STORED BEAM STABILITY DURING PULSED SEXTUPOLE INJECTION AT THE PHOTON FACTORY STORAGE RING

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Abstract

We measured stored beam stability in "top-up" injection with a pulsed sextupole magnet (PSM) injection system at the Photon Factory storage ring (PF-ring). The PSM has a parabolic-shaped magnetic field, which is expected to provide an effective kick to the injected beam with little effect on the stored beam. The dipole oscillation of the stored beam in the PSM injection was much reduced in both horizontal and vertical directions as compared with that in the conventional pulsed bump injection. The change of the photon intensity measured at BL-14A in the top-up injection was only 1~2%. The stored beam current in the top-up injection with the PSM was less than 0.02% in peak-to-peak for two hours. We confirmed that the stability of the stored beam in the top-up injection was improved by the PSM injection compared with the conventional bumped orbit injection.

INTRODUCTION

To suppress stored beam oscillation during beam injection for synchrotron radiation (SR) sources, we proposed a new beam injection system using a single pulsed sextupole magnet (PSM) [1][2] and installed it at the PF-ring in the spring of 2008. The beam injection using the PSM system was successfully operated [3] and the electron beam up to 450 mA, regular operating beam current of the PF-ring, could be stored using this system.

The principle of the PSM injection system is as same as that of a pulsed quadruple magnet (PQM) injection system at the Photon Factory Advanced Ring [4]. Conventionally, a bumped orbit with several kicker magnets has been employed for beam injection in most SR sources to reduce coherent dipole oscillation of an injected electron beam. In the PSM (or PQM) injection system, the bumped orbit is not used. The injected beam is captured into the ring acceptance by the kick of the PSM, the strength of which increases in proportion to the square of the distance from the magnetic field center. The stored beam passes through a center of the PSM where the magnetic field is almost zero.

The difference between the PSM and PQM is the magnetic field strength to the stored beam, which disturbs the stored beam during the beam injection. Figure 1 shows magnetic field distributions for both the PSM and PQM. When we provide the same field strength at a horizontal position of x_0 to both magnets, the strength of the PSM at the position of Δx is weaker by a factor of $\Delta x/x_0$ than that of the PQM. At this point, the PSM is superior to the PQM. For x_0 = 15 mm and Δx = 0.5 mm, which correspond to the PSM injection position and the horizontal beam size of the PF-ring respectively, the magnetic strength of the PSM for the stored beam becomes about 3% compared with that of the PQM. Thus, we expect that the PSM enables us to realize a high-quality photon beam for SR users with less coherent oscillation of the stored beam even in top-up injection.

To check this advantage of the PSM injection, we measured stability of the stored beam during top-up operation from many aspects. In this paper, we present the stability of stored beam current, the stored beam oscillation, and the photon intensity stability during the PSM top-up injection comparing with the bumped orbit injection.

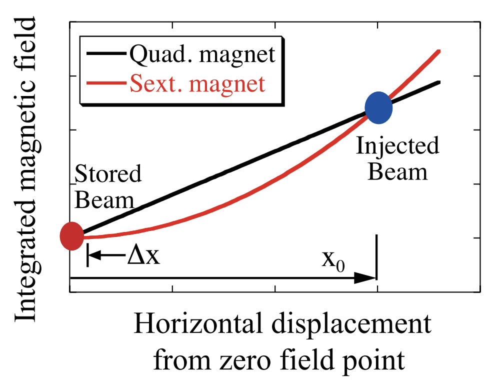

Figure 1: Integrated magnetic field of PSM and PQM as a function of the horizontal displacement from the zero field point. To compare effects of the two magnets on a stored beam, both magnets' fields are drawn so as to have the same value at the position of an injected beam.

STABILITY OF STORED BEAM CURRENT

Firstly, we checked the stability of stored beam current during top-up injection with the PSM system. The top-up injection was examined at 450 mA. The operating conditions were that:

- The PSM injection started with 1 Hz when the stored beam current was less than 450 mA.

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- The injection stopped if the beam current exceeded 450.05 mA.
- The stored beam current was monitored with 2Hz.

Figure 2 shows the stored beam current during the top-up injection for two hours and the small window is an expanded view of 10 minuets. The injection rate, injected beam current per an injection pulse, was 0.005~0.02 mA/pulse. The figure shows that the top-up injection with the PSM allowed us to achieve good stability of less than 0.02% in peak-to-peak for two hours.

