COUPLING CORRECTION STUDY AT NSRRC

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Abstract

Emittance coupling between vertical and horizontal planes at TLS has been investigated. Using a set of skew quadrupoles, the coupling can be corrected to an acceptable value. The coupling sources are studied and possible errors are reduced.

INTRODUCTION

The equation of motion of the bunched beam is governed by the guiding fields, focusing quadrupole fields, nonlinear higher order fields such as the sextupole fields, and wake fields. It could be uncoupled or coupled motion either in the transverse planes and/or between transverse and longitudinal planes. In this study we are interested in the investigation of the error sources and the finding of the ways to controlling the coupling strength.

We have studied the error sources of the linear optics of the NSRRC 1.5 GeV storage ring TLS (Taiwan Light Source) and compared with the measured magnetic field data using LOCO code in the de-coupled case.[1] The results show that the major gradient field errors are from the sextupoles. Off-center orbits at the sextupole positions are attributed to be the case of the distortion of the linear optics in the NSRRC storage ring. Misplaced sextupole magnets might be the major contributions.

We also studied the coupled case using cross orbit response method and the results are useful for the routine operations at the NSRRC.[2] We also concluded that the major error sources are from the off-center orbit at the sextupole locations in the vertical plane. These are in good agreement with those using LOCO de-coupled case.

In this report, we describe the interesting results of the consistency between the simulated shifts of the sextupole center and the measured mechanical off-sets.

We also found that the rolls of the steering magnets are not negligible and a complete set of the rolls is mapped.

The MATLAB LOCO version is employed in this study of the linear optics in the coupled motion case.[3] The results with MATLAB LOCO are compared with the cross orbit response analyses.

THEORY

The vertical cross orbit response due to a horizontal orbit change through the coupling elements and the vertical dispersion functions due to the small effective "dipole fields" such as the steering magnets, off-center orbits in the quadrupoles, skew quadrupoles and off-center orbits in the sextupoles in the dispersion region, are given as follows:

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

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

where

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

$G(z) = \tilde{K}_1 x_c + K_2 x_c y_m - G_y$, $\tilde{K}_1, K_2, G_y$ 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

$F(z) = -G_y - K_1 y_c - \tilde{K}_1\eta_x + K_2 y_c \eta_x$.

Let $\mathbf{M}$ be a unified response matrix for a set of horizontal steering and installed (or virtual) skew quadrupoles (8 in total at the NSRRC) 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. 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.

On the other hand, MATLAB-LOCO was employed to this study. The MATLAB LOCO code links to the MATLAB-based AT accelerator modeling code. [4] The LOCO algorithm is well described in ref [3, 5, 6]. The response matrix, M, is the response of BPM shifts for a change of each steering strength,

$$\begin{pmatrix}\vec{x}\\ \vec{y}\end{pmatrix} = M_{\text{meas,mod}}\begin{pmatrix}\vec{\theta}_x\\ \vec{\theta}_y\end{pmatrix} \tag{3}$$

The quadrupole gradient errors are fitted to minimize the difference between the model and measured response matrices.

$$\chi^2 = \sum_{i,j}\frac{(M_{\text{meas,ij}} - M_{\text{mod,ij}})^2}{\sigma_i^2} \tag{4}$$

To calibrate the coupling strength, the off-diagonal sub-matrices are included in the fitting. The skew gradients, steering gain and tilt, BPM gain and coupling,

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as well as quad gradients are included in the fit. The fitting can also include dispersion functions to minimize the vertical emittance and beam size. The fitted skew gradients in the above mentioned 8 locations are compared with those resulted from the other method.

EXPERIMENTAL RESULTS

In ref [2], we have reported some interesting results using cross orbit response matrix, for instance, the measured coupling strength $|G_{1,-1,3}|$=0.0119 and 0.0016 before and after correction, respectively; the consistency of the model and measured normal mode tunes as a function of the distance away from the linear coupling resonance line; the beam size as a function coupling ratio, etc. As examples, we display the normal mode tunes and coupling ratio κ, before and after correction, as a function of the proximity of the resonance line in Fig. 1.

