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SUPPRESSION OF STORED BEAM OSCILLATION AT INJECTION BY FAST KICKER IN THE SPRING-8 STORAGE RING

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Abstract

When the injection bump orbit is not closed perfectly, the horizontal stored beam oscillation of the amplitude more than 0.5 mm (r.m.s.) is excited at the top-up injection in the SPring-8 storage ring. Many efforts had been devoted to reduce the beam oscillation to get this amplitude level. We have made efforts to reduce the oscillation furthermore, as a result, the averaged oscillation amplitude has successfully been suppressed to less than 0.15 mm (r.m.s.) by applying a fast counter kick to the residual oscillation with a pulse width of 500 ns. To confirm the suppression effect, we observed the turn-by-turn photon beam profile at the diagnostics beamline with the undulator. The photon axis oscillation was significantly suppressed down to less than 4 μrad from more than 30 μrad by applying a counter kick at 3rd turn after injection. The bunch-by-bunch feedback system applied during the user time had reduced the oscillation in 80 turns without the kicker correction. By this suppression scheme, in addition to the effect of providing the stable synchrotron radiation, we succeeded in not only shortening the effective damping time but also filling a single bunch current to the any bucket address of the ring in the hybrid filling mode including a single bunch with high current up to 5 mA and a bunch train part of 95 mA in total.

INTRODUCTION

The top-up operation in the SPring-8 was started from May 2004 [1] to improve the effective beam life time which was shortened due to Touchek effect [2] that was enhanced by the reduction of beam emittance. In the top-up mode, the beam must be frequently injected to the storage ring without interrupting user experiment. The effect of disturbance for the stored beam at injection is significant compared with periodical injection, so-called non-top-up mode. On the other hand, when the injection bump orbit is not closed perfectly for the stored beam at the top-up injection, the horizontal stored beam oscillation is excited.

In the SPring-8, four bump magnets are used to form the bump orbit at a beam injection. For injection, four bump magnets are excited by four individual pulsed power supplies. The kick angle for the stored beam energy of 8 GeV is more than 2 mrad at the peak of 8.4 μs half sine shape excitation. To get the kick angle, the output current of power supply reaches to more than 4 kA.

In the SPring-8 storage ring, many efforts had been devoted to reduce the beam oscillation by adjusting the temporal shape and timing of four bump magnets precisely. The oscillation amplitude was improved to acceptable level for SR users by a factor of more than 10 in 2004 [3]. Even after drastic improvements, there were residual oscillations of the stored beam orbit caused by the imperfection of bump magnet pulse shape matching; timing jitters between the four pulses, pulse shape difference of the rising and falling part of the half sine pulses of 8.4 μs width, etc. The magnitude of oscillation was 0.5 mm in amplitude, spike-like 400~800 ns in width which was caused by the mismatch at the rising part, and 0.25 mm amplitude with 1.4 μs width at the falling part mismatch.

The still remaining residual horizontal oscillation of the stored beam directly caused an effective beam size growth by a factor of 1.1, corresponding to 14 μm increase in the horizontal, and the unwanted photon axis oscillation of more than 30 μrad at the rising part mismatch. Furthermore, the residual oscillation also affected a hybrid filling operation with a high current single bunch and bunch train covering about one-third of the storage ring: a single bunch current and the stored bucket address of a high current single bunch were limited by the beam instability caused by the residual oscillation.

FEED-FORWARD FAST COUNTER CORRECTION SCHEME

First of all, we aimed at suppressing the spike-like oscillation which was caused by the non-similarity of the rising part of the output fields. We started the development of the fast pulsed correction kicker system [4] in order to apply a counter kick to the residual oscillation. We had done the studies for suppressing the residual spike-like oscillation with the 33 μrad kick angle with 800 ns pulse width by using two compact fast pulsed power supplies in 2010 [5]. We installed them at the large horizontal beta function point in the small space between components in the storage ring (see the left figure of Fig. 1). The correction was applied during the user time from 2012 for suppression of the spike-like one, which was caused by rising part mismatch.

Following the success, we installed the secondary correction kicker to suppress the broad width and small amplitude oscillation, which was caused by the non-similarity of the falling part of the output fields. The kicker was put at another point with a large horizontal beta function in 2013 (see the right figure of Fig. 1). Now, we are operating the primary and secondary correction kicker systems in the storage ring during the user operation. The residual oscillations

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at injection are suppressed more significantly than before, with this correction kicker magnet added in 2013.

Figure 1: Installed fast correction kickers in the SPring-8 storage ring. Left photo shows the primary fast correction kicker system. Right photo shows the secondary one. The power supplies driving the kicker are put in the radiation and noise shield boxes on both side of the kicker.

