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ON-RESONANCE ROUND BEAM EXPERIMENT IN THE HLS-II STORAGE RING*

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Abstract

The strong intra beam scattering effect and the increase in horizontal emittance become common issues for next-generation ultra-low emittance storage rings. The round beam can be an effective method to solve these problems. Moreover, the produced round synchrotron radiation is suitable for optical matching. The on-resonance tune is an easier method to achieve round beam. In this paper, simulation and experimental results are introduced based on the nominal lattice of the HLS-II storage ring.

INTRODUCTION

Horizontally flat beams have been used in typical storage ring based light sources for decades. The large particle density leads to strong intrabeam scattering (IBS) effect which causes short beam lifetime. Approaching the diffraction limit, this becomes a challenge to light source operation. The round beam can then be a solution to overcome this challenge. The round photon beam produced by the round beam has a better match for optics, which is inclined to be used by some synchrotron radiation users. In addition, the round beam applied on booster will help to ease beam injection [1]. The study of the round beam has been applied in some light sources, such as APS, NSLS-II and HEPS [2].

Two commonly used methods to obtain the round beam are use of on-resonance and strong linear coupling manipulated by skew quadrupoles. Compared with the strong linear coupling, the on-resonance lattice is easier to achieve. And the lattice parameters are close to those in the flat beam, which means that the existing lattice design and correction technology is still available.

There are 32 quadrupoles in the HLS-II storage ring. Each quadrupole has its own independent power supply. Therefore, the quadrupole strengths can be adjusted respectively, which provides convenience for the tune adjustment. Main parameters of the bare lattice are shown in Table 1. This article introduces the study on the on-resonance round beam at the HLS-II storage ring.

THEORY OF THE ON-RESONANCE ROUND BEAM

The effect of weak coupling on the particle dynamic can be regarded as a perturbation. By solving the perturbed Hamiltonian, the modulation factor F and the interchange period T can be expressed as [3]

Table 1: HLS-II Storage Ring Main Parameters

Parameters	Value
Energy	0.8 GeV
Circumference	66.13 m
Tune v_x,v_y	4.4447/2.3597
Emittance	37.98 nmrad
Chormaticity ξ_x,ξ_y	+1/+3
Energy Spread	4.72282e-04
Beta function at the injection point β_x,β_y	18.85/2.54 m

$$F = \frac{|C|^2}{\Delta^2 + |C|^2}, \quad (1)$$

$$T = \frac{1}{\eta f_{rev}}, \quad (2)$$

where Δ is the difference in the tune in the uncoupled case, f_{rev} is the particle's revolution frequency and C is the coupling coefficient related to the coupling strength. Therefore, achieving the round beam requires the same fractional part of the vertical and horizontal tune and certain coupling.

The Ohmi method provides a formalism of the beam envelope, emittance and radiation integrals using the diffusion matrix. This formalism is suited for accurate numerical calculation and also works in the case of coupling [4]. In addition, the particle motion in the coupling case can also be decoupled to the normal mode. The $\boldsymbol{C}$ matrix and parameter γ are used to describe the coupling of the lattice. Associated with the twiss parameter, $\overline{\boldsymbol{C}}$ can be obtained . Then, the beam size of the on-momentum particle can be calculated by [5]

$$\sigma_x^2 = \gamma^2\epsilon_a\beta_a + \epsilon_b\beta_a(\overline{\boldsymbol{C}}_{11}^2 + \overline{\boldsymbol{C}}_{12}^2); \quad (3)$$

$$\sigma_y^2 = \gamma^2\epsilon_b\beta_b + \epsilon_a\beta_b(\overline{\boldsymbol{C}}_{22}^2 + \overline{\boldsymbol{C}}_{12}^2), \quad (4)$$

where β_a and ϵ_a are the β-function and the emittance in the a mode, β_b and ϵ_b are the β-function and the emittance in the b mode.

For the on-resonance case, only weak coupling is required to obtain the round beam. In this case, the vertical dispersion can be neglected and the increase in the beam size because of the horizontal dispersion can be expressed as

$$\sigma_{x,total}^2 = \sigma_x^2 + \eta^2\Delta E^2; \quad (5)$$

$$\sigma_{y,total}^2 = \sigma_y^2, \quad (6)$$

where η is the dispersion function in the horizontal plane and ΔE is the energy spread.