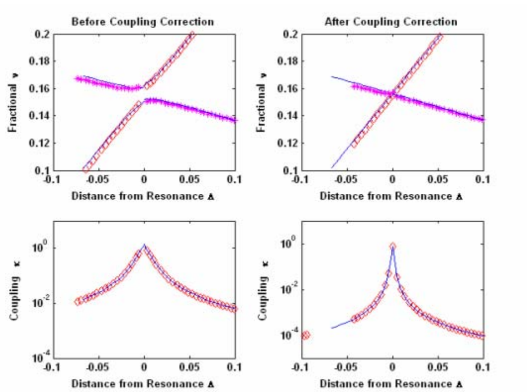

Figure 1: Extracted coupling ratio as a function tune difference from the resonance point

And we also show the turn-by-turn BPM data before and after coupling correction and corresponding Poincaré surface of the section in the resonant processing frame derived from (x, x') and (y, y') in Fig. 2 and 3, where $Q = \sqrt{2J_1\beta_x}\,\cos\phi_1$, $P = \sqrt{2J_1\beta_x}\,\sin\phi_1$.

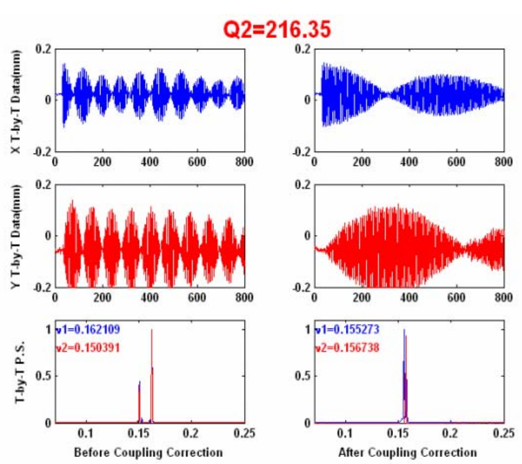

Figure 2: Measured turn-by-turn data after a horizontal kick and the corresponding tune spectra near the coupling resonance before and after corrections.

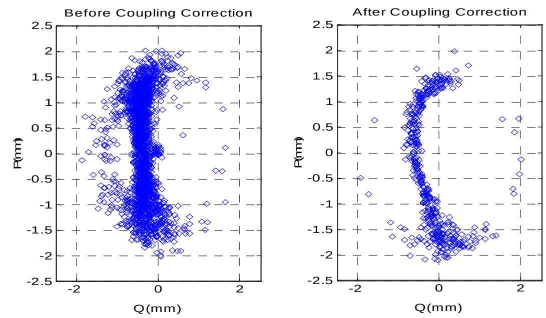

Figure 3: Poincaré surface of the section in the resonant processing frame derived from (x, x') and (y, y'), where $Q = \sqrt{2J_1\beta_x}\,\cos\phi_1$, $P = \sqrt{2J_1\beta_x}\,\sin\phi_1$. The overall coupling phase is 15° and 90° to have the upright cross section before and after correction, respectively.

To verify our previous conclusion that the coupling errors mainly stem from the off-center sextuples, we changed the sextupole strength and the corresponding fitted off-sets are examined. It is found that the fitted off-sets are similar as shown in Fig. 4. Two data sets obtained for six-month separation reveal that there are substantial changes in some sextupoles in the vertical plane. It is found that six sextupoles were adjusted by the Survey and Alignment Group with the movable girders in the vertical plane. Figure 5 is a comparison between fitted movement and measured mechanical shifts in these six sextupoles and the larger error bars in survey data is due to errors in the optical survey method, in which the resolution is about 0.1mm. Moreover, we changed one sextupole position in the vertical plan with high resolution mechanical readings and fitted data are also close to the measured movements as depicted in Fig. 6. It is shown that the coupling strength could be reduced by shifting the sextupole heights.

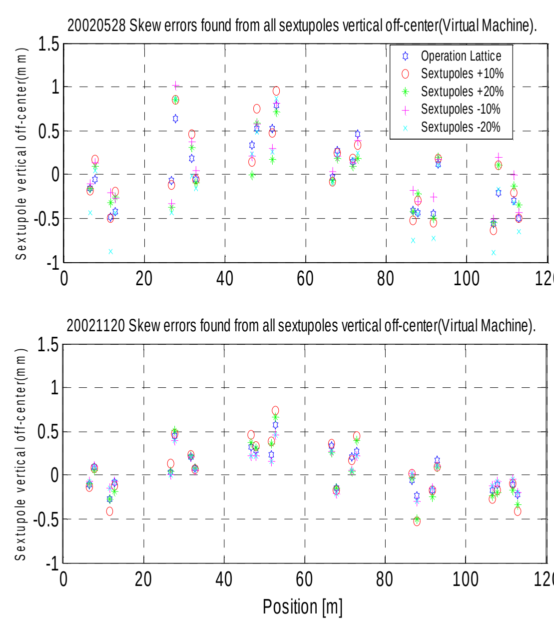

Figure 4: Fitted sextupole vertical position changes at different sextupole setting. Data taken on different date are compared.

