# VERTICAL BEAM SIZE CONTROL AT SRRC

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*Abstract*

Vertical beam size control in the 1.5 GeV synchrotron radiation storage ring at SRRC was investigated. Linear coupling model based on the measured orbit response was attempted. Manipulation of transverse beam betatron coupling as well as the vertical dispersion correction using a set of skew quadrupoles around the ring has been conducted. The correlation of the coupling strength, vertical beam size, beam brightness, as well as beam lifetime was measured and optimal operation conditions have been searched for the routine users operations.

## 1 INTRODUCTION

We have studied the error sources of the linear optics of the SRRC 1.5 GeV storage ring and compared with the measured magnetic field data before.[1] The results show that the major gradient field errors are from the sextupoles. Alignment errors of the sextupoles are attributed to be the case of the distortion of the linear optics in SRRC storage ring. In this report, we investigate the linear coupling error sources and develop a method to correct it.

It is known that, in a storage ring, error sources which cause the vertical emittanc blow-up can be due to collective instabilities such as fast-ion instabilities, single-bunch broad-band instabilities, coupled-bunch instabilities, etc., or owing to betatron coupling originated by skew quadrupole errors from quadrupole rotation errors and vertical closed orbit distortion in sextupoles. In addition, spurious vertical dispersion affects significantly on the vertical beam size. Supirous vertical dispersion is caused by (1) vertical bend error from bending rotation errors and vertical closed orbit errors in the quadrupoles and (2) dispersion coupling due to skew quadrupole errors in the dispersive region which are from quadrupole rotation errors in the dispersive region and vertical closed orbit distortion in sextupoles in the dispersive region.

All these errors need to be eliminated or minimized in order to achieve a lower vertical emittance of the stored beam.[2] In this report, we focus on the correction of the above mentioned betatron coupling and vertical dispersion using a set of skew quadrupoles installed around the ring. Our goal is to reduce the betatron coupling and vertical dispersion coupling in the ring so that the vertical beam size can be reduced to an acceptable value.

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## 2 THEORY

One can calculate vertical closed orbit and vertical dispersion as follows:

$$y_c(s) = \frac{1}{2\sin\pi\nu_y}\int_s^{s+c} g(s,z)G(z)dz,$$

$$\eta_y(s) = \frac{1}{2\sin\pi\nu_y}\int_s^{s+c} g(s,z)F(z)dz,$$

$$\mathrm{g(s,z)} = \sqrt{\beta_y(s)}\,\sqrt{\beta_y(z)}\,\cos(\psi_y(s)-\psi_y(z)+\pi\nu_y)$$

where $G(s) = \tilde{K}_1 x_c + K_2 x_c y_m - G_y$, $\tilde{K}_1, K_2, G_y$ are the skew quadrupole, sextupole strength and vertical dipole error, respectively. $y_m$ is the orbit offset with respect to the sextupole magnetic center, and $F(s) = -G_y - K_1 y_c - \tilde{K}_1 \eta_x + K_2 y_c \eta_x$.

Let $\mathbf{M}$ be a unified response matrix for a set of horizontal steering and installed (or virtual) skew quadrupoles and $\mathbf{V}$ be the measured normalized vertical orbit and dispersion, the skew quadrupole array $\mathbf{K}$ in the ring can be obtained using singular value decomposition (SVD) for a linear equation $\mathbf{MK} = -\mathbf{V}$ such that the betatron coupling and vertical dispersion can be minimized simultaneously. Moreover, one can set a correction target in the vector $\mathbf{V}$. That is to say that we not only correct it globally, but we can choose the weighting factor either on the betatron coupling correction or on the vertical dispersion correction. We can even have the local beam size or local coupling control if there are enough skew correction quadrupoles.[3]

In the SRRC storage ring, there are 48 beam position monitors and 8 skew quadrupoles. We chose 24 horizontal steering magnets in the measurements. In this way, we have 48×24+48=1200 elements in $\mathbf{V}$ and the dimension of $\mathbf{M}$ is 1200×8. Once $\mathbf{K}$ is obtained, we can establish a virtual machine and compare it with the real machine in terms of the measurable parameters such as normal mode tunes, vertical dispersion, coupling ratio, etc.

## 3 EXPERIMENTAL RESULTS

In order to reduce the coupled-bunch instabilities, we conducted the measurements of the coupling correction at lower beam current. The measured response matrix is consistent with the model. Except for a multipole wiggler, all the other insertion devices were open during the measurements.

