TUNE SURVEY OF DYNAMIC APERTURES FOR HIGH-BRILLIANCE OPTICS OF THE POHANG LIGHT SOURCE

Eun-San Kim, Pohang Accelerator Laboratory, POSTECH, Pohang, Kyungbuk, 790-784 Korea.

Abstract

The Pohang Light Source (PLS) storage ring is a synchrotron light source with the emittance of 18.9 nm at 2.5 GeV. We designed a new lattice with the emittance of 13 nm that might provide more brilliant synchrotron radiation. We investigated dependence of the dynamic aperture on the betatron tune to search for large dynamic aperture in the low emittance lattice by a simulation method. We examined the dynamic apertures by a tune survey within a specified tune space without and with machine errors. It is also shown that how large are the dynamic apertures in the storage ring compensated after correction of a closed orbit distortion (COD). The operating tune for the low emittance lattice could be chosen on the view point of dynamic apertures obtained from a tune survey. The new lattice with achromat shows reduced horizontal and vertical beam sizes by 10 % and 29 % than the present lattice with the emittance of 18.9 nm in the positions of insertion devices, respectively.

INTRODUCTION

In December 1994 PLS storage ring started to operate with 2 GeV beam. Since Sep. 2002 the storage ring has being operated by a 2.5 GeV full energy injection from a linac. Design efforts for low emittance lattice of a high-brilliance at the ring have been performed and it was shown that the emittance could be reduced to around 10 nm. This can lead to a higher brilliance of the synchrotron radiation. We also note with the fact that the low emittance lattice can affect the beam dynamics in the ring. It is necessary to examine the dynamic aperture in the low emittance lattice that may affect beam injection and beam lifetime. Accordingly, it is desirable to perform scanning of the betatron tunes within a specified tune space to search for betatron tunes that result in large dynamic aperture. From the computer simulation using a model of an ideal machine without any errors, it was shown that we could obtain betatron tunes to provide a sufficient dynamic aperture in the lattice with the emittance of 13 nm. As the machine has various imperfections, however, we estimated the dynamic aperture in a machine which includes various errors. Measured errors in the magnetic field, alignment, rotation, length, kick of steering magnet and beam position monitor in the ring are considered as machine errors in our simulation. Since the CODs were corrected by steering magnets, we also estimated how large the dynamic apertures in the lattice are compensated by corrections of the COD. The simulation was performed by using the computer code Strategic Accelerator Design (SAD)[1]. The dynamic aperture in this simulation is defined as the maximum initial amplitude to give a circulation of 1000 turns. The dynamic apertures are investigated by scanning the betatron tunes within a specified tune space. In result, we could choose an optimal operating tune from the dynamic apertures obtained by a tune survey in the lattice with the emittance of 13 nm.

MACHINE OVERVIEW

The lattice of the PLS ring is Triple Bend Achromat structure with 12 superperiods[2]. Typical parameters in the low emittance lattice are given in Table I. Here, H and V mean the horizontal and vertical directions, respectively. The strengths ($1/m^2$) of the focusing and defocusing sextupole magnets to correct the chromaticities are also given.

DYNAMIC APERTURE

The dynamic aperture gives a description of the nonlinear effects arising from sextupoles to correct for the chromaticity and field imperfections of the magnets. However, it is analytically difficult to obtain the dynamic aperture in the presence of nonlinear fields and thus in general it is obtained by a simulation method. The dynamic aperture is determined in our simulation as follows: first, set the initial amplitude of the betatron oscillation and track its amplitude through the ring's components. If the initial amplitude performs stable betatron oscillation within a region until given turns, we assume that a particle with its amplitude can infinitely perform stable motion. Whether the initial amplitude can perform stable betatron oscillation until the given turns or not, we call this boundary value of its initial amplitude to the dynamic aperture. In electron storage rings, because an initial large amplitude dampens its amplitude by synchrotron radiation, we assume that 1000 turns is sufficient as a condition of stable betatron oscillation.

TUNE SURVEY BY A TRACKING SIMULATION

The dynamic aperture has a relation with the betatron tune. It is difficult to obtain analytically betatron tunes which enable us to provide a large dynamic aperture. To obatin a batatron tune which gives a large dynamic aperture, the only method is to check the dynamic aperture by changing the betatron tunes. Therefore, by changing the betatron tunes it is possible to obtain a resonable operating point which gives a large dynamic aperture.

