REMOTE TILT-CONTROL SYSTEM OF INJECTION BUMP MAGNET IN THE SPRING-8 STORAGE RING

K. Fukami, M. Hasegawa, C. Mitsuda, T. Nakanishi, M. Oishi, T. Ohshima, M. Shoji, K. Soutome,
H. Yonehara and C. Zhang
SPring-8, 1-1-1, Kouto, Sayo-cho, Saya-gun, Hyogo, 679-5198, Japan

Abstract

The SPring-8 storage ring has four pulse-bump magnets to generate bump orbit for beam injection. A rotational error of the bump magnets around a beam-axis (tilt) induces the stored-beam oscillation in vertical direction due to horizontal field. In the top-up operation, vertical perturbation of the stored-beam during beam injection is mainly produced by the tilt. To correct the tilts, we developed a remote tilt-control system. By using this system, we succeeded in on-beam reduction of the perturbation.

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 of 0.1 mm-thick laminated silicon-steel of C-type configulation, and 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 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 from September in 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 at 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].

Furthermore, if the bump magnets have an alignment error in rotation around a beam-axis (tilt), the stored beam is also oscillated in vertical direction. Therefore, the vertical oscillation can not be suppressed by adjusting pulse shape. Before installation of a remote control system, the tilts were estimated using the beam position data, which was measured by turn-by-turn beam position monitors (BPMs), and the bump magnets were realigned manually inside the accelerator tunnel. It was required to repeat the measurement and realignment processes two or three times for convergence.

In addition, if BP1 or BP4 is tilted 0.1 mrad, an amplitude of the oscillation is estimated to be one-fifth of nominal beam size (18.5 μm) since the beam is kicked 0.24 μrad at the magnet. Therefore, the tilts of all the magnets is required to be less than 0.1 mrad. Because it is difficult to align manually to this level, we developed a remote tilt-control system.

INSTRUMENTATION

A power machinery of the system for BP1 is shown in Fig. 1. The magnet is settled on a stainless steel plate. A stepper motor is attached on one side of the plate through 1/30 warm gears. On the other side of the plate is supported at two fixed points. The bump magnet is tilted clockwise (CW) toward the beam traveling direction if the stepper motor side is moved above. Sign of the tilt is defined as positive in CW. The range of adjustment is ±4mrad with resolution of 8.74 μrad/1000pulse. Other three magnets were also settled on the stages. After installation, the magnets were aligned based on the field measurement [6], and then initial tilts were defined as zero.

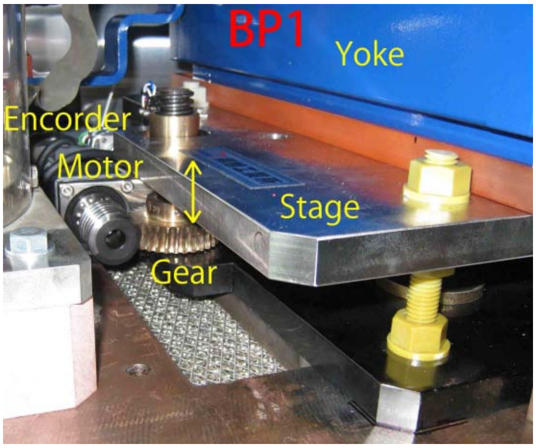

Figure 1: The remote tilt-control system for BP1. The beam traveling direction is from the surface to the back. A stepper motor adjusts the tilt of a stage. A rotary encoder was also attached to measure the number of pulse for driving of the motor.

The system was installed for all the bump magnets (BP1-4). Because a contact point between two gears has a backlash, we decided that the stages are always adjusted in CW. To confirm response of the system, the tilt and rotation around x-axis (pitch) were measured with precise leveling instruments (Taylor Hobson Inc., Talyvel) settled on the top of the bump magnets. A reproducibility is defined as a difference between two measured tilts with the same set tilt. An absolute accuracy is defined as a difference between measured tilt and set tilt. The difference was normalized with set tilt. A coupling to the pitch is defined as a ratio of fluctuation on the pitch to the set tilt. The reproducibility, absolute accuracy and coupling to the pitch are shown in Table 1. For all the stages, the reproducibility was enough better than the required value, 0.1 mrad.

