ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUAB1

CORRECTION OF NONLINEAR COUPLING RESONANCES IN THE SPRING-8 STORAGE RING

M. Takao*, K. Soutome, K. Fukami and Y. Shimosaki
JASRI/SPring-8, Hyogo, Japan

INTRODUCTION

At recent light source rings, the top-up operation, in which the beam is injected during the user experiments, is widely used to make up the short lifetime and to keep the current constant. Since the beam is injected in the magnet array gap of the insertion device closing, it is important to protect the insertion devices from the electron irradiation.

The injection efficiency decreases as the vertical scraper closing as shown in Fig. 1. This implies that, although the injected beam initially oscillating in horizontal direction with a large amplitude, the vertical spread of the injecting bean is generated by a coupling resonance [1–3].

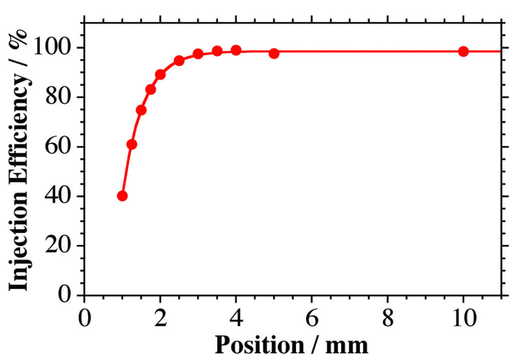

Figure 1: Injection Efficiency vs. Vertical Scraper position.

This is true for a particle scattered by Thouschek effect, i.e. the collision within a bunch. Figure 2 shows the typical dependence of the Touschek lifetime on the RF accelerating voltage. The electron scattered at the nonzero dispersion starts to oscillate in horizontal direction with an amplitude proportional to the momentum deviation. Although in low RF voltage the lifetime is limited by the longitudinal dynamics, it is dominated by the transverse dynamics in high RF voltage. Similar to the injection efficiency, the lifetime decreases as the vertical scraper closing, which implies that the coupling plays important role in beam loss mechanism [1–3].

At the spring-8 storage ring one of the insertion devices generates the strong coupling resonance, i.e. the skew octupole resonance, affecting the injection efficiency and the beam lifetime. Here we report the correction of the coupling resonance by using the skew octupole magnet. Furthermore, the simulation study for the improvement of the momentum acceptance by means of the skew sextupole magnet.

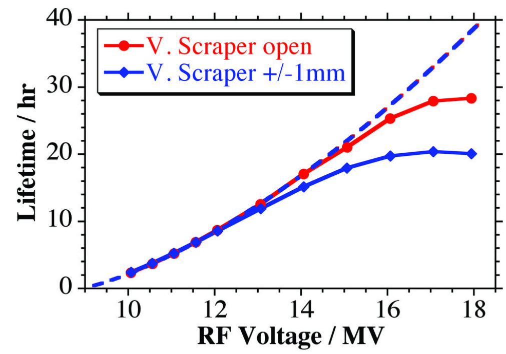

Figure 2: Lifetime vs. Vertical Scraper position.

COUPLING RESONANCE INDUCED BY AN INSERTION DEVICE

The insertion device ID07 of the SPring-8 is a special one composing of 8 figure-8 (4 horizontal and 4 vertical) undulators [4]. It is found that the vertical figure-8 undulator strongly excites the skew octupole coupling resonance so as to reduce the injection efficiency and the beam lifetime. Figure 3 shows the variation of the injection efficiency as the gap of ID07 closing under the condition of the vertical scraper gap 2mm. To emphasize the effect of the coupling resonance, we close the scraper to 2 mm. Since ID07 is out-vacuum undulator, the reduction is caused by the dynamical effect, i.e. the coupling resonance.

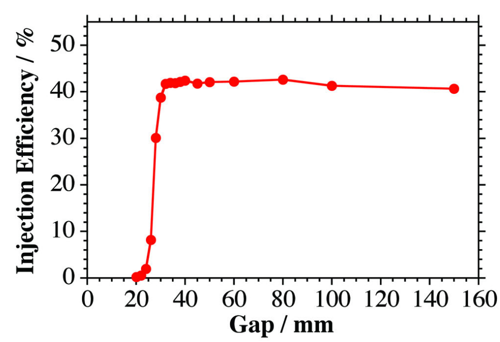

Figure 3: Injection Efficiency vs. ID07 gap.

To understand the dynamics, we measure the beam oscillation by using the turn-by-turn beam position monitor (BPM). We kick the stored single bunch beam to give a large amplitude like an injection beam by means of the bump magnet. Figures 4 show the beam oscillation with the initial amplitude 10 mm, which is a typical amplitude of the injection beam. The left (right) figure at the upper row shows the hor-

* takao@spring8.or.jp

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUAB1

izontal (vertical) beam oscillation with ID07 gap open (150 mm). If it were not for the coupling, the vertical oscillation does not appear. Actually, the beam also oscillates in the vertical direction due to the coupling. The lower figures are those with ID07 minimum gap (20.1 mm). Figure 4 implies that the vertical oscillation is excited by closing the ID gap.

