DYNAMIC APERTURE STUDY AT THE SPring-8 STORAGE RING

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Abstract

The dynamic aperture is of importance for high injection efficiency and long lifetime of a storage ring. At the SPring-8 storage ring, a third generation light source facility, various improvements of the dynamic aperture were developed, e.g. the introduction of supplemental sextupole magnets at long straight sections, and the symmetry restoration of linear lattice. To understand the nonlinear dynamics limiting the aperture, the measurements of the dynamic aperture were performed for the various operation conditions with the improvements. Using injection bump magnets and turn-by-turn beam position monitor system, we measured the horizontal dynamic aperture. The Fourier analysis of the oscillation of the kicked beam shows the resonance excitation influential on the dynamic aperture. The knowledge through the experiments is essential to the further improvements of the dynamic aperture of the present ring and the new storage ring design of the future SPring-8 upgrades.

INTRODUCTION

In the SPring-8 storage ring there are four magnet-free long straight sections of 30 m length. These long straight sections were installed in 2000 by locally rearranging quadrupole and sextupole magnets. At that time we maintained the periodicity of the cell structure, especially that of sextupole field distribution along the ring, since the high periodicity leads to the large dynamic aperture. To keep the periodicity as high as possible, we adopted a scheme in which *betatron phase matching* and *local chromaticity correction* are combined. The betatron phase matching keeps the dynamic aperture for on-momentum particles large and the latter enlarges that for off-momentum ones by local chromaticity correction with focusing sextuple magnets (SFL) at matching cells. However the nonlinear kick of the SFL slightly breaks the periodicity and reduces the dynamic aperture.

To improve the symmetry of the storage ring, we installed *counter-sextupole magnets* (SCT) in every long straight section in 2007 [1]. These magnets are placed π apart from the SFL in the horizontal betatron phase, so they can minimize the harmful nonlinear kick by the SFL. After installing the SCT, we confirmed the enlargement of the dynamic aperture through measuring the injection efficiency.

To get the knowledge of the nonlinear dynamics in the SPring-8 storage ring, we performed the experiment of measuring the dynamic aperture. The relevant parameters of the SPring-8 storage ring are listed in Table 1.

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Table 1: Parameters of the SPring-8 storage ring.

Beam energy [GeV]	8
Horizontal / vertical betatron tune	40.15 / 18.35
Horizontal / vertical chromaticity	2 / 6
Natural emittance [nmrad]	3.4
Emittance coupling ratio	0.002
Energy spread	0.0011
Revolution period [μs]	4.8

MEASURING TECHNIQUE

The aperture of an electron storage ring is the maximum transverse deviation from the design orbit without beam loss. Measuring the beam loss after kicked by the fast kicker can give the aperture. In the experiment the beam loss was measured by the turn-by-turn beam position monitor (BPM). The voltage sum of the four electrodes is proportional to the beam intensity, so we can measure the turn-by-turn survival rate of the kicked beam. We can judge whether the aperture is dynamic or not by means of the way of the intensity decaying.

As a fast kicker we use the injection bump magnet system, which consists of four pulse magnets forming the bump trajectory for the stored beam. By exciting the bump magnets by upstream or downstream half, we can give the initial amplitude in both the positive and negative directions to the stored beam. The specifications of the bump magnet system are as follows: the maximum height of the bump orbit is 20 mm, and the pulse width 8 μs. The pulse width of the bump magnets is so narrow, it is possible to give an amplitude instantaneously to a single bunch beam.

To measure the dynamic aperture, we measure the survival rate of the stored beam after kicked with changing the bump height. The survival rate begins to decrease over a certain bump hight, from which we can estimate the aperture.

EXPERIMENTS

Effect of Counter Sextupole Magnets

Figure 1 shows the optics functions at a long straight section of the SPring-8 storage ring and the magnet arrangement including the SCT. It was observed that the installation of the SCT improves the injection efficiency and the lifetime. Since there is changed the magnet arrangement only, the improvement of the injection efficiency is due the enlargement of the dynamic aperture. This implies the possibility of measuring the aperture.