Table 1: Precision of tilt-control stages

Parameter	**BP1**	**BP2**	**BP3**	**BP4**
Reproducibility [μrad]	11.7	18.7	15.6	34.4
Absolute accuracy [%]	-1.3	-0.9	-0.6	-1.9
Coupling to pitch [%]	1.5	2.3	2.7	0.7

MEASUREMENT

The oscillation of the stored beam just after the injection timing was measured by using turn-by-turn beam position monitors (BPMs) at 20 points in the ring up to 4096 revolutions. Beta functions β_x and β_y and horizontal dispersion η_x of the monitor points were 11.61 m, 24.69 m and 0.20 m, respectively. Because the peak-hold time of the circuit was about 2 μsec, beam was stored at only one rf-bucket in the ring and was shaken by pulse of bumps without beam injection to measure the amplitude at the specified timing. An intensity of the beam was 1 mA.

To measure the oscillation amplitude of the beam stored in any rf-bucket of the ring (2436 buckets) at the injection timing, the position data were taken by shifting the trigger timing of the pulse between 0 nsec and 4719.0 nsec with 196.6 nsec-step. The step and the range are equivalent to 100 and 2400 buckets in the ring, respectively.

The set tilts of all the magnets were changed separately by the tilt-control system between -3.3 mrad and +3.3 mrad with 0.66 mrad-step to survey optimum tilts.

RESULTS

A root-mean-square of 20 position data (r.m.s. amplitude) were calculated with the same-trigger timing and with the same revolutions. The r.m.s. amplitude of all the trigger timing were rearranged against the time from the trigger timing. Origin is set to the start timing of the pulse of bump magnets. The r.m.s. amplitude with various tilt angles of BP1 are shown in Fig. 2 between -1 and 7 revolutions. The noise level of the BPM system was estimated to be 24.6 μm by the amplitude before the trigger timing.

About the r.m.s. amplitude of the same set tilts, a root-mean-square between 0 and 7 revolutions was calculated and was defined as an overall amplitude after the noise level was subtracted as a background from all the amplitude. The overall amplitude were plotted against the set tilts to survay the optimum tilt, which gave the minimum overall amplitude (Fig. 3). A least squares fit was carried out with a parabolic function to obtain a minimum point. The minimum overall amplitude (offset) and the difference between the optimum tilt and the initial tilt (shift) were determined to be 22.3 μm and -0.43 mrad, respectively. The offset and the shift of BP2-BP4 were also determined by the same process.

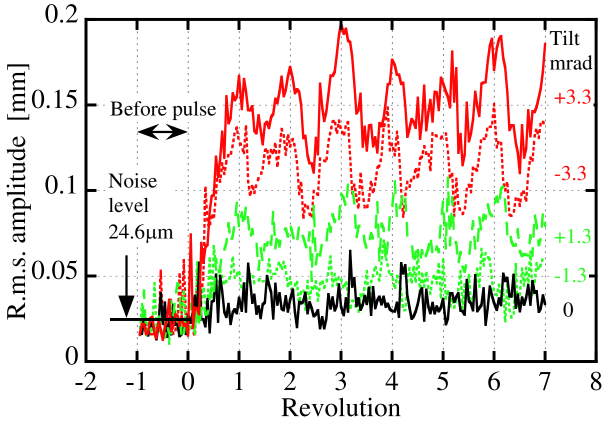

Figure 2: R.m.s. amplitude of the vertical oscillation of a stored beam versus revolutions with various tilts of BP1. The r.m.s. between -1 and 7 revolutions are shown.

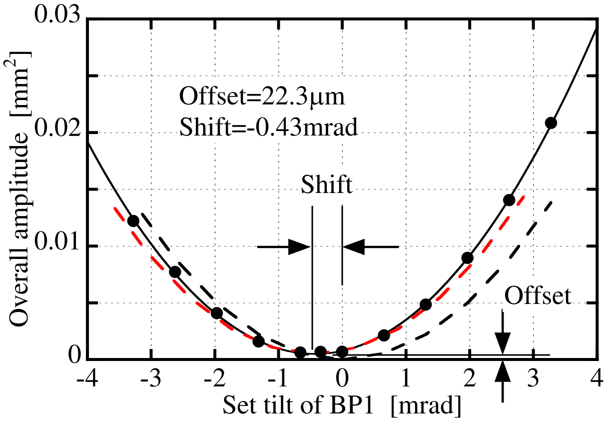

Figure 3: Overall amplitude versus the set tilt of BP1. Solid line represents a result of least squares fit with a parabolic function. Black- and red-dashed lines indicate calculated overall amplitudes (see DISCUSSION).

DISCUSSION

Method of Tilts Correction

The overall amplitude versus the set tilt of BP1 was calculated by a beam tracking code (Fig. 4). If all the bump magnets have no tilt error, the offset is equal to zero (see Fig. 3 black-dashed line). But, if each bump magnets have a tilt error, the offset is not equal to zero. The offset was mainly induced by the tilt of BP4 because the kick angles of BP1 and 4 were about four times bigger than that of BP2 and 3. In the case of Fig. 3, the tilt of BP4 was estimated to be -0.74 mrad (see Fig. 3 red-dashed line). However, since the offset was comparable to the noise of the BPM system, it was not clear that the offset was generated only by the tilt of BP4.