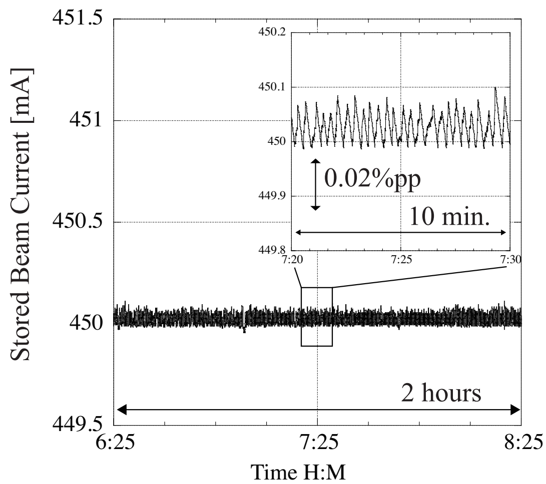

Figure 2: Stability of stored beam current during the top-up injection with the PSM.

STORED BEAM OSCILLATION

The advantage of the PSM injection is that the beam oscillation of the stored beam during the injection can be very small. We compared the stored beam oscillation in the PSM injection with that in the bumped orbit injection using a turn-by-turn beam position monitor (BPM). The stored beam oscillation was measured in the single-bunch mode to monitor it precisely and the stored beam current was set to around 10 mA. Figure 3 shows the horizontal and vertical beam dipole oscillations. During the bumped orbit injection, large dipole oscillations in both the horizontal and vertical directions were observed as shown in Fig. 3 (c) and (d). The oscillations were generated due to the leakage of the bumped orbit formed with four pulsed kicker magnets. The amplitudes of the oscillations were about 850 μm for the horizontal direction and 130 μm for the vertical direction at the maximum. On the other hand, as shown in Fig. 3 (a) and (b), the amplitudes during PSM injection were reduced to about 180 μm in the horizontal direction and 40 μm in the vertical direction. The amplitude of the vertical oscillation with the PSM injection corresponds almost the noise level of the turn-by-turn BPM system.

The dipole oscillations of the stored beam in the PSM injection were sufficiently reduced, compared with those in the bumped orbit injection. In particular, such small vertical oscillation allows high-quality SR experiments even during the injection. We suppose that causes of the residual horizontal beam oscillation in the PSM injection are as follows:

- Alignment error of the PSM.
- The center motion of the finite-size beam in parabolic-shaped magnetic field (see Fig. 4).

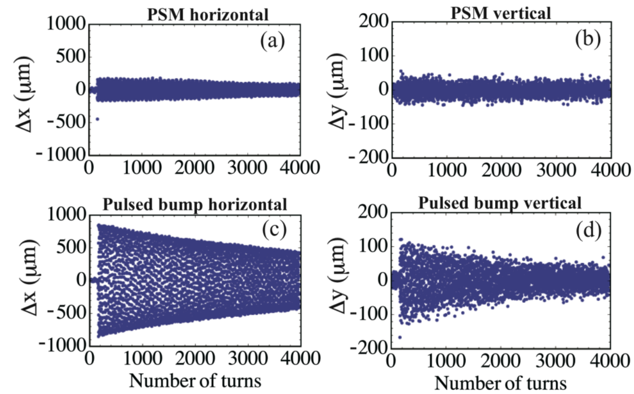

Figure 3: Horizontal and vertical beam oscillations (Δx and Δy) of the stored beam immediately after the beam injection. The oscillations produced by the PSM injection are shown in the upper two figures, (a) and (b), and those by the bumped orbit injection are in the lower two figures, (c) and (d).

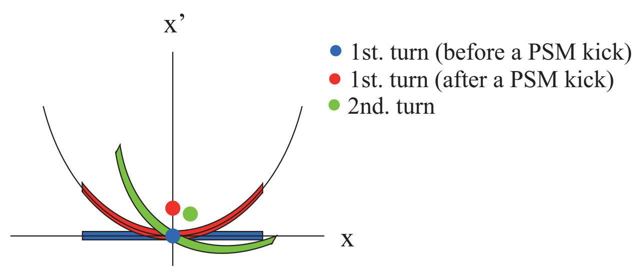

Figure 4: Schematic view of distributions and their centers of a stored beam in phase space. Blue, red, and green color strips show distributions of a stored beam just before and after a PSM kick and at the 2nd turn respectively. The corresponding color circles represent their beam centers.