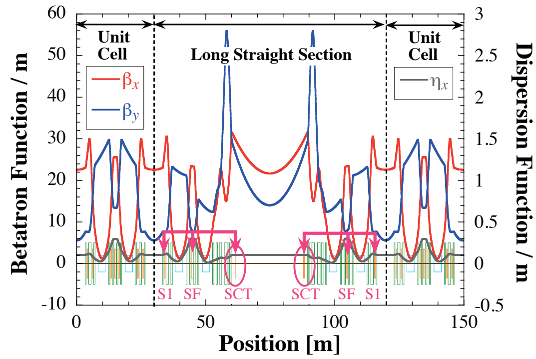

Figure 1: Optics functions and magnet arrangement of the long straight section in the SPring-8 storage ring.

We performed the experiments for the conditions with and without the SCT, whose results are shown in Fig. 2. Note that the survival rates with the SCT are limited not by the dynamical aperture but by the physical one. In the case of the SCT on, the survival rates at a large bump height suddenly drop at a few turn, which means the stored electrons are lost by the physical aperture. On the other hand, the decreasing of the survival rate with the SCT off continues over some handreds turns, which implies the dynamical phenomenon.

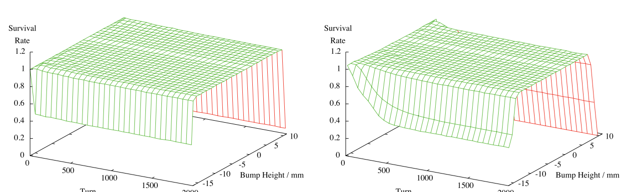

Figure 2: Survival rates with turning the SCT on (left) and off (right).

We compare the measured survival rates with the calculated dynamical aperture as shown in Fig. 3. In the figure the survival rates are the final ones at 2000 turn, where the survival rate deceasing well settles down. Although the measured dynamical aperture is horizontal only, it seems that it consistently agrees with the calculated one.

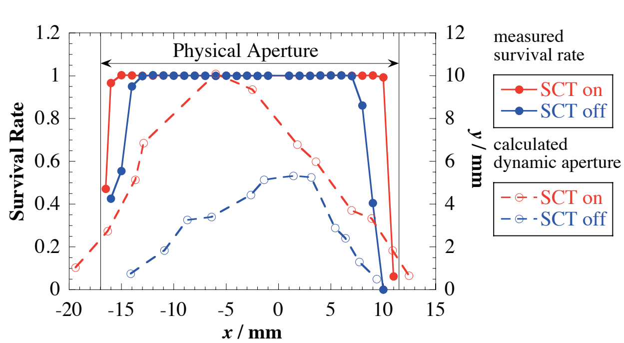

Figure 3: Final survival rates and calculated dynamic apertures.

In order to investigate the mechanism of limiting the dynamic aperture, we analyzed the beam oscillation after kicked. In Fig. 4, the graphs at the upper (lower) row show oscillations in horizontal (vertical) direction, and those at the left (right) column indicate oscillations in the condition with the SCT on (off), respectively. From Fig. 4 we find that in the case with the SCT off the horizontal oscillation shows the severe filamentation and the vertical oscillation is more excited than that in the case of the SCT on.

