VERTICAL BEAM SIZE CORRECTION AT THE SSRF STORAGE RING*

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Abstract

Vertical beam size is an important parameter for 3rd generation light source. Correcting the vertical beam size is a realistic way to increase brightness or beam lifetime without any additional equipments in a machine under operation. The main sources of vertical beam size are betatron coupling and vertical dispersion. At the SSRF storage ring, LOCO is used for coupling measurements and corrections. The betatron coupling and vertical dispersion is corrected by skew quadrupoles that calculated by LOCO. Vertical beam size can be changed from 10s um to several um for different purposes. Touschek lifetime is also measured to testify the vertical beam size. Simulations show that if smaller vertical beam size is required, more skew quadrupoles are needed.

INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) [1] is a dedicated third generation synchrotron light source with nominal energy of 3.5 GeV. The storage ring provides a high brightness source of x-rays from bending magnets and insertion devices. Serving as a user facility, the spectral brightness is an important figures of merit. The electron beam size is the most important parameters for brightness. Reducing the vertical beam size provides the possibility to increase brightness. In a electron synchrotron storage ring, the vertical beam size contains a global contribution "vertical beam emittance" and a local contribution. There are mainly three contributions to the vertical beam size : betatron coupling, vertical dispersion and non-zero opening angle of radiation.

Betatron coupling originates from skew quadrupoles. The skew quadrupoles rise from quadrupole rotation errors and vertical closed orbit distortion in sextupoles in the dispersive region. The vertical beam size from both the sum and difference resonances is [2]:

$$\frac{\sigma_y^2(s)_{local}}{\beta_y(s)} = \frac{\varepsilon_x}{16}\left[\sum_{\pm}\frac{|C_\pm(s)|^2}{\sin^2\pi\cdot\Delta_\pm} - 2\,\mathrm{Re}\frac{C_+(s)C_-^*(s)}{\sin\pi\Delta_+\sin\pi\Delta_-}\right]$$

where $C_\pm(s) = \int_s^{s+C} dzg\sqrt{\beta_x\beta_y}\,e^{i[(\phi_x(s)\pm\phi_y(s)-(\phi_x(z)\pm\phi_y(z))+\pi\Delta_\pm]}$

is the driving term, g is the skew quadrupole strength and $\beta_u, \phi_u, \nu_u, \gamma_u, \eta_u$ are the twiss parameters in each plane. The first expression represents the projection of the horizontal emittance into the vertical plane. The second expression describes the contribution to the vertical emittance from the horizontal dispersion.

Vertical dispersion is caused by 1) vertical bend error from bending rotation errors; 2) vertical closed orbit errors in the quadrupoles; 3) dispersion coupling due to skew quadrupole errors in the dispersive region. Vertical dispersion increases vertical beam size in two ways[2]: (1)by coupling a particle's energy deviation to it' s vertical position $\frac{\langle\sigma_y^2(s)\rangle_{local}}{\beta_y(s)} = \frac{\langle\eta_y^2(s)\rangle}{\beta_y(s)}\sigma_\varepsilon^2$, and (2) by causing the vertical emittance to increase like the emittance from horizontal dispersion:

$$\varepsilon_y = \frac{C_q\gamma^2}{J_y}\frac{\oint|G|^3 \mathrm{H}_y ds}{\oint G^2 ds} = \frac{C_q\gamma^2}{J_y}\frac{\langle \mathrm{H}_y/\rho^3\rangle_s}{\langle 1/\rho^2\rangle_s}.$$

The opening angle increases the vertical emittance[3]: $\varepsilon_y = \frac{C_q\bar{\beta}_y}{2J_y}\frac{\langle 1/\rho^3\rangle_s}{\langle 1/\rho^2\rangle_s}$, if ignore the correlation between the energy and angle of the radiated photons.

The betatron coupling and vertical dispersion are two main sources for the vertical beam size.

COUPLING MEASUREMENT

The betatron coupling can be measured by the tune split method. According to the perturbation theory of second order difference resonance, by the single resonance approximation[4], the tune split C is the minimum value between the two measured tunes. At the nominal work point, $\Delta = \nu_x - \nu_y - p$. The currents of a family named Q4 are changed for the measurement. Betatron coupling measurement result is shown in Figure 1. The betatron coupling factor $\frac{\varepsilon_y}{\varepsilon_{x0}} = \frac{|C|^2}{2\Delta^2 + |C|^2} = 0.29\%$.

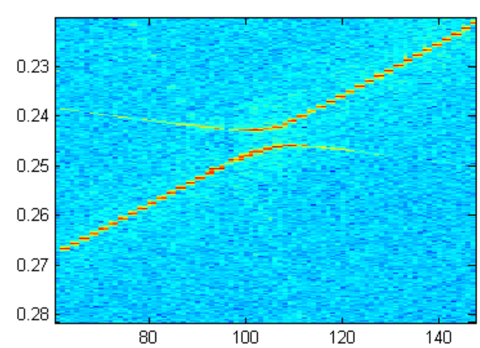

Figure 1: The tune split.