STABILITY OF PHOTON INTENSITY

To show that the PSM top-up injection is also effective for high-quality SR experiments, we measured the stability of photon intensity at three beam lines, BL-5A, BL-14A, and BL-17A. The operating mode of the PF-ring was a multi-bunch mode and the top-up beam current was 450 mA. The both injection systems, the PSM injection and the bumped orbit injection, were fired at 1 Hz without an injected beam, so as to monitor the effect on the stored beam directly. The effect of the injected beam on the photon intensity is estimated 2~3% in the top-up injection from the ratio of the number of particles in the injected beam to the stored beam, slightly depending on the injection conditions.

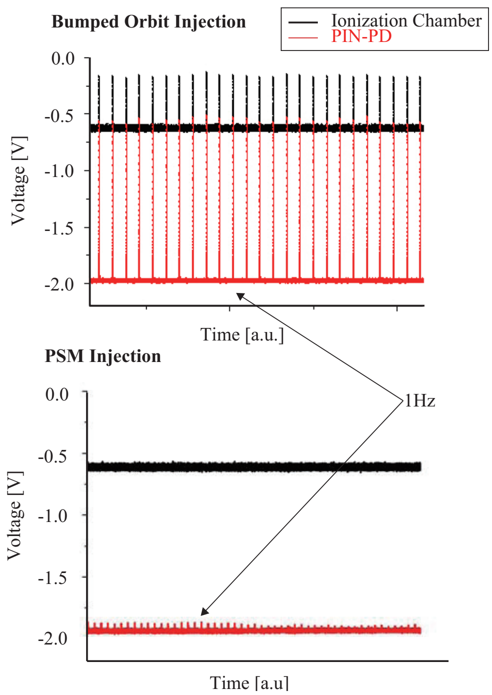

Figure 5: Stability of photon intensity at BL-14A in the pulsed bumped orbit injection (upper graph) and the PSM injection (lower graph). The spike appeared at exactly 1 Hz in both graphs. The horizontal scales are different in the two graphs.

BL-14A

BL-14A has a vertical superconducting wiggler and its photon intensity stability is very sensitive to the horizontal beam oscillation during beam injection. The photon intensity was measured with an ionization chamber and a PIN photodiode after focusing by a troidal mirror and passing through a pinhole of 0.8mm diameter. In Fig. 5, the black line is an output signal of the ionization chamber and the red one is that of the PIN photodiode. The sampling rate of the signals is 10 kHz. The PIN photodiode has faster response and good S/N than the ionization chamber. If the photon intensity during the beam injection is constant, the signal from the ionization chamber and the photodiode has a constant value of about -0.6 V for the ionization chamber and about -2.0 V for the PIN photodiode respectively. However, the photon intensity had a 1 Hz spike train, which exactly synchronized with the beam injection. For the bumped orbit injection, the maximum change of the photon intensity was very large, about 70%. On the other hand, it became only 1~2% with the PSM injection. This result shows that the PSM injection is very effective for the top-up injection.

BL-5A and BL-17A

BL-5A and BL-17A have horizontal undulators. We measured the photon intensity at these undulator beam lines in the same run as the BL-14A experiment described in the previous subsection. In each beam line, PIN photodiode was placed after focusing the source image and a slit of 50 μm was used for BL-17A and 200 μm for BL-5A. The sampling rate of the signal was 100 Hz. The maximum change of the photon intensity during the bumped orbit injection was 80% at BL-17A and 35% at BL-5A. On the other hand, during the PSM injection, the maximum change was 25% at BL-17A and was 7% at BL-5A. The PSM beam injection also improved the photon intensity stability at these beam lines compared with the bumped orbit injection.

SUMMARY

We measured stability of the stored beam current, the stored beam oscillation, and the photon intensity during top-up operation comparing the PSM injection with the bumped orbit injection at the PF-ring. The stored beam current during the top-up injection with the PSM was less than 0.02% in peak-to-peak during two hours. By changing the injection scheme from the pulsed bump injection to the PSM injection, the maximum amplitude of dipole oscillation of the stored beam was reduced from 850 μm to 180 μm in the horizontal direction and from 130 μm to 40 μm in the vertical direction. The photon intensity fluctuation at BL-14A during the top-up injection was also stabilized from 70 % to 1~2% at maximum. We confirmed that the stability of the stored beam during the injection was improved by the PSM compared with the conventional bumped orbit scheme at the PF-ring.

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