BEAM-BASED ALIGNMENT FOR INJECTION BUMP MAGNETS OF THE STORAGE RING USING REMOTE TILT-CONTROL SYSTEM

K. Fukami*, K. Kobayashi, T. Nakamura, C. Mitsuda, and K. Soutome
SPring-8, 1-1-1, Kouto, Sayo-cho, Sayo-gun, Hyogo, 679-5198, Japan

Abstract

In the top-up operation, the stored beam is oscillated in vertical direction during beam injection by an alignment error in rotation around the beam-axis (tilt error) of the injection-bump magnets. Therefore, a method of beam-based alignment of the bump magnets was built up using a remote tilt-control system. By the method, the minimum amplitude was achieved to be 0.41 μm, which is less than 1/40 of one standard deviation of the vertical beam size.

INTRODUCTION

SPring-8 is one of the third generation synchrotron radiation facilities. Electron beam energy and circumference of the storage ring are 8 GeV and 1435.95 m, respectively. The ring has four injection bump magnets (BP1-4), which are made by stacking C-shaped 0.1 mm-thick laminated silicon-steel plates. These magnets are excited with pulsed current by four individual power supplies. Two of them, BP1 and BP4, have 320 mm-long pole length and other two magnets, BP2 and BP3, have 170 mm-long one. Nominal kick angles of the long-type and the short-type magnets are 2.4 mrad and 0.7 mrad, respectively. These pulses are synchronized to the timing of the beam injection. Wave form of the excitation current is half-sinusoidal shape with the pulse-width of 8.4 μsec.

In the SPring-8, the top-up operation has been started since May 2004 [1]. The operation requires that electrons are injected while photon beam users are making their experiments. To keep perturbation-free condition and to prevent demagnetization of insertion devices, it is important to suppress oscillation of the stored beam during beam injection. If all the pulses of bump magnets are not similar figure, the stored beam is oscillated in horizontal direction. Power supplies of the bump magnets have been modified specifically to suppress the oscillation at the SPring-8 [2] and at other light sources [3]- [5].

The stored beam is also oscillated in vertical direction by an alignment error in rotation around the beam-axis (tilt error) of the bump magnets. The vertical oscillation can not be suppressed by adjusting pulse shape. In addition, even if the tilt error is negligibly small, the beam out of the median plane is kicked in vertical direction. Also, there is a small long-term drift of the vertical beam positions in the bump magnets, which causes the gradual increase of the oscillation. Therefore, it is necessary to realign the bump magnets periodically.

We have already installed a remote tilt-control system to make a smooth realignment [6]. The system consists of four sets of stage, stepper motor, and controller for all the bump magnets. In order to suppress the oscillation effectively, we studied a method of beam-based alignment using the tilt-control system.

METHOD

Beam stored in only one rf-bucket was kicked by the pulse of the bump magnets without beam injection to observe vertical oscillation of the stored beam due to the tilt errors. The beam position was measured turn-by-turn at one point in the ring by using a strip-line type beam position monitor for the bunch-by-bunch feedback system [7]. The monitor system achieved high signal-to-noise ratio with high-resolution beam position monitor and 12-bits ADC with analog demultiplexer. The stored current was determined to be 0.4 mA to obtain maximum gain under a condition of avoiding saturation of the front stage circuit for the monitor system.

In order to observe responses to the tilts of all the magnets separately, the oscillations were measured under the condition that tilt was set intentionally for each magnet. The set tilts were determined to be 1.639 mrad for BP1 and BP4, which give relatively large oscillation amplitude, and to be 3.077 mrad for BP2 and BP3, which give relatively small oscillation amplitude. The oscillation without setting the intentional tilt was subtracted as a background.

A flowchart for tilt-correction procedure is shown in Fig. 1. Tilt errors of all the magnets were calculated by most effective corrector method using the measured responses. Firstly, the most effective magnet, which can minimize the oscillation, was selected. For the selected magnet, a tilt error was estimated. Secondary, the oscillation was observed against the set tilt for the selected magnet nearby the estimated tilt in order to find the optimum tilt, which gave the minimum amplitude of the oscillation. After the optimum tilt was set, a residual oscillation was measured to correct the tilts again. This procedure was repeated until an amplitude of the residual oscillation reached at the noise level of the monitor system.