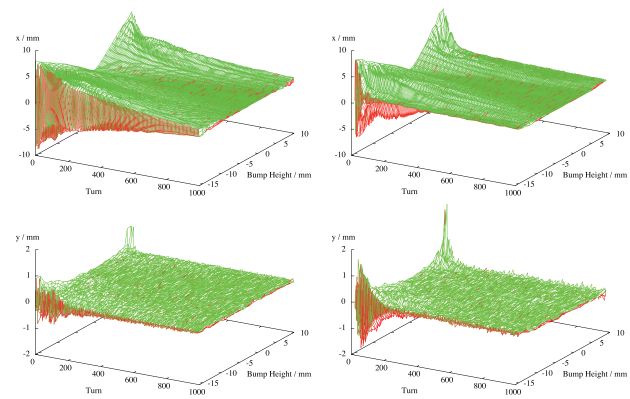

Figure 4: Beam oscillations after kicked by bump magnets. Upper line: horizontal, lower: vertical, and left column: SCT on, right: SCT off.

To further investigate the dynamics, we perform the Fourier transformaton of the beam oscillations, whose mountain views are shown in Fig. 5 in order as following the above figure. It is found that the horizontal oscillation in the case of the SCT off is smeared.

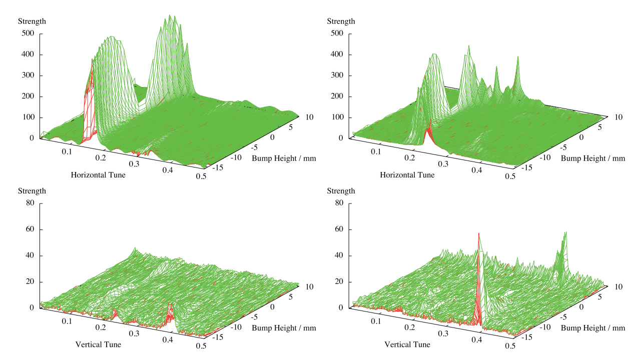

Figure 5: Fourier transform of beam oscillation.

Figure 6 shows the map view of the Fourier transform of the beam oscillation, where one finds the higher order components as well as the betatron tunes. The SCT suppresses the amplitude dependent tune shift, so that the filamentation is weakened.

In the vertical oscillation with the SCT off we detect the crossing of the tune component ν_y and the higher order component $1 - \nu_x - \nu_y$, or the resonance $\nu_x + 2\nu_y = \text{int.}$ generated by the normal sextupole potential xy^2. Namely, we expect the dynamic aperture is limited by the coupling resonance.

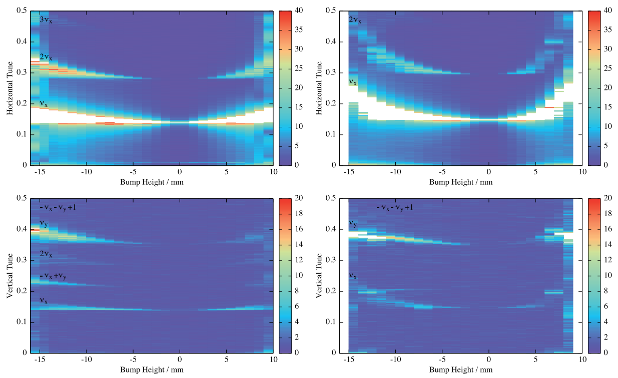

Figure 6: Map representation for Fourier transform.

Impact of an Insertion Device and the Cure

The novel insertion device ID07, a figure-8 undulator [2], at the SPring-8 storage ring has a severe impact on the injection efficiency. Since the good field region is relatively narrow and it is installed at the long straight section of high betatron functions, the nonlinear kick is stronger than other insertion devices at the SPring-8 storage ring. As shown in Fig. 7, it is observed that the injection efficiency decreases exponentially as the ID07 gap closes.

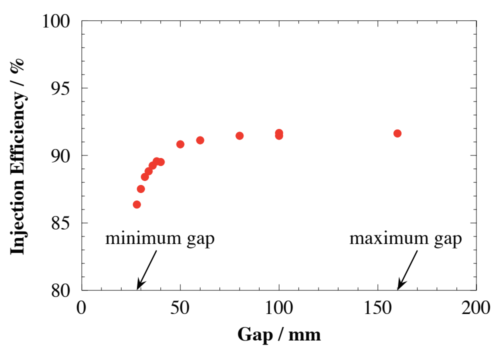

Figure 7: Injection efficiency vs. ID07 gap.

