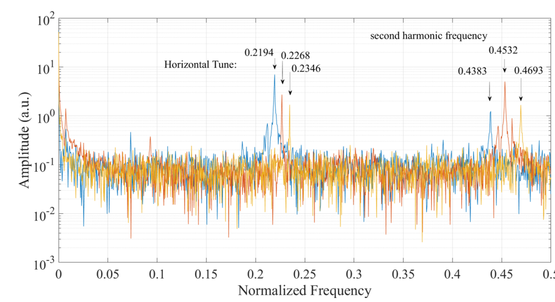

Figure 5: Size spectrum comparison of maximun amplitude bunch in three injections.

In position spectrum, the frequency peak presented at the horizontal tune and a small peak was at its second harmonic frequency. While, in size spectrum, the second harmonic frequency displayed similar amplitude as horizontal tune in three injections.

The horizontal tune moved to higher frequency along the injection captured timing. And also, there were no synchrotron sidebands in the yellow channel (April 2018 injection), as the same conclusion in temporal wave discussions.

Damping Time

The transverse damping time of storage ring could be analyzed from the turn-by-turn spectrum using peak curve fitting [4]. The fitting type was derivated from classical temporal damping function and its Fourier transform in the spectrum. Figure 6 showed the fitting results and calculated damping time of three injections.

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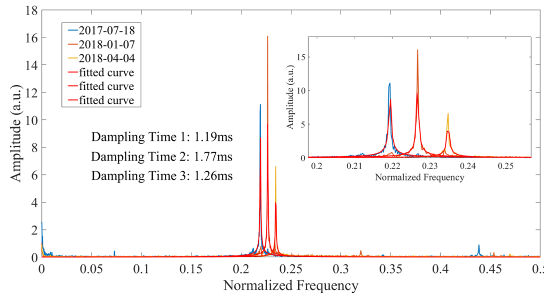

Figure 6: Damping time fitting results in three injections.

The damping time was 1.19 *ms* in July 2017, 1.77 *ms* in January 2018 and 1.26 *ms* in April 2018. The damping time of January 2018 injection was larger than others because the transverse feedback system closed at that period. Comparing with numbers in July 2017 and April 2018, the damping time had a little enlarged.

However, from the detailed plot of Figure 6, the fitting curve could not completely match the peak and its envelope. The deviation was coming from fewer data points on the spectrum peak. Hence, the spectrum peak curve fitting method had precision limitation and the results should be verified by other calculation methods.

OSCILLATION MODE ANALYSIS

The PCA method was applied to signal noise reduction in system data processing. Furthermore, it also had advantages in oscillation mode analysis. In the section, we discussed the oscillation mode analysis both in bunch-by-bunch direction and turn-by-turn direction using PCA method.

Turn-By-Turn Mode

Figure 7 showed the spectrums of first 5 modes after PCA analysis of turn-by-turn position oscillation. The mode 1 and 2 pointed out the main betatron oscillation from kicker mismatch with the horizontal tune at peak. Mode 3 might be the residual oscillation of kicker mismatch and mode 4 might be the wakefield oscillation with biased center frequency and different envelope.

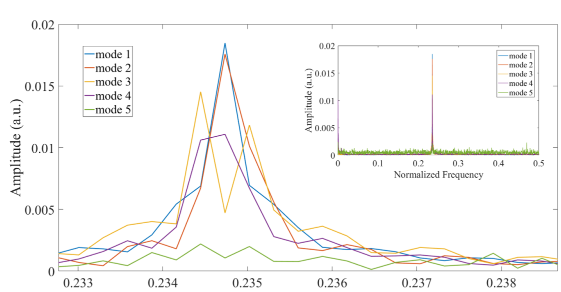

Figure 7: PCA modes spectrums of turn-by-turn position oscillation.

Bunch-By-Bunch Mode

In bunch-by-bunch mode analysis, Figure 8 showed the first 4 modes waves comparison of bunch-by-bunch position and size distributions after PCA analysis. The position and size bunch-by-bunch distributions in four modes were similar, which demonstrates the result consistency. In mode 2,3 and 4, a highlight bunch displayed in size distribution with bunch ID 398, which expressed a refilled bucket.

Figure 9 showed the spectrum waterfall plot of turn-by-turn size oscillation, which was another method to point out the refilled bucket. In bunch ID 395-400, the spectrum had a huge enlargement with refilled buckets expression. Hence, the conclusion in Figure 7 was credible.

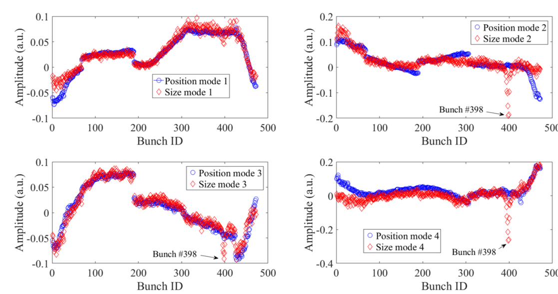

Figure 8: First 4 modes waves comparison of bunch-by-bunch position and size distributions after PCA analysis.

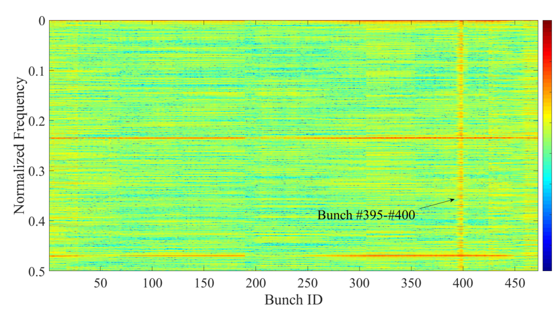

Figure 9: Spectrum waterfall plot of turn-by-turn size oscillation.

CONCLUSION

With bunch-by-bunch beam size measurement system, the injection comparison between July 2017, January 2018 and April 2018 had been completed successfully. The differences in initial oscillation amplitude, temporal wave, spectrum and damping time of three injections had been analyzed. The injection process had been optimized during 2018 winter maintenance with less oscillation amplitude and no synchrotron sidebands.

In addition, the PCA method was applied for oscillation mode analysis in both turn-by-turn and bunch-by-bunch directions. Different turn-by-turn behaviors of each mode and refilled bunch ID had been figured out, which could be deeply developed.

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