We tuned the correction kicker timings by observing the suppression effect with 14 Single Passed Beam Position Monitors (SPBPMs) and considering the phase advance and the betatron function at each position of two correction kickers. Fig. 2 shows a comparison of the oscillation amplitude with and without the correction observed with SPBPMs: horizontal axis is the turn number beginning with zero, meaning the injection timing. In this case, the Bunch-By-Bunch Feedback (BBF) [6] was OFF. The spike-like oscillation amplitude of 0.38 mm at the 3rd turn was reduced by 90%. In this operation, the pulse width and the kick angle of primary kicker were 500 ns and 31 μrad respectively. By adding the secondary correction kicker, the averaged oscillation amplitude was successfully suppressed to the level of less than 0.15 mm within 5th revolution of the stored beam. The pulse width and the kick angle for the secondary kicker were 1400 ns and 12 μrad in this operation. When the beam tilt is occurred horizontally due to the skew contamination of the magnetic field error along the storage ring, the vertical oscillation is also excited by the horizontal oscillation. Fig. 3 shows that the residual vertical oscillations were also suppressed simultaneously by suppressing the horizontal oscillation with counter kicks.

As another way to observe the suppression effect of the stored beam oscillation, we confirmed the oscillation suppression by a BBF monitor. Our BBF monitor is able to acquire the beam position data of turn-by-turn and bunch-by-bunch up to about 2000 turns with the filling mode of uniformly stored 203 bunches. Fig. 4 shows the convoluted oscillation amplitudes (in arbitrary unit) of 128 turns for each bunch. This result indicates the averaged distribution of the oscillation amplitude along the accelerator ring. From the BBF monitor results, we saw that the amplitude was reduced by 70% by applying the correction kickers.

OSCILLATION SUPPRESSION EFFECT

Since the light axis stability is necessary from the view point of photon beam usage, we confirmed the suppression of the light axis oscillation as shown in Fig. 5 with Turn-

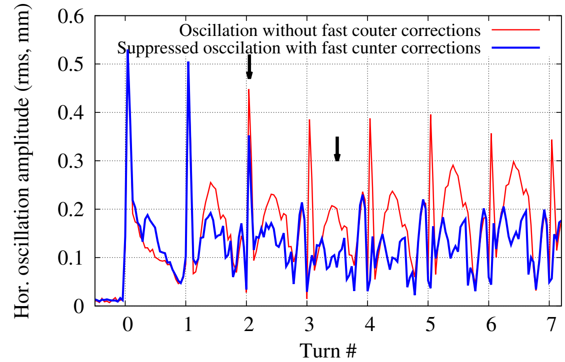

Figure 2: The horizontal oscillation amplitudes observed by SPBPMs with and without the fast counter corrections. Arrows at 2nd and 3rd turn in the figure show each applied timing of primary and secondary kicker respectively.

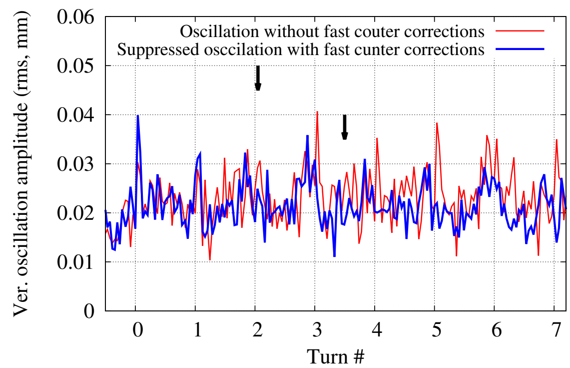

Figure 3: The vertical oscillation amplitudes observed by SPBPMs with and without the fast counter corrections. Meaning of arrows in the figure is same as Fig. 2

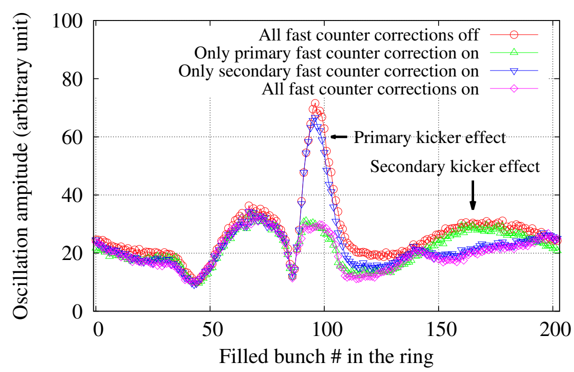

Figure 4: The data of horizontal oscillation amplitudes acquired by BBF monitor. The suppression contributions of each fast counter correction are shown by the arrows.

by-Turn beam Profile Monitor (TTPM) [7], which measures the monochromatic X-ray beam profile of the undulator radiation at the beam diagnostic beamline. TTPM system enables us to observe fast phenomena such as oscillations of the stored beam at injections for top-up, blowups of transverse size and energy spread of a high-current single bunch caused by beam instabilities. The 200 ns gate window of TTPM was fixed at the timing of the rising part mismatch of

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bump fields, where a huge spike-like oscillation was caused. The oscillation in Fig. 5 indicates the turn-by-turn light axis amplitude observed at a point of the maximum horizontal oscillation amplitude.

