SUPPRESSION OF STORED BEAM OSCILLATION EXCITED BY BEAM INJECTION

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Abstract

Top-up operation has been started from May 2004 at SPring-8. For this operation it is important that frequent beam injections should not excite the oscillation of stored beams. However, injection bump orbit was not closed perfectly and residual beam oscillations lead to increase of effective beam sizes by twice and three times in the horizontal and vertical direction, respectively. We then tried to reduce these excited oscillations to less than one-third of the nominal beam sizes. For the suppression of horizontal one, we applied a novel scheme to reduce the effect due to the nonlinearity of sextupole magnets by adjusting the strength ratio of the sextupoles. The field similarity of bump magnets was also improved by replacing them with newly designed ones, where the effects of eddy current at the end plates were reduced. These countermeasures suppressed the horizontal oscillation by about one order. For the suppression of vertical one, the tilt angles of bump magnets were adjusted and the vertical oscillation was reduced to about half of initial amplitude. For further reduction of these oscillations, corrections with pulse-magnets are used.

INTRODUCTION

SPring-8 is one of the third generation synchrotron radiation (SR) facilities. The electron beam energy is 8GeV. Various efforts have been made to increase the brilliance of X-ray by reducing the emittance of electron beam, which however reduced the beam lifetime due to Touchshek effect [1]. To improve the effective lifetime, top-up operation is a good solution [2]. However if the injection bump is not closed, the oscillation of stored beam is excited with betatron frequency. Though this oscillation is damped with damping time of 8 ms, it leads to the momentary increase of effective beam size. Mask signal is then prepared for SR users for masking the data during injection. But some users who use imaging plates complain that they would have difficulty with the intensity modulation even in a few milliseconds. Most users also do not want to introduce complicated mask system in their experiment. So we tried to reduce the oscillation amplitudes of stored beam to the acceptable level for such users.

We use four pulse magnets for making injection bump. Two of them have 320mm-long pole length and rest of them have 170mm. The magnet was made by stacking 0.1mm thick silicon steel lamination. The end plates made of 20mm-thick stainless steel were used to hold the thin plates. The waveform of the bump field is half sine with about 8μs width. The beam is injected at its peak amplitude.

The pulse width of the bump corresponds to the period of two turns of the ring. We have several kinds of filling patterns in user operation including multi-bunch in which 80% of buckets are filled. So it is necessary to close the bump orbit at any timing.

In the following we describe how we measure the oscillation amplitude, and show sources of error kicks in the bump. We also present counter measures for these sources and what we could achieve.

SOURCES AND CURES

The oscillation amplitude just after the beam injection was measured by using turn-by-turn monitor. After the trigger signal of beam injection is received, the horizontal and vertical positions at 288 points in the ring are measured turn by turn up to 4096 turns. Because the peak-hold time of the circuit is about 2μs, single-bunch beam is stored to measure the amplitude at the specified timing. To measure the oscillation amplitude at whole timing of the pulse bump, the position data is taken by shifting the trigger timing of the bump. The strength of the error kick is calculated by fitting the position data.

Error in field patterns of magnets

The deviations in field shape of four bump magnets were first examined as the source of horizontal oscillation. The waveform of the magnetic field was obtained by integrating the output signal from an air core search coil located between the pole of the magnet and the ceramics chamber. We carefully adjusted the trigger timings for power supplies of magnets. The pulse widths were adjusted by changing the inductance of matching circuit. Though the patterns were carefully adjusted, there remained deviations near starting point and at ending point of the waveform as shown in Fig. 1 (a). It was suspected that the eddy currents at the end plates were the cause of these errors. So we made new magnets with non-metallic endplates [3]. Fig. 1 (b) shows waveform of the new bump magnets, which have non-metallic end plates. The similarity of field patters was improved with new magnets.

Effect of sextupoles in injection bump orbit

The peak height of the injection bump is about 14.5mm. The strengths of bump magnets were adjusted to close the bump at its peak height. The large horizontal oscillations were observed before and after the peak. These amplitudes were sensitive to the strengths of sextupoles. We found that the nonlinearity of sextupole fields in

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bump orbit made these oscillations and found that there is an optimum ratio of sextupoles to minimize these oscillation amplitudes [4, 5].