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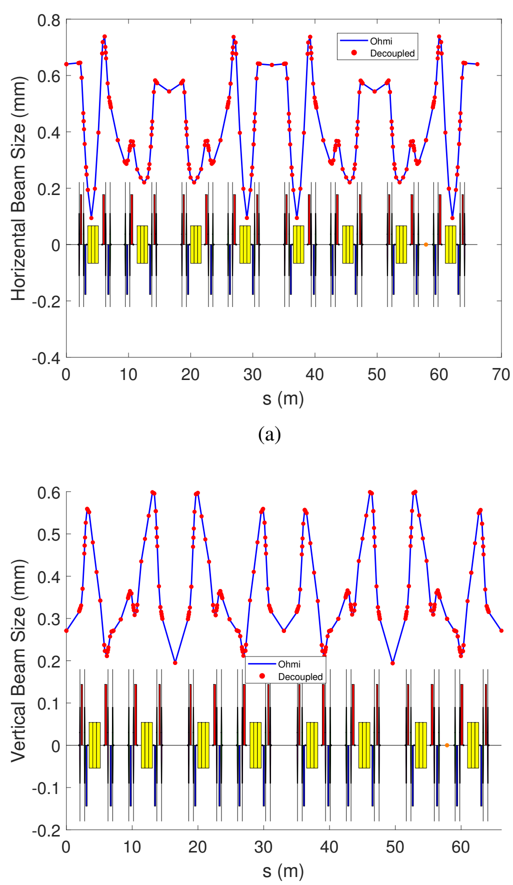
The on-resonance lattice based on the nominal lattice in the HLS-II storage ring is used for beam size analysis. The tunes in the vertical and horizontal planes are adjusted to the same fractional number, while skew quadrupoles are used to provide weak coupling. Applying the Ohmi and the decoupled method for the beam size calculation in the on-resonance case, the calculation results are shown in Fig. 1. At HLS-II, the light source points are located at the 1/3 bend length away from the entrance of the bends. The beam size at the light source point of a bending magnet (B8) is 198 µm in the horizontal plane and 408 µm in the vertical plane.



(a)

(b)

Figure 1: Beam size calculation from the Ohmi method and the decoupled method. Because the values of the emittances are close due to the resonance, the beam size in both directions is comparable. (a) The horizontal plane. (b) The vertical plane.

ROUND BEAM OBTAINED USING TUNE KNOB

As mentioned above, the on-resonance round beam needs a certain coupling and the same fractional part of the transverse tune. During the construction of the real storage ring, small misalignments and magnet imperfections are unavoidable. With these, off-center of setupoles in the vertical plane brings coupling to the motion of the particle. Meanwhile, the roll error of the quadrupoles will also introduce coupling. Although these are uncontrollable, the introduced coupling is expected to be sufficient for resonance. At HLS-II, the multi-function sextupoles are able to provide skew quadrupole fields, which can be used for coupling compensation.

It is well known that the transverse tune can be adjusted using quadrupoles. When the adjustment amount of the quadrupole strengths is small, the dependence can be expressed as

$$\Delta\nu_{x,y} = \oint \Delta K(s)\beta_{x,y}(s)ds, \tag{7}$$

where $\Delta K(s)$ is the change in the quadrupole strength, $\Delta\nu$ is the difference in the tune, and $\beta(s)$ refers to the β-function at the location s. In the HLS-II storage ring, a tune knob method is proposed to adjust the tune, which also has a small impact on the beam dynamics [6]. To maintain the injection efficiency, the strength of the nearest four quadrupoles from the injection point remains unchanged. The twiss parameters at the entrance and exit of this section are also constrained to remain unchanged. The change in the quadrupole strength in the tune adjustment process is shown in Fig. 2.

ONLINE ROUND BEAM EXPERIMENT

The relationship between the tune and the quadrupole strength is not linear. The measured tune near the resonance is not equal to the uncoupled one. Therefore, the difference between the initial and set tune is used for the quadrupole strength calculation. In the HLS-II storage ring, the weak coupling introduced by misalignments and imperfections of the magnets is supposed to be sufficient for the generation of the round beam. Therefore, the skew quadrupole magnets are turned off in this experiment.

The on-resonance round beam experiment works as follows:

1) Measure the initial tune of the lattice with weak coupling.

2) Calculate the difference between the set and initial tune. According to the variation, the quadrupole strength in the next step is calculated.

3) Change the excitation current value of the quadrupoles.