Using SVD method, a set of skew quadrupole correction strengths was obtained to reduce both betatron coupling and vertical dispersion. Figure 1 shows the measured vertical orbit response with respect to the corresponding horizontal kick as well as the calculated response. Figure 2 depicts the measured dispersion function and the model results using 8 skew quadrupoles. It is found that in the virtual machine with fitted skew errors, the rolls of the 48 quadrupoles in the ring can be as large as a few mrad, which is unrealistic. However, the misalignment of sextupoles in the vertical plane in the range of 0.5 mm can generate integrated skew quad strengths of about 4 $10^{-3}$ $m^{-1}$, which is reasonably in agreement with the virtual machine. Figure 3 is the skew error distribution of the virtual machine, assuming that all errors are from sextupoles, and also a comparison between the experimental and model vertical dispersion is given. Both betatron coupling and vertical dispersion can be well corrected. Figure 4 shows the experimental and model normal mode tunes before and after correction as a function of quadrupole family Q2 strength. Notice that we employed a turn-by-turn BPM system to measure both horizontal and vertical beam betatron oscillations after a horizontal kick. Normal mode tunes were extracted from the fast Fourier transform of the turn-by-turn data.

The normal mode tunes can be expressed in terms of the fractional tunes and coupling strength as $\nu_{1,2} = \frac{\nu_x + \nu_y}{2} \pm \frac{1}{2}\sqrt{\Delta^2 + G^2_{1,-1,\ell}}$ and $\Delta = \nu_x - \nu_y$, where $\ell = 3$.

The extracted coupling strength $|G_{1,-1,3}|$=0.0119 and 0.0016 before and after correction, respectively.[4] Figure 5 and 6 show the measured beam images, turn-by-turn data and the corresponding tune spectra near the coupling resonance and in users operations mode before and after corrections, respectively. Figure 7 gives the measured and model calculated beam size as well as beam lifetime as a function of the quadrupole Q2 strength. The extracted coupling ratio as a function of tune difference from the resonance point is shown in Fig. 8. Coupling ratio is defined as: $\kappa = \frac{G^2_{1,-1,3}}{G^2_{1,-1,3} + 2\Delta^2}$.

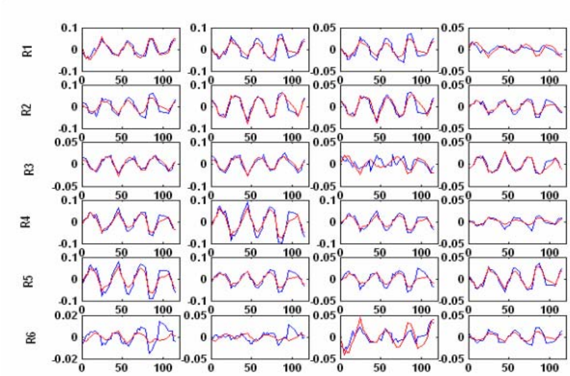


Figure 1: Measured vertical orbit response with respect to the corresponding horizontal kick as well as calculated response in six sections with four steerers in each section.

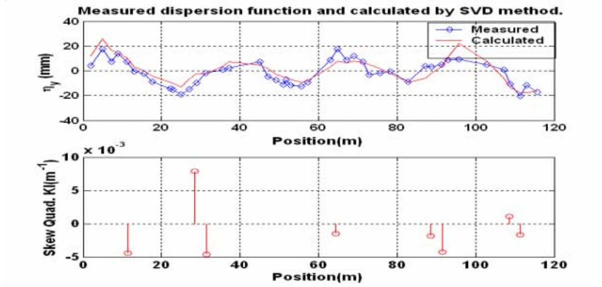


Figure 2: Correction strength of skew quadrupoles and a comparison between experiment and model in vertical dispersion.

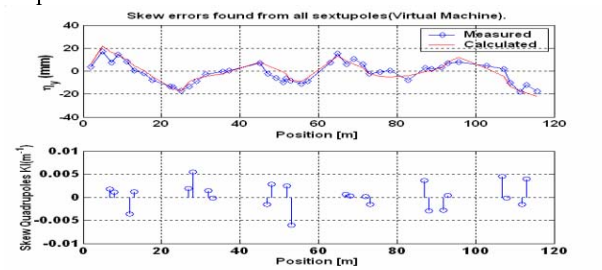


Figure 3: Assuming all errors are from sextupoles, a virtual machine is obtained using SVD method. Measured and model vertical dispersion is also shown.

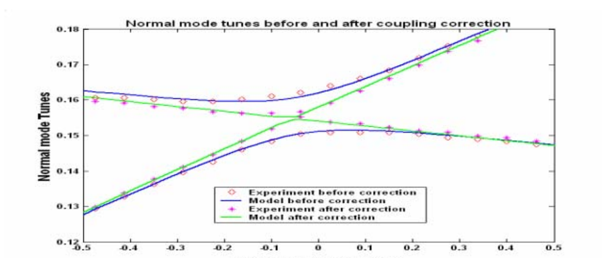


Figure 4: Experimental and model normal mode tunes, before and after correction.

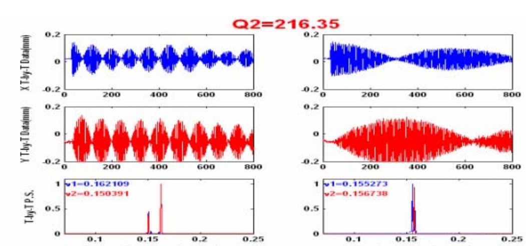


Figure 5: Measured turn-by-turn data after a horizontal kick and the corresponding tune spectra near the coupling resonance before and after corrections.