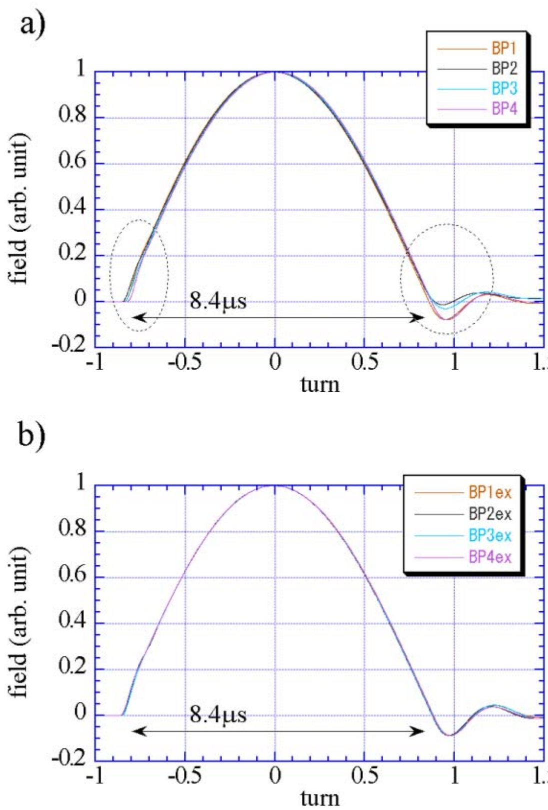

Figure 1: a) Magnetic field with old magnets and b) with new magnets

Source of vertical oscillation

After the horizontal oscillation amplitude was reduced, the vertical beam oscillation still remained as a source of perturbation. The error kicks had similar pattern to the half sine waveform. The errors were mainly produced by tilt of the magnets. We adjusted the tilt angles of two bump magnets to cancel the error kick.

Further reduction of oscillation amplitudes

After counter measures are applied, the residual oscillation amplitudes can be further reduced by introducing additional corrector magnets. Corrector magnets with ceramics chambers were installed for both horizontal and vertical corrections. For horizontal and vertical corrector magnets the maximum values of error kicks were 10μrad and 1μrad, which correspond to the excitation currents of 50A and 5A, respectively. The shapes of residual error kicks were so complicated that we applied system using an arbitrary waveform generator (AWG) that can deal with fast changes (~1MHz) of the pulse shape. After the injection trigger signal is received, the signal from AWG was amplified and fed to a corrector magnet. We could not find commercially available amplifier that met our purpose. So we made amplifiers in house.

RESULTS

The progress in reduction of oscillation amplitude is shown in Fig. 2. It shows the typical amplitude of horizontal and vertical beam oscillation at the centre of an insertion device using the data from the turn-by-turn monitor. The horizontal axis is a time in unit of revolution period and origin is set to the timing of beam injection. The original oscillation amplitude is shown by the solid line with open circles. The maximum amplitude reached to 2.5mm, which is 6 times larger than the horizontal beam size. By introducing the optimum set of sextupole strengths, the amplitude was drastically reduced, which is shown by the dashed line with triangles. The amplitude was reduced to about one-tenth.