To investigate the impact of ID07, we measured the dynamic aperture at the minimum gap of ID07, whose result the left graph in Fig. 8 shows. As well as the SCT off, the survival rate at a large bump height decreases over some hundreds turns. This implies the beam loss is caused by the dynamical phenomenon. It is expected that the field of the ID07 magnet array excites the resonance so as to limit the dynamic aperture.

The lower left graph in Fig. 9 show the Fourier transform of the vertical oscillation after kicked with the minimum gap of ID07. It is striking that the mode $-\nu_x + \nu_y$ is strongly excited as well as the tune component. This mode is driven by the normal sextupole potential, so that the tuning of the sextupole magnets leads to the suppression of the vertical oscillation mode.

We tried to improve the injection efficiency at the minimum gap of the ID07 by means of tuning the SCT at the long straight section where ID07 is installed. Figure 10 shows the dependence of the injection efficiency on the strength of the SCT. Decreasing the strength of the SCT from the nominal value of 0.7 m^{-2} leads to recover the injection efficiency.

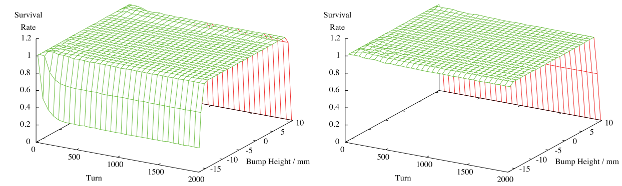

Figure 8: Survival rates with ID07 gap close (left) and corrected by the SCT (right).

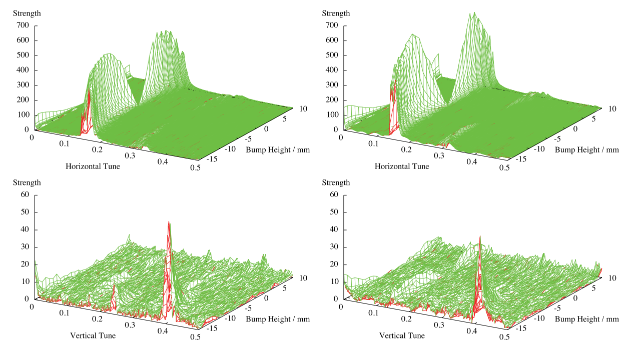

Figure 9: Fourier transform of beam oscillation for ID07 gap close (left) and the correction by SCT (right).

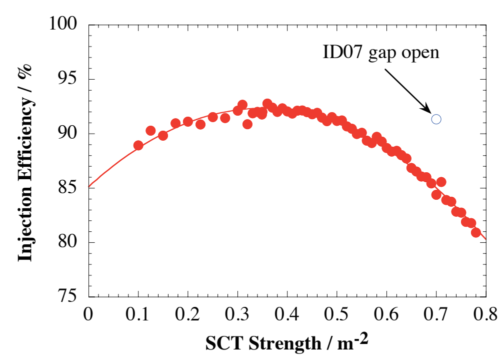

Figure 10: Correction of the impact of ID07 by the SCT.

At the optimum value of the SCT 0.35 m^{-2}, we perform the dynamic aperture measurement. The right graph in Fig. 8 shows the survival rate, which implies the enlargement of the dynamic aperture as expected. One finds in Fig. 9 that in the vertical oscillation the mode $-\nu_x + \nu_y$ driven by the normal sextupole potential disappers. Thus we can recover the injection efficiency deteriorated by the magnet field of the ID07.

REFERENCES

[1] K. Soutome, et al., in Proc. of EPAC 2008, Genova, 3149.

[2] T. Tanaka and H. Kitamura, Nucl. Instr. and Meth. in Phys. Res. **A 364** (1995) 368.