Based on the same simulation for BP2-4, responses of the offsets were obtained to the tilts of all the magnets (Eq. 1). A similar equation was also obtained between the tilts and the shifts. If the noise is suppressed, the tilts of all the magnets can be corrected to zero absolutely using these equations. In the present case, tilt of all the magnets were separately set to the minimum points.

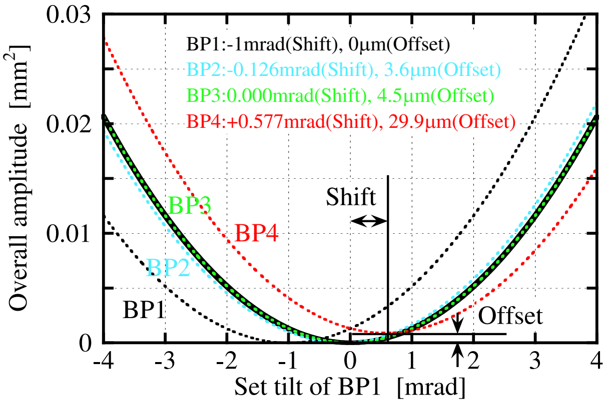

Figure 4: Calculated overall amplitude versus the set tilt of BP1. Black-solid line indicates the amplitude with no tilt. Dashed lines mean the amplitude with the tilt error of 1 mrad of BP1-4.

$$\begin{pmatrix} 0 & 3.6 & 4.5 & 29.9 \\ 22.3 & 0 & 3.6 & 36.3 \\ 35.9 & 4.5 & 0 & 20.7 \\ 29.5 & 5.8 & 2.6 & 0 \end{pmatrix} \begin{pmatrix} |\,T_1\,| \\ |\,T_2\,| \\ |\,T_3\,| \\ |\,T_4\,| \end{pmatrix} = \begin{pmatrix} O_1 \\ O_2 \\ O_3 \\ O_4 \end{pmatrix} \qquad (1)$$

Symbols T_1-T_4 indicate tilts [mrad] of BP1-BP4. Symbols O_1-O_4 indicate measured offsets [μm] with the stage for BP1-BP4, respectively.

Reduction on Effective Beam Size

Effective beam size of the stored beam was measured for 2 msec from the injection timing at a bending section by using two-dimensional interferometer of SR [7]. Beam was stored in 203 bunches with equal intervals. Total intensity of the beam was 65 mA. To survey minimum vertical beam size, the size was measured with various tilts of BP4 (Fig. 5).

The minimum size was 12 % larger than the beam size of the equilibrium stored beam. If it is assumed that the effective beam size is expressed by a root-mean-square of the equilibrium-beam size and the amplitude of vertical oscillation, the minimum amplitude is determined to be 9.5 μm. It was found that the above mentioned offset did not reflect exactly the minimum amplitude because the noise was not negligibly small. The minimum amplitude was not achieved to aimed size, however, the amplitude can be minimized by adjusting tilts to zero absolutely.

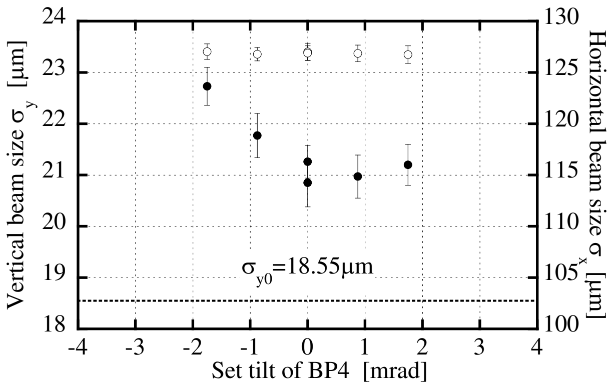

Figure 5: Effective beam size of the stored beam from the injection timing with various set tilts of BP4. Error bars represent one standard deviation of 40 shots. Broken line and symbol σ_{y0} indicates vertical beam size of equilibrium stored beam.

SUMMARY

By using the remote tilt-control system, all the bump magnets were aligned to the optimum tilts, which gave the minimum amplitude. The amplitude of vertical oscillation at beam injection was suppressed to one-second of the nominal beam size. In the future plan, the tilts will be aligned to nearly zero absolutely by improving a noize of the BPM system.

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