LOCO[5] gives us the possibility to find a model well explaining the machine employing a large number of skew gradient error fit parameters. If the model is established, equilibrium beam envelope is calculated by Ohmi's beam envelope formalism[6]. By carefully choosing the skew quadrupole number and vertical dispersion weight, one can get the coupling result. Figure 2 shows the coupling calculation result. The average vertical emittance is 17.2 pmrad, the average horizontal emittance is 3.89 nmrad, and the coupling is 0.44%.

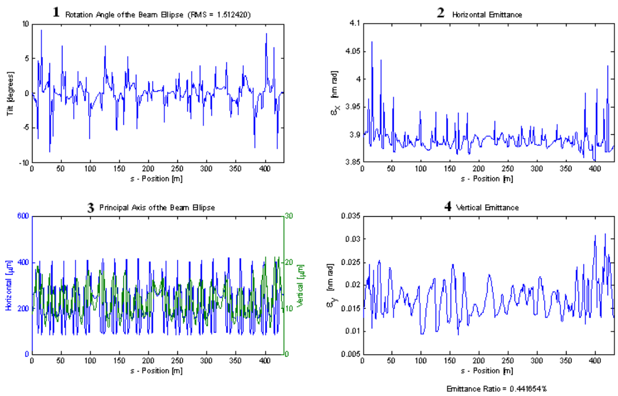

Figure 2: The coupling in the whole ring.

The Touscheck lifetime is proportional to the horizontal and vertical beam sizes and hence sensitive to the coupling ratio[5]: $\frac{1}{\tau} \propto \frac{N_b}{8\pi\sigma_x\sigma_z\sigma_z} \propto \frac{\sqrt{\kappa}}{(1+\kappa)I_{bunch}}$.

VERTICAL BEAM SIZE CORRECTION

There are 140 skew quadrupole windings at the SSRF storage ring, but only 20 of them are powered by power supply. The skew quadrupoles in the SSRF storage ring all are in the same position in each cell.

Skew Quadrupole Calibration

Before correcting the vertical beam size, the skew quadrupole should be calibtated. The response for each skew quadrupole is measured, and the skew quadrupole polarities are find. Figure 3 shows the response matrix of betatron coupling-skew quadrupole current.

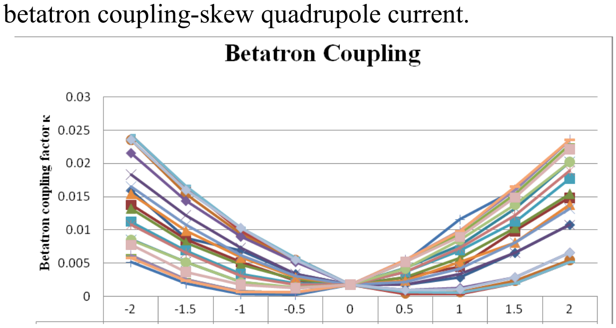

Figure 3: The betatron coupling responds to the skew quarupole current.

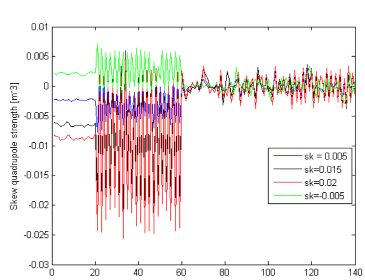

Figure 4: The skew quadrupole calibration.

The emittance coupling is used to calibrate the skew quadrupole strength. Figure 4 shows the skew quadrupole strenght fitted by LOCO using different power supply current settings. One can find that the 0.005 of SD1 introduced 0.0056 of SD1 and also 0.0021 of SF.

Betatron Coupling Correction

By using the most effective wingding 'SKQ07', the betatron coupling can be changed from 0.014% to 2%. Figure 5 shows two coupling correction results, 0.66% and 0.014%.

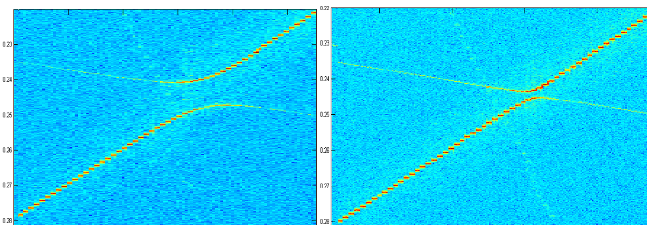

Figure 5: The betatron coupling correction result.

Betatron Coupling Correction

In order to get a smaller vertical beam size, LOCO is chosen that correct betatron coupling and vertical dispersion at the same time. The different skew quadrupole numbers in LOCO will produce different rolls and gains of the BPM and corrector, this may yeild confusing results. The solution is to decouple the vertical dispersion and orbit response matrix by using the rolls and gains. Figure 6 shows the measured vertical dispersion and decoupled results.