The following method in this paper is applied for this tune survey: 1) The fractional tune is changed from the starting point, which is given by (15.45, 9.65). 2) The variation in the horizontal and vertical tunes is given by 0.03

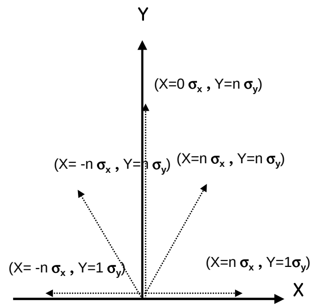

Figure 1: The dynamic aperture in this paper is given by averaging these five points in the X-Y plane.

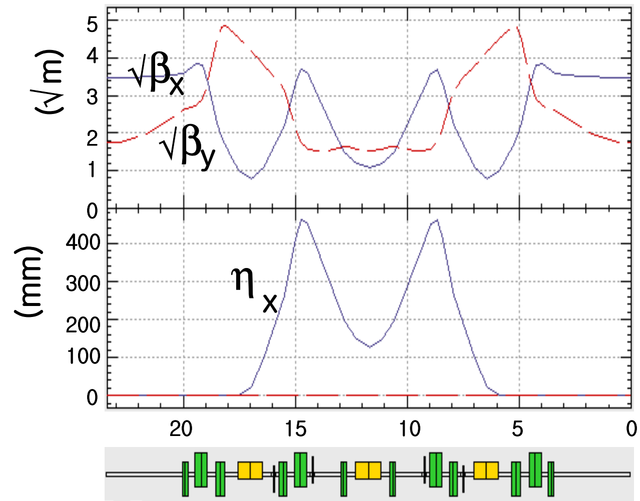

Figure 2: A lattice with achromat for the emittance of 13 nm in 2.5 GeV ring.

in a step and matching of the optics is performed. The tune survey is performed over the range $0 \leq \Delta\nu_x \leq 0.5$ and $0 \leq \Delta\nu_y \leq 0.5$ in the horizontal and vertical directions, respectively. 4) The dynamic aperture is obtained by averaging five points in the X-Y plane, as shown in Fig. 1[3].

TUNE SURVEY OF DYNAMIC APERTURE FOR A LOW EMITTANCE LATTICE

Fig. 2 shows the optical functions in the designed lattice for the low emittance. Fig. 3(a) shows the dynamic apertures in the case that machine errors are not included. The magnitude of the dynamic aperture is expressed in unit of beam size, and is shown as the average value of five points in the $X-Y$ plane, as shown in Fig. 1. The particle momentum is kept at $\delta P/P$=0 during tracking. The tune plot showing the resonances of (a) $2\nu_x+3\nu_y = 12\times5$, (b) $3\nu_x+4\nu_y = 12\times7$ and difference resonances of (c) $2\nu_x-2\nu_y = 12\times1$ and (e) $3\nu_x - \nu_y = 12\times3$ is presented by the heavy line and dotted line, respectively, in Fig. 3(a). It is shown that the dynamic apertures are not affected to these resonances. Fig. 3(b) shows the dynamic apertures in the case that the machine errors are included in Fig. 3(a). The magnitudes of the errors considered in the simulation are listed in Table II. The errors are assumed to have a Gaussain distribution with the rms values given in Table II, and have been truncated by 3σ in their distributions. The resonances are not also observed in the case with errors, but it shows that the machine errors greatly affect the dynamic aperture. After corrections of COD in Fig. 3(b) are performed, we can see that significant changes are observed in the performance of the dynamic aperture, as shown in Fig. 3(c).

We can obtain a comparative large dynamic aperture around ($\nu_x = 15.39$, $\nu_y = 9.74$) in Fig. 3(c). Fig. 4 shows the dynamic apertures at the tune in the center of a straight section. Fig. 4(a) shows the dynamic apertures without machine errors. The dynamic apertures are shown in the cases of -1%, 0% and 1% momenta deviations. We can see that the dynamic apertures decrease a little for off-momentum particles. Fig. 4(b) shows the dynamic apertures with machine errors. It shows that the dynamic apertures are greatly reduced in the horizontal and vertical directions. Fig. 4(c) shows the dynamic apertures after corrections of COD are applied in Fig. 4(b). The dynamic apertures in Fig. 4(c) show the same tendency with Fig. 4(a). The rms CODs in the horizontal and vertical directions in Fig. 4(b) are 1.450 mm and 2.58 mm, respectively. The rms CODs in the horizontal and vertical directions in Fig. 4(c) are adjusted to 0.183 mm and 0.211 mm, respectively.

In the PLS ring, physical apertures are limited by the ducts of insertion devices in straight sections. Then, the physical apertures become 36 mm and 5 mm in the horizontal and vertical directions, respectively. From the simulation results, it is shown that the low emittance lattice in the ring has a sufficient dynamic aperture after a correction of the COD when the machine errors are kept within the level given in Table II.