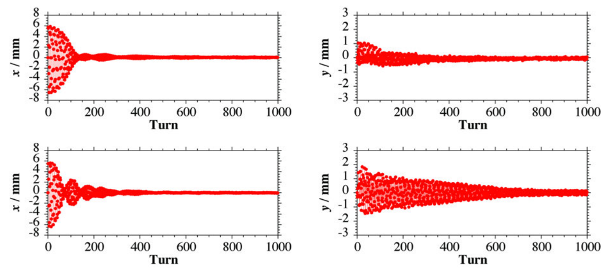

Figure 4: Horizontal (left) and vertical (right) beam oscillation. Upper (lower) raw with ID07 gap open (close)

Figures 5 show the Fourier transform of the beam oscillation 4. The large peak in the upper left figure is the horizontal betatron mode, and the second higher harmonics (the normal sextupole coupling resonance) is observed. In the right figures we can find the linear coupling mode having the same tune to the horizontal betatron tune and the second higher mode of the skew sextupole resonance in addition to the largest peak of the vertical betatron mode. By closing the ID gap, the vertical tune component is strongly excited comparable to the horizontal as shown in lower right figure. This is because the skew octupole resonance ($3\nu_x - \nu_y$ = int.). The peak of the horizontal betatron mode splits into double, which is also effect of the skew octupole magnet.

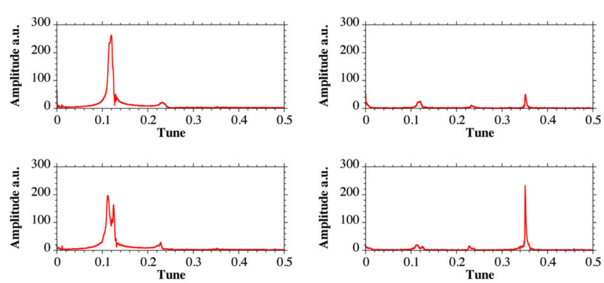

Figure 5: Fourier transform of horizontal (left) and Vertical (right) beam oscillation. Upper (lower) raw with ID07 gap open (close)

Figure 6 shows the trend of the foudamental betatron modes as the ID gap closing. While the horizontal tune component not so changes as the ID gap closing, the vertical one rapidly grows as the gap approaching to the minimum.

CORRECTION OF ID INDUCED COUPLING RESONANCE

To cure the skew octupole coupling resonance, we installed the four skew octupole magnets adjacent to the vertical figure-8 undulators of ID07. By using the skew octupole

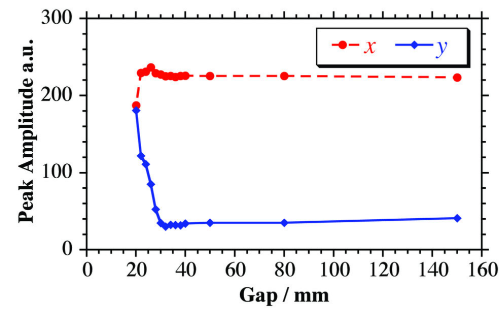

Figure 6: Peak of vertical amplitude vs. ID07 gap.

magnets, we can correct the coupling resonance. Figure 7 shows the trend of the peak amplitudes of the fudamental betatron modes as the skew octupole magnet evolving. Hence the vertical tune component is reduced to the level of ID07 open as shown in Fig. 8.

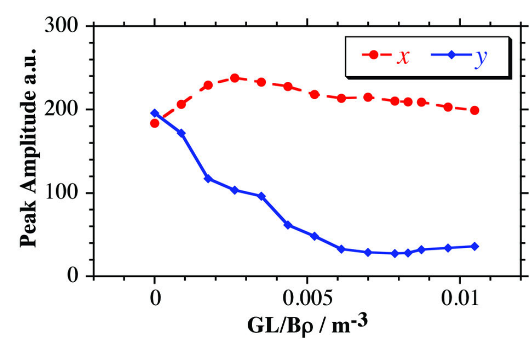

Figure 7: Peak of vertical amplitude vs. Skew octupole magnet.

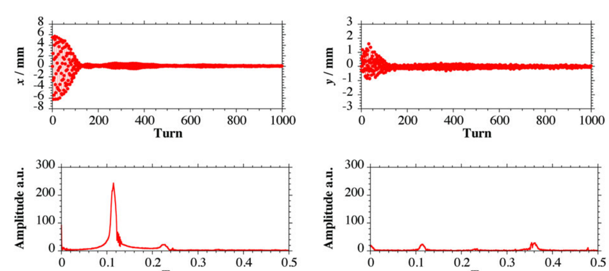

Figure 8: Horizontal (left) and vertical (right) beam oscillationand and the Fourier transform (lower)

As the result of the coupling correction, the injection efficiency is improved as shown in Fig. 9. In the case of the vertical scraper gap 2 mm, the injection efficiency is recovered up to 10 % while 40 % at ID07 gap open. On the other hand, in the case of the vertical scraper gap 2.5 mm, the injection efficiency reaches 30 %. We expect that it is caused by the incomplete correction. Although we use four octupole magnets, we tune those not individually but uniformly.