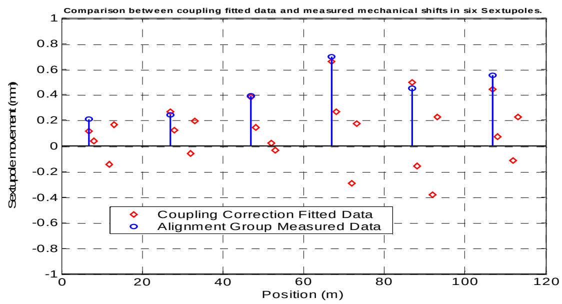

Figure 5: Girder movement data and fitted sextupole vertical position changes. The survey data is with resolution of 0.05 mm.

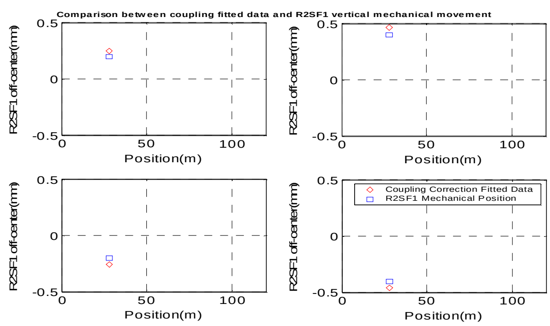

Figure 6: A comparison between the girder movement in one sextupole and coupling fitted data.

By employing the MATLAB-LOCO code, we can obtain not only gains and couplings (tilts) of the steering magnets and BPMs but also the quadrupole and skew quad strengths so that the linear optics can be adjusted to restore the model optics, and the linear coupling as well as dispersions can be corrected. Figure 7 shows the gains and tilts of the horizontal and vertical steering magnets from LOCO and using cross orbit response method. The skew quad strengths are also shown, both from the cross orbit response analysis and LOCO code, in Fig 8. Both results are in good agreement with each other.

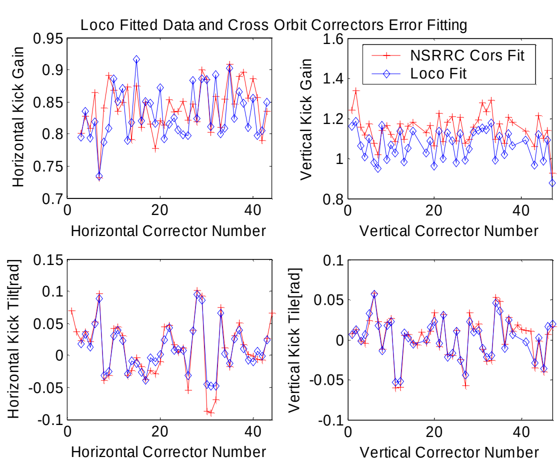

Figure 7: A comparison between the LOCO and cross orbit response analyses results for the gain and tilt of the steering magnets.

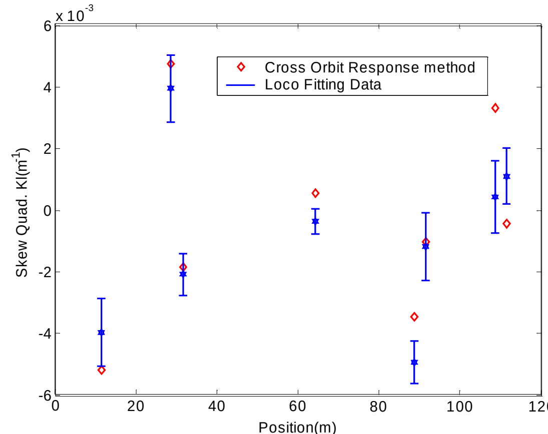

Figure 8: A comparison between the LOCO and cross orbit response analyses results for the correction skew quad strengths.

CONCLUSION

Using cross orbit response method and SVD correction algorithm as well as MATLAB-LOCO, 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 NSRRC. 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.

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