The target tune is set from 0.385 to 0.375 in the horizontal plane and from 0.375 to 0.385 in the vertical plane. The measured beam sizes and tune are shown in Fig. 3. The on-resonance beam sizes at the light source point in the bend (B8) obtained from the tune knob method are 272 µm in the horizontal plane and 288 µm in the vertical plane. The minimum separation of the measured tune is 0.005, which is equal to the coupling coefficient $|C|$. The difference between the calculation and experimental result is mainly caused by the tune adjustment error of the tune knob and the difference between the real lattice and the nominal lattice. The error of the tune affects the degree of resonance (see Eq.(1)), while

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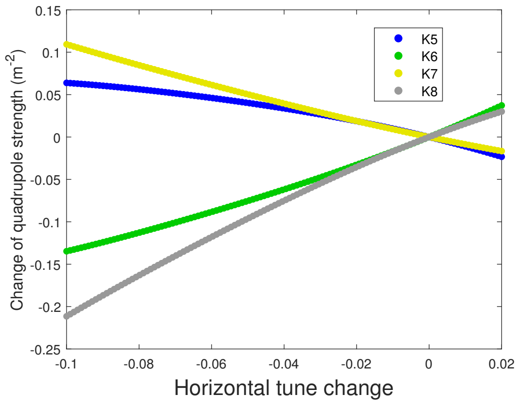

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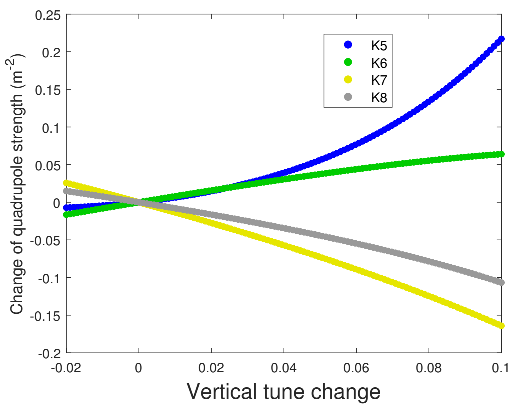
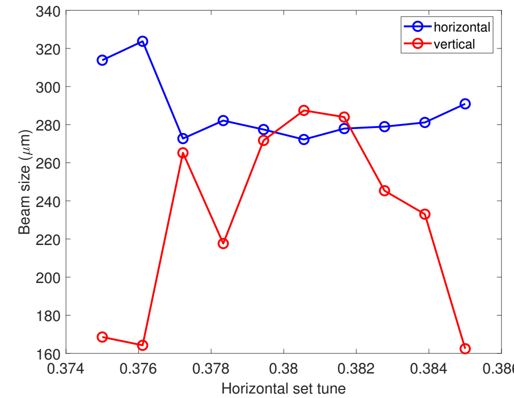


(b)

Figure 2: Quadrupole strength changes in the tune adjustment process. (a) Only the horizontal tune is changed; (b) Only the vertical tune is changed. Quadrupole families K5-K8 are used for tune adjustment.



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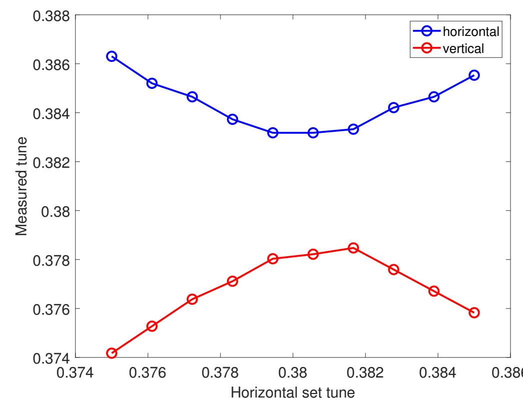

(b)

Figure 3: The relationship between the measured beam size and measured tunes and the horizontal set tune.

the twiss parameters difference between the real lattice and the nominal lattice affects the theoretical computation result.

SUMMARY

In the HLS-II storage ring, simulation is carried out for the beam size calculation for the on-resonance round beam. On-line experiment based on tune knob is applied to achieve the on-resonance round beam. In this experiment, the beam size is 800 µm in the horizontal plane and 288 µm in the vertical plane. The minimum separation of the measured tune is 0.005. The tune knob is a flexible method to achieve on-resonance round beam, which can be an effective method to solve the problems introduced by the strong IBS effect. For future work, a tune feedback system independent of the measured tune should be developed to make the tune adjustment more precise and compensate for the tune shift introduced by the change in the gaps of the insertion devices.

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