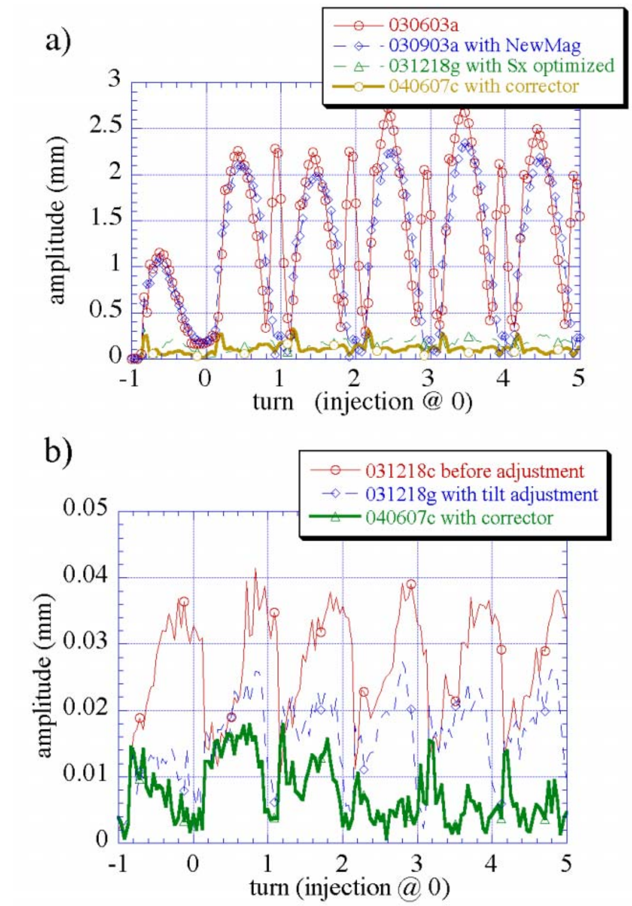

Figure 2: The oscillation amplitude in a) horizontal and b) vertical direction as a function of the time in unit of revolution period.

Fig. 2 b) shows the typical vertical oscillation amplitudes. The amplitude before improvement is shown by the solid line with open circles. The maximum amplitude reached to 0.04mm. The vertical error kick was a half sine shape similar to the main bump field. So we selected two bump magnets and adjusted their tilt angles. The measured oscillation amplitude after this adjustment is show by the dashed line with diamonds. The vertical oscillation amplitude was reduced to about half of original amplitude.

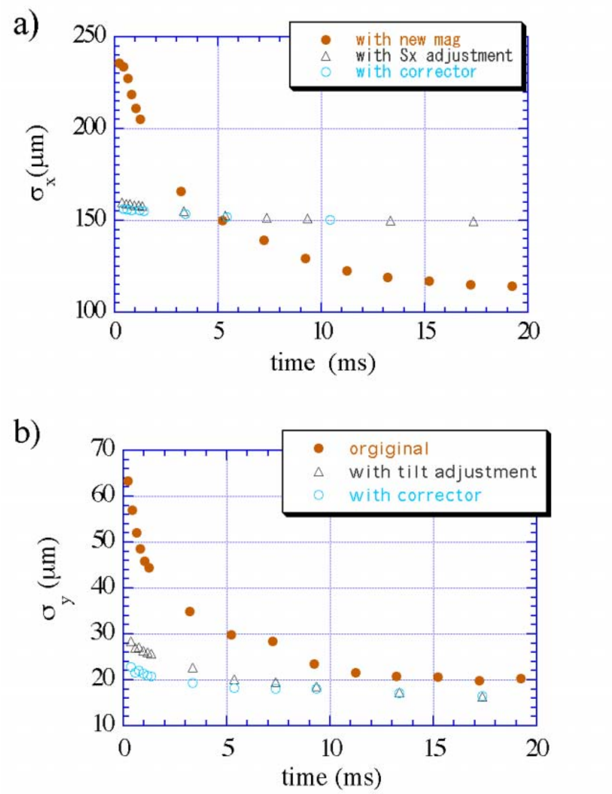

Figure 3: a) Horizontal and b) vertical beam size measured with interferometer as a function of time after beam injection.

Reduction on effective beam sizes

We checked the effectiveness of our suppression scheme of stored beam oscillation by another detector. The change of stored beam size just after the injection was measured at bending section by using two-dimensional interferometer of SR [6]. Fig. 3 shows the results. The exposure time of the camera was 0.7ms, which is much longer than betatron oscillation periods. The horizontal and vertical beta functions are 2.1m and 27.8m, respectively. These values correspond to one-twelfth and seven-times of those at the straight sections for insertion devices. After the suppression schemes were applied, the increases of the effective beam size just after beam injection were about one-third and half of nominal size in horizontal and vertical direction, respectively. The equilibrium sizes in horizontal direction differ in two data sets because they were taken with different of optics. The data with filled circle was taken with low emittance optics (3.2nmrad) and the others were taken with achromat optics (6nmrad).

The oscillation amplitude was also measured at X-ray end-station by ion chamber [2] and profile monitor using a zone plate [7]. We found that the effect of beam injection was not significant after the reductions were performed.

We also found that the bunch by bunch feedback system works effectively to reduce the damping time of the oscillation [8].

CONCLUSION

The stored beam oscillation during beam injection was degrading the quality of SR in top-up operation. The oscillation amplitudes were measured by using turn-by-turn monitor and the sources were investigated. Counter-measures were applied and the amplitudes were reduced to one-third and two-third of the equilibrium beam size in horizontal and vertical direction, respectively. The SR users in SPring-8 are enjoying perturbation free top-up operation.

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