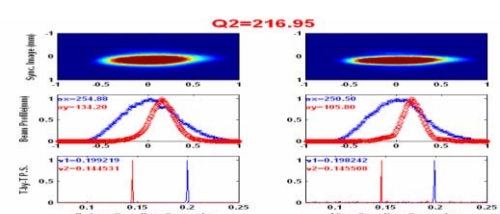


Figure 6: Measured beam images and corresponding tune spectra in the routine operations before and after

correction.

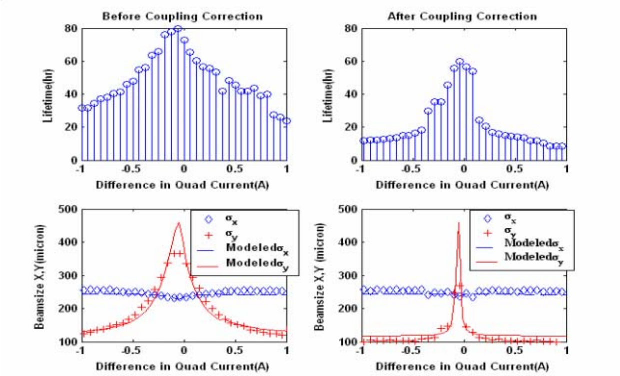


Figure 7: Measured and modeled beam size as well as lifetime as a function of the quadrupole Q2 strength.

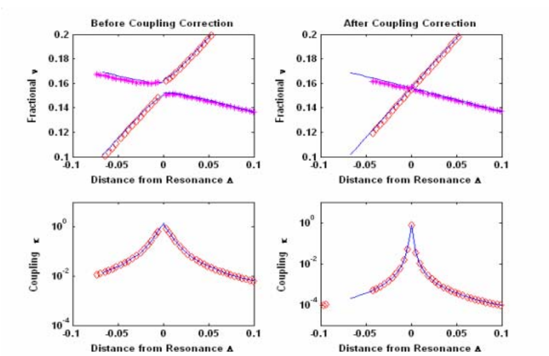


Figure 8: Extracted coupling ratio as a function tune difference from the resonance point.

## 4 OPERATIONS

In the routine users operations, we need to compromise between the beam lifetime and coupling strength. Figure 9 shows the beam lifetime, synchrotron light intensity from a pinhole measurement, and vertical beam size as a function of the correction ratio, assuming full correction is 100%. This data provide a guideline for the routine operations in different operation modes.

The gap closing of the insertion devices introduce stronger coupling terms. With these field errors and the vertical tune shift during gap change, if not compensated for, the coupling strength is changed. Figure 10 displays the additional required skew quadrupolar strength to accomplish the correction as a variation of the EPU gap and phase. A compensation scheme following the gap change will be built-in in the future.

## 5 CONCLUSION

Using cross orbit response method and SVD correction algorithm, we can characterize the betatron coupling behavior and conduct corrections using a set of independent skew quadrupoles in the 1.5 GeV storage ring at the SRRC. As a result, both coupling strength and vertical dispersion can be well corrected. A virtual machine can be established and it is found that the vertical alignment errors of the sextupoles are the major coupling error sources. This study provides useful data set for the routine operations.

## 6 ACKNOWLEDGEMENT

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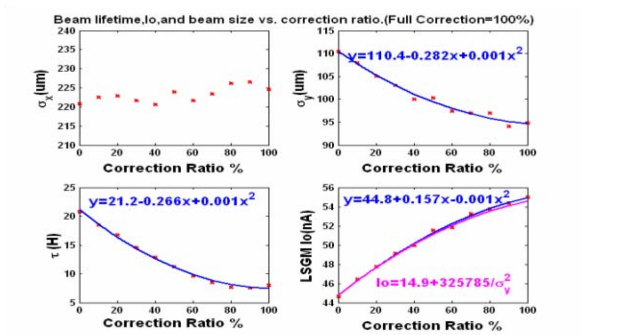


Figure 9: Horizontal and vertical beam sizes, synchrotron light intensity from a pinhole measurement, beam lifetime (from top left to right left in clockwise) as a function of the correction ratio, assuming full correction is 100%.

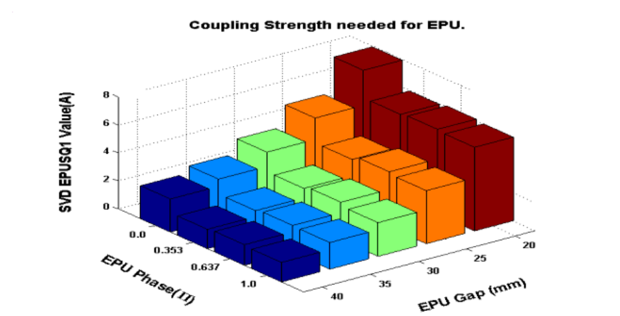


Figure 10: Additional required skew quadrupolar strength to accomplish the correction as the EPU gap and phase are varied.

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