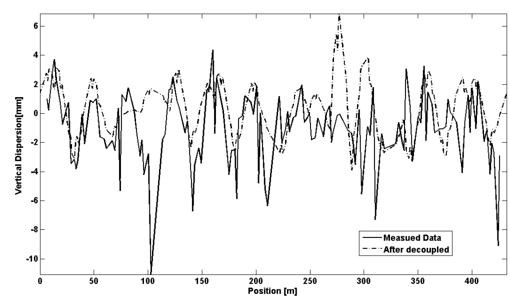

Figure 6: The measured and decoupled vetical dispersion.

Figure 7 shows the skew quadrupoles strength. These strength are applied to the real machine, and get a lifetime decrease from 32hrs to 22.5hrs. The measured betatron coupling is also reduced from 0.29% to 0.014% and the emittance coupling from LOCO is changed to 0.17%. Figure 8 shows the beam profile before and after correction. The vertical beam size is smaller. Figure 9 shows the measured and decoupled vertical dispersion after correction. Compared to Figure 6, the decoupled vertical dispersion is 2 times smaller.

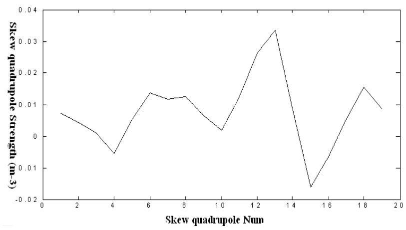

Figure 7: The skew quarupole strength for correction.

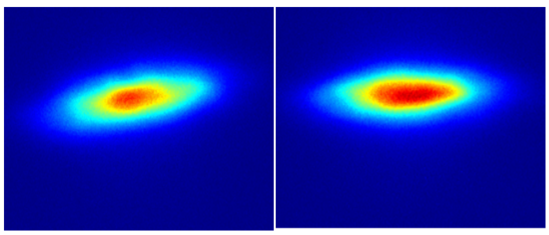

Figure 8: The beam profile before and after correction.

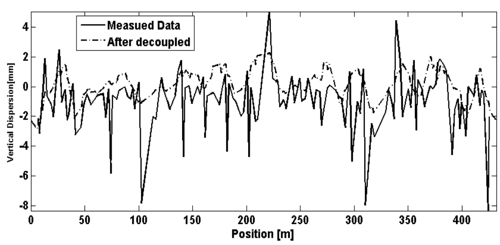

Figure 9: The vetical dispersion after correction.

Simulation

In order to reach the limit of vertical beam size correction, several simulations were done using the model and random errors. The simulations show that 1) the coupling from sextupole shifts is easier to correct than the one from quadrupole rolls and 2) more skew quadrupoles are needed if a smaller vertical beam size is required. Table 1 shows a simulation example. When the skew quadrupole number rises, the vertical dispersion and the coupling from quadrupole rolls are more corrected. The last result in the Table 1 is an amazing value because the simulation only employed skew quadrupole errors, quadrupole errors and quadrupole shifts. No BPM errors are found from nonlinear effect, BPM noise and collective effect. But the simulation illuminates that more skew quadrupoles are needed and the wingdings in the resonance sextupole are important for correction. Fortunately, the installtion error for the quadrupole rolls is 0.2mrad, the shifts error of sextupole is 0.08mm, and the coupling from the second one is larger than the first one.

Table 1: Effect of the Skew Quadrupole Number

SK Numbers	Initial	19	60	140
Vertical dispersion (mm)	37.7	12.3	11.6	2.3
Coupling	1.1%	0.86%	0.82%	0.09%

Vertical Beam Size Control

In order to change the vertical beam size expediently, the relationship of coupling and skew quadrupole strength were measured. Figure 10 gives the results of different method to calculate the coupling: fit by LOCO, measure the vertical beam size at the x-ray pin hole, using the calibrated skew quadrupole strength, and also the normalized beam lifetime. They are well correspond with each other.

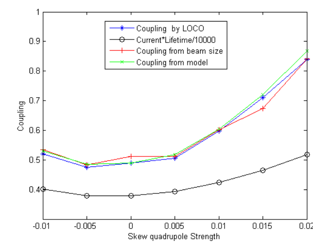

Figure 10: The coupling changed by different skew quadrupole strength.

CONCLUSION

Vertical beam size rises from the vertical dispersion and the betatron coupling caused by skew quadrupole fields, such as quadrupole rolls and sextupole shifts. Tune split method is used for betatron coupling measurement in the SSRF storage ring The betatron coupling is 0.29%, and can be varied from 0.014% to 2% employing a single skew quadrupole. LOCO is used for emittance coupling meausurement and correction. The initial emittance coupling is 0.44%. After decoupling the orbit response matrix and vertical dispersion, emittance coupling is reduced to 0.17%. The whole family skew quadrupoles are used for vertical beam size control, and the result shows high correspond with each other. The experiment has proved that this method is good for the vertical beam size reduction. More simulations indicate that more skew quadrupoles are required if a smaller beam size is demanded

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