RESULTS

Responses to the Tilts

Measured responses to the tilts of 1 mrad for all the bump magnets are shown in Fig. 2. This figure represents vertical

---

* fukami@spring8.or.jp

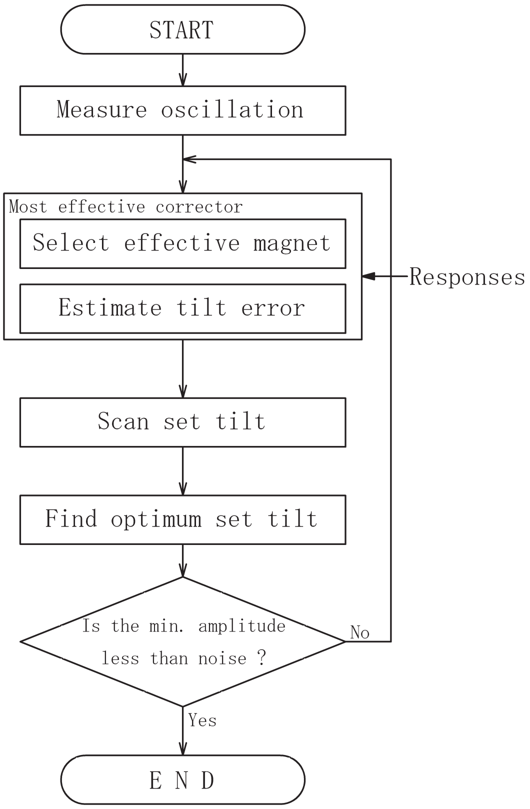

Figure 1: Flowchart for tilt-correction procedure.

positions for 100 turns after the bump magnets are turned on. Relatively high frequency components are the oscillation caused by the tilts of bump magnets. The frequency was estimated to be 0.344 cycle/turn. This value was consistent with the fraction of vertical betatron tune. Relatively low frequency components are aliasing-noises because the sampling frequency is not enough higher than the above estimated frequency.

An absolute amplitude was calibrated by comparing with the simulated amplitude. The least significant bit of the ADC for the position monitor was equivalent to 0.175 μm.

Correction of the Tilt Errors

An example of the oscillation before the correction is shown in Fig. 3 (dashed line). After the correction, r.m.s. amplitude was suppressed to 1/25 (solid line). However, the amplitude could not be less than the noise level. The residual oscillation could be attributed to the horizontal oscillation observed in the vertical axis in the position monitor coordinate. A small angle mismatch between the observation and the oscillation axes introduces a superficial vertical oscillation because the horizontal oscillation has the amplitude of two-orders of magnitude larger than the vertical one.

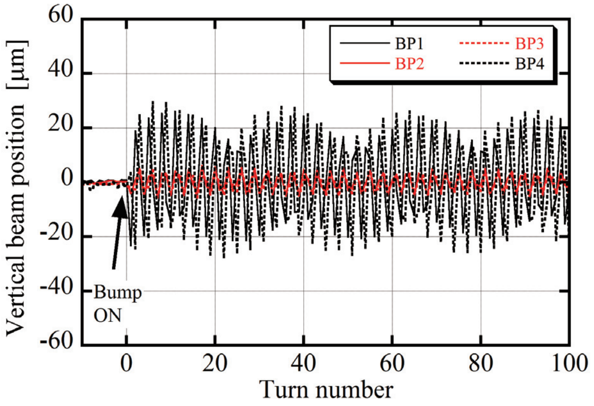

Figure 2: Measured oscillation responses to the tilts of 1 mrad for all the bump magnets, BP1 - BP4. Vertical positions are shown for 100 turns after the bump magnets are turned on.

In order to confirm the source of the residual oscillation, a frequency analysis was carried out with FFT method using the position data from 1-st to 128-th turns. The peak amplitude versus frequency is shown in Fig. 4. There are two peaks in this figure. The peak of high-frequency side indicates the oscillation caused by the tilt errors of bump magnets (Vertical component) because the frequency is followed the fraction of vertical betatron tune. On the other hand, the other peak indicates the oscillation caused by horizontal sources (Horizontal component) because the frequency, 0.133 cycle/turn, is consistent with the fraction of horizontal betatron tune.

Before the correction (dashed line), peak amplitude of the vertical component was 20 times as large as that of the horizontal component. After the correction (solid line), the vertical component was suppressed to 0.41 μm and was smaller than the horizontal component. Thus, the majority of the residual oscillation was the horizontal component.

DISCUSSION

Accuracy of the Alignment Method

In the correction procedure, the peak amplitude of the vertical component was scanned against the set tilt for the selected magnet in order to find the optimum tilt. Examples of the peak amplitude versus set tilt of BP1 are represented in Fig. 5. In this measurement, we repeated the peak amplitude scan twice under the same condition. In case of the upper figure, the optimum tilts for each scan was consistent each other. In this case, we set the optimum tilt and repeated the correction procedure. On the other hand, if the optimum tilts for each scan was inconsistent like the lower figure, we stopped the procedure.

Consequently, an effective accuracy of the remote tilt-control system was estimated to be 30 μrad although a resolution of the system is less than 1 μrad. The peak amplitude could be minimized to sub-micron order in the best case, and was regularly achieved few μm order.