As shown in Fig. 5, a huge light axis oscillation was generated after the injection and the data was out of the acceptance angle of 30 μrad of the TTPM up to the 10th turn. After applying the fast correction kicker at the 2nd turn, the oscillation was reduced at least by 87%, down to 4 μrad. The change of the oscillation phase by applying the kicker was seen after 3rd turn. Without the kicker correction, it took about 80 turns to reduce the oscillation down to less than 4 μrad, which was determined by the damping time with the BBF system. In this measurement, the BBF system was always ON. When the kicker correction was switched off, the damping time becomes 1.3 times longer, and this indicates that the fast correction kicker well suppress the initial huge oscillation and this helps the BBF to work more effectively.

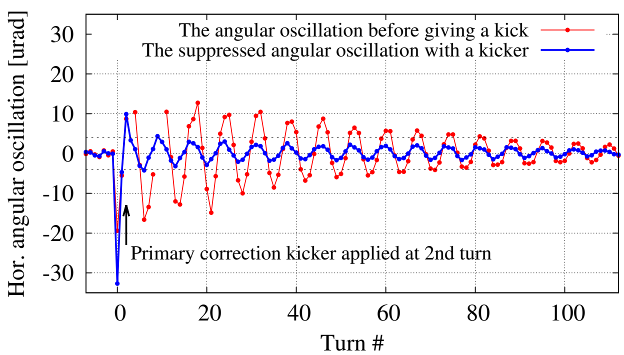

Figure 5: Horizontal light axis oscillations acquired by the TTPM. The two dashed lines indicate ±4 μrad level.

REMAINING PROBLEM

We started monitoring the beam oscillation reduction during user time operation by using TTPM in 2013 to confirm the reduction effect of the fast correction kicker. In this long-time measurement, we found the reduction effect was gradually loosed over day. This phenomenon was occurred by the slight changes of the fire-timing of four bumps with the seasonal drift of the temperature in the bump power supply room. To estimate this phenomenon quantitatively, we did the following studies. By shifting the 200 ns gate window, TTPM can also observe the oscillation structure around the injection timing. Fig. 6 shows the experimental result of the light axis oscillation amplitude observed by shifting the gate window with a 200 ns step as a function of the gate timing. The oscillation structures with and without the fast correction kicker were similar to that acquired by the SPBPM and BBF monitor systems. At the peak position of 1 μs gate timing, the light axis oscillation was significantly suppressed by a factor of 5 by applying a counter kick. We however observed that the light axis oscillation amplitude and hence the reduction performance was drastically changed when we shifted the fire-timing of one bump magnet from -20 ns to +20 ns as shown in Fig. 6. In the cases of ± 10 ns shifts, the reduction ratio did not change within 10%. The timing fluctuation due to fire-timing jitter of shot-by-shot and the timing drift due to day-night and seasonal temperature drift are estimated from 5 to 7 ns and from 10 to 20 ns respectively.

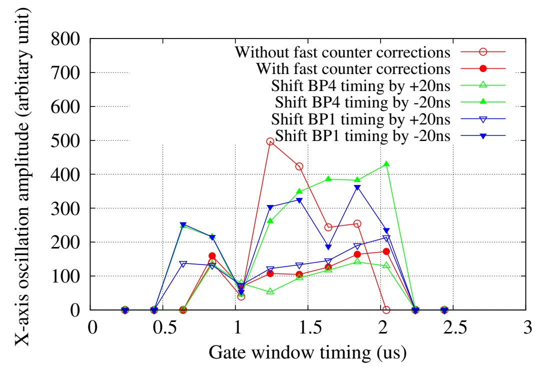

Figure 6: The distribution of horizontal light axis oscillation at around injection timing.

CONCLUSION

The fast correction kicker system plays an important role in not only the stable synchrotron radiation light supply but also the achievement of the various hybrid fillings including a high current single bunch and multi-bunch filling. The reduction ratio of the horizontal oscillation observed by the SPBPM, BBF, TTPM systems had consistency and reached to 90% level compared with no kicker correction. Now, we are planning the improvement of the feed-forward scheme of this kicker system. Because we found that the oscillation phase and the amplitude were drastically changed just by the 20 ns timing shift of only one bump magnet. The timing shift is thought to be caused by the seasonal change of the environmental temperature around the bump power supply system. We are considering the feedback scheme to keep the suppression effect at the initial level during the user-time and making the room temperature stable.

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