CONCLUSION

A low emittance lattice in the PLS ring is designed to provide more brilliant synchrotron radiation. The dynamic apertures in tune space for the low emittance lattice have been investigated by a simulation method. From the simulation results, we could get a betatron tune that showed a comparatively large dynamic aperture from the tracking method. It is shown that the tune obtained from the simulation can be used as operating tune based on the view point of the dynamic aperture. Machine studies for studies of tolerance of COD to keep enough dynamic apertures will be performed soon.

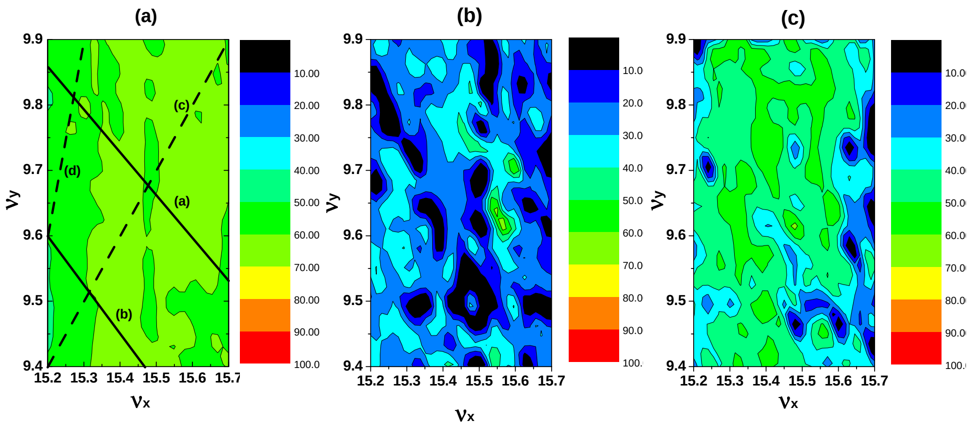

Figure 3: Dynamic apertures obtained from a tune survey. (a) without machine errors, (b) with machine errors, (c) after corrections of COD in (b)

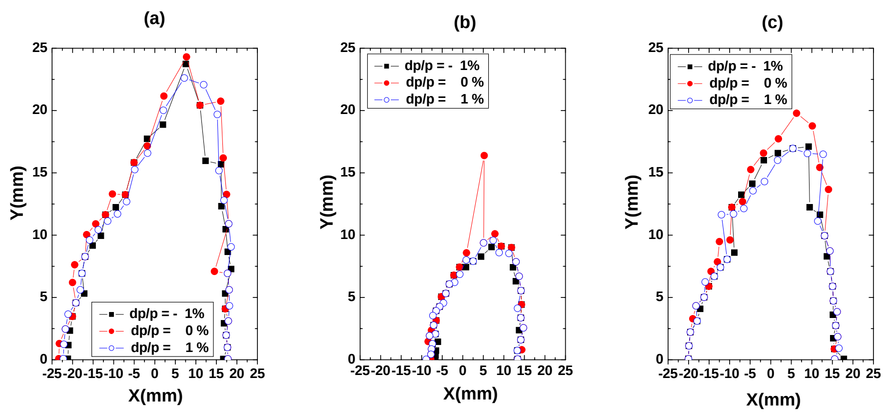

Figure 4: Dynamic apertures at the center of the straight section. ν_x=15.39. ν_y=9.74. (a) without machine errors, (b) with machine errors and (c) after corrections of COD in (b).

Table 1: Main parameters in the PLS storage ring.

	Units	Values
Beam emittance	nm	13
Beam energy	GeV	2.5
Rms energy spread		0.000864
Rms bunch length	mm	6.88
RF voltage	MV	1.6
Strength of sextupole (SD/SF)	$1/m^2$	-7.42/4.82
Linear chromaticity (H/V)		-33.34/-20.1
Betatron tune (H/V)		15.39/9.74
Beam size (H/V) at ID	μm	394/19.7
Circumference	m	280.56

Table 2: Main machine errors in the PLS storage ring.

	Qua.	Bend	Sext.
Rms magnetic field (%)	0.02	0.02	0.04
Rms alignment error (H/V)(μm)	80/80		80/80
Rms rotation error (mrad)	0.1	0.1	0.1
Rms length error (μm)	100	100	100
Steering magnet :0.001%			
BPM offset error(H/V)(μm):10/5			
BPM resolution (H/V)(μm):10/5			

REFERENCES

[1] K. Hirata, Second Advanced ICFA Beam dynamics Workshop, CERN 88-04, (1988), p.62.

[2] PLS design report, January (1992).

[3] Eun-San Kim, Yukinori Kobayashi and Masahiro Katoh, Jpn. J. Appl. Phys. Vol. 36 pp. 7415 (1997).