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUAB1

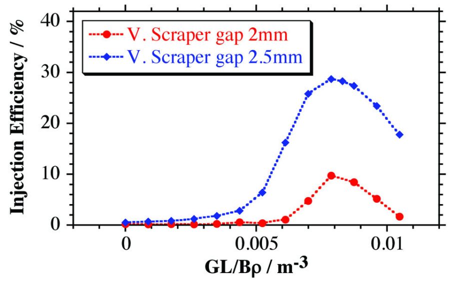

Figure 9: Injection efficiency vs. skew octupole magnets.

The effect of the coupling resonance correction on the Lifetime is shown in Fig. 9. Although the optimum point is slightly different from that of the injection efficiency, the tendency is similar to each other.

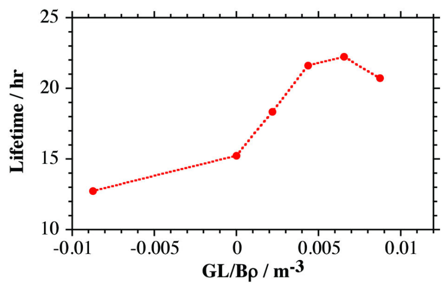

Figure 10: Touschek lifetime vs. skew octupole magnets with the vertical scraper gap 2 mm.

SIMULATION STUDY OF ANOTHER NONLINEAR COUPLING RESONANCE

For the purpose of improving momentum acceptance further, we perform a simulation study of single particle motion with a sudden momentum change like Touschek effect. It is expected that the skew sextupole coupling resonance affects the momentum acceptance.

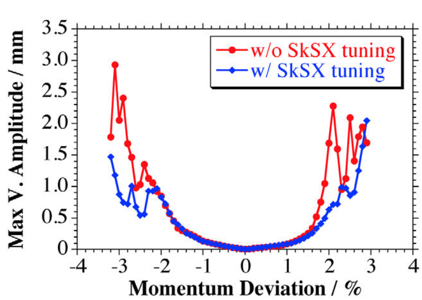

Figure 11: Maximum vertical amplitude of vertical oscillation after kicked in longitudinal direction.

Figure 11 shows the simulation result of the vertical beam oscillation after given sudden momentum change. Before the correction of the skew sextupole coupling resonance, there are some peaks in the region of the momentum deviation larger than 2 %. By tuning the resonance driving term of the skew sextupole coupling, these peaks are suppressed, which implies the momentum acceptance is improved in the case with a narrow vertical aperture from 1 mm to 2 mm.

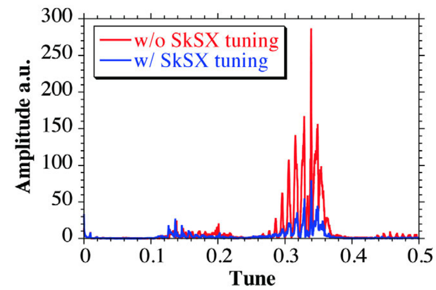

Figure 12: Touschek lifetime vs. skew octupole magnets with the vertical scraper gap 2 mm.

As an example, the spectrum of the vertical oscillation of the particle with given a sudden momentum deviation 2 %. Due to the synchrotron oscillation, there are sidebands surrounding the vertical betatron tune. The correction by using the skew sextupole magnet well suppresses these peaks.

SUMMARY

The nonlinear coupling resonance plays an important role in the beam loss mechanism like the beam injection or the lifetime. Hence it is important to correct the nonlinear coupling resonance.

One of the insertion devices of the SPring-8 strongly excites the skew octupole coupling resonance, which severely reduces the injection efficiency and the beam lifetime, especially at the condition of the narrow vertical aperture.

To recover the injection efficiency and the lifetime, we correct the nonlinear coupling resonance by using the skew octupole magnets.

The simulation study of the beam oscillation after given sudden momentum change implies that the coupling resonance is excited in the vertical direction, and that the resonance can be suppressed by the skew sextupole magnet. The tuning of the skew sextupole magnet to improve the momentum acceptance is in progress.

REFERENCES

[1] M. Takao, et al., IPAC'11, San Sebastián, September 2011, WEPC069 (2011), http://www.JACoW.org

[2] M. Takao, et al., IPAC'12, New Orleans, May 2012, TUPPC016 (2012), http://www.JACoW.org

[3] M. Takao, et al., IPAC'14, Dresden, June 2014, THPRO066 (2014), http://www.JACoW.org

[4] T. Tanaka and H. Kitamura, Nucl. Instrum. Methods Phys. Res. **A 490**, (2002) 583.