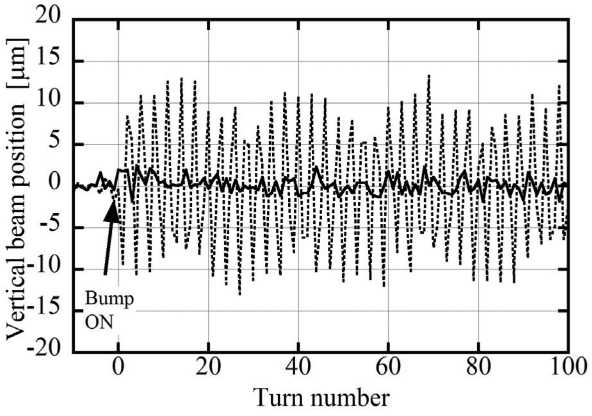

Figure 3: Vertical beam position versus turn number. The positions are shown for 100 turns after the bump magnets are turned on. Dashed and solid lines indicate the positions before the correction and one after the correction, respectively.

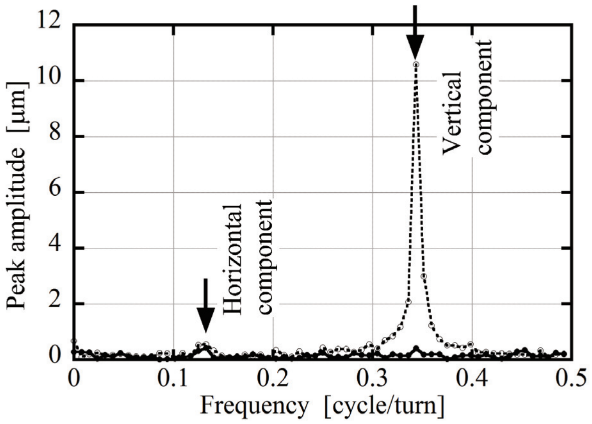

Figure 4: Peak amplitude versus frequency. Dashed and solid lines indicate the peak amplitudes before the correction and one after the correction, respectively.

CONCLUSION

Beam-based alignment method for the tilt errors of the injection bump magnets was established by using the remote tilt-control system. Peak amplitude of the vertical oscillation can always be suppressed to few micron-order. The method has been applied for user operation since last year. Since then, any beam size growths in vertical direction have never been observed during beam injection.

REFERENCES

[1] H. Tanaka, et. al., J. of Synchrotron Radiation, vol.13 (2006) p.378.

[2] T. Ohshima, et. al., Proc. of EPAC'04, July 2004, p.414, Lucerne, Switzerland.

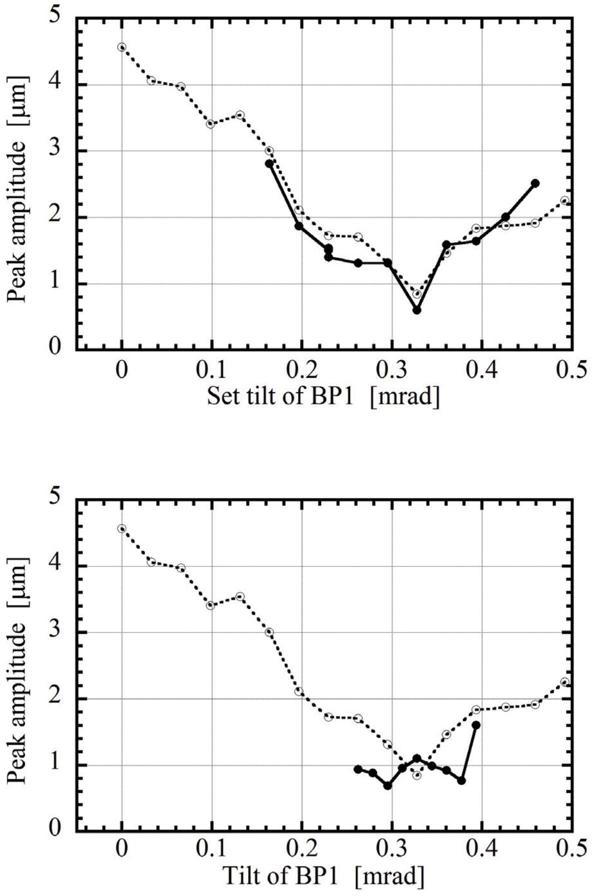

Figure 5: Examples of the peak amplitude versus set tilt of BP1. Set tilt before correction was defined to be 0 mrad. Open circles and dashed lines indicate the peak amplitude in the first scanning. Closed circles and solid lines indicate the peak amplitude in the second scanning. In the upper figure, the optimum tilts were consistent each other. In the lower figure, the optimum tilts were inconsistent each other.

[3] A. Ueda, et. al., Proc. of PAC'05, July 2005, p.2717, Knoxville, Tennessee, U.S.A.

[4] G. D. Stover, et. al., Proc. of PAC'05, July 2005, p.1254, Knoxville, Tennessee, U.S.A.

[5] L. Shen, et. al., Proc. of PAC'07, July 2007, p.2140, Albuquerque, New Mexico, U.S.A.

[6] K. Fukami, et. al., Proc. of EPAC'08, July 2008, p.2172, Genoa, Italy.

[7] T. Nakamura, et. al., Proc. of EPAC'04, July 2004, p.2649, Lucerne, Switzerland.