CORRECTION OF LATTICE OPTICS IN THE PRESENCE OF STRONG WIGGLER MAGNET AT SRRC

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Abstract

A wiggler magnet of 26-poles and 1.8 Tesla peak fields has been installed in the 1.5 GeV storage ring TLS (Taiwan Light Source) since March 1995. The vertical betatron beating can be up to 30% with the magnetic gap fully closed. It was not possible to correct this beta-beat until a set of independent quadrupole power supplies were installed in March 1997. Using orbit response matrix method we are able to correct the vertical beta-beat and the periodicity of the machine lattice optics is then restored.

1 INTRODUCTION

Taiwan Light Source, located in Hsinchu, Taiwan, began to provide the beam time to the synchrotron light users in 1993 after its 10-year preparation and construction. This facility TLS is equipped with one of the first third generation synchrotron radiation storage rings. The nominal beam energy of the TLS storage ring is 1.3 GeV and usually is ramped up to 1.5 GeV after injection from a 1.3 GeV booster synchrotron. The ring circumference is 120 meters long and it is with 6-fold symmetry. The lattice is a triple-bend achromat with one family of quadrupole in the arc and three families of the matching quadrupoles in the long straight sections. Therefore there are 6 long straight sections for the installation of the acceleration cavities, injection pulsed magnets and other insertion devices such as wiggler and undulator magnets, etc. A 1.8 Tesla wiggler magnet, W20, was installed in one long straight section in 1995 and was successfully commissioned. This insertion device has been routinely in use for the x-ray users. This strong wiggler magnet is of 26-poles, each pole length is 10 cm. The vertical effective quadrupole gradient of such a strong wiggler field can cause the tune shift as large as $\Delta\nu_y \simeq 0.036$ and betatron beating $(\Delta\beta_y/\beta_y)_{\max} \approx 30\%$ in the vertical plane. As a result, the 6-fold periodicity of machine is broken[1]. It was not able to correct the betatron beat as well as working tune with four families of quadrupoles powered with four power supplies. In march, 1997, we installed eighteen power supplies for the three quadrupole families Q1, Q2, and Q3. For each quadrupole family of Q1, Q2, and Q3, there are twelve quadrupole magnets connected with six quadrupole power supplies and each quadrupole power supply is used for a pair of quadrupole magnets in both sides the long straight section. This report describes the observation of the effects with and without optics corrections.

2 CORRECTION METHOD

There are several ways to compensate lattice optics for the deleterious effects in the presence of the strong perturbation with such wiggler magnet. It can be done with the local quadrupoles or using all useful quadrupoles, namely, global corrections. One can use the existing accelerator design codes such as MAD, RACETRACT, PATPET, etc. to simulate the changes of the machine parameters in the presence of the insertion devices and, furthermore, to look into the differences of the beam dynamics behavior. It is expected that one can find the optimal quadrupole settings so that the machine behavior is acceptable.[2]. However, this kind of studies is usually for the case that the machine is treated ideally and the quadrupole field errors as well as the error sources due to nonlinear elements such as sextupoles are neglected. Moreover, if the insertion devices are not located in the center of the long straight, the betatron beat correction is then troublesome. One good way to correct the real machine parameters changes is to employ the LOCO (Linear Optics from Closed Orbit) method[3]. LOCO uses the global fitting of the orbit response matrix to find a best set of the quadrupoles for the real machine. It is most likely to find an optimal solution to eliminate the deleterious perturbation in the existence of the strong insertion devices for the real machine.

For a storage ring of known magnet strengths, one can calculate the model orbit response matrix ($\underline{M}_{ij}$) by the COMFORT or MAD accelerator optics program.

$$\underline{M}_{ij} \equiv \frac{\sqrt{\beta_i\beta_j}}{2\sin\pi\nu}\cos(\pi\nu - |\phi_i - \phi_j|) \qquad (1)$$

The LOCO program reverses this process and calculates the magnetic field gradients from the measured orbit response matrix($\overline{M}_{ij}$).

$$\overline{M}_{ij} \equiv \frac{\Delta u_i}{\Delta u'_j} \qquad (2)$$

where $\Delta u'_j$ is a change in the orbit steering magnets and Δu_i is the resulting change in electron orbit. The real response matrix (M_{ij}) can be obtained by either the model response matrix with gradient error adjustment (see Eqn. 3) or the measured response matrix with gain factor correction of BPMs and correctors (see Eqn. 4).

$$M_{ij} = \underline{M}_{ij} + \sum_q \frac{\partial \underline{M}_{ij}}{\partial k_q}\Delta k_q + \cdots \qquad (3)$$

$$M_{ij} = \overline{M}_{ij} \times \frac{c_j}{m_i} + \cdots \qquad (4)$$

Adjusting the gradients in the model until the calculated model response matrix is best fit to the measured one with the scale error or gain factor correction of BPMs ($m_i = 1 + \Delta m_i$) and correctors ($c_j = 1 + \Delta c_j$), we can obtain the real machine gradient distribution. The fitting procedure is to minimize the merit function defined as

$$\chi^2 \equiv \sum_{ij} \left[\frac{\overline{M}_{ij} \times \frac{c_j}{m_i} - \underline{M}_{ij} - \sum_q \frac{\partial \underline{M}_{ij}}{\partial k_q} \Delta k_q}{\sigma_i / m_i} \right]^2 \tag{5}$$

where σ_i is the measured standard deviation of the i-th BPM and the sum is over the 62 orbit steering magnets (30 horizontal and 32 vertical) and the 96 BPMs (48 horizontal and 48 vertical). After ignoring the second order terms of Δm_i, Δc_j, and Δk_q, we have

$$\chi^2 \simeq \sum_{ij} \left[\frac{\overline{M}_{ij} - \underline{M}_{ij}}{\sigma_i} - \frac{\underline{M}_{ij}}{\sigma_i} \Delta m_i + \frac{\overline{M}_{ij}}{\sigma_i} \Delta c_j - \sum_q \frac{\partial \left(\underline{M}_{ij} / \sigma_i \right)}{\partial k_q} \Delta k_q \right]^2 \tag{6}$$

In this study, we ignored the coupling terms for the transverse planes such that only the normal terms of the gradients were fitted. The vector has 2976 elements for the un-coupled response matrix in this study. Because the response matrix is not a linear function of the quadrupole gradient, LOCO must be iterated until it converges to a best set of parameters, i.e., the best gradient distribution.

In the fitting of the response matrix, the effective energy shift due to the horizontal corrector in the dispersion region is also included as following.

$$\Delta x_i = \eta_i \times \delta \tag{7}$$

where η_i is the dispersion function and the δ is the effective off-energy deviation. The energy shift effect can be derived by the change of total path length caused by the change of corrector settings[4]

$$\Delta L = \oint \eta(s) \frac{\Delta B(s)}{B\rho} ds = \sum_j \eta_j \left(\Delta u'_j \right). \tag{8}$$

Combining the momentum compaction factor $\Delta L = \alpha L \delta$, the orbit response matrix should be modified as

$$\frac{\Delta x_i}{\Delta u'_j} = \frac{\eta_i \eta_j}{\alpha L}. \tag{9}$$

Hence the final used merit function is given as

$$\chi^2 \simeq \sum_{ij} \left[\frac{\overline{M}_{ij} - \underline{M}_{ij}}{\sigma_i} - \frac{\underline{M}_{ij}}{\sigma_i} \Delta m_i - \frac{\eta_i \eta_j}{\sigma_i \alpha L} + \frac{\overline{M}_{ij}}{\sigma_i} \Delta c_j - \sum_q \frac{\partial \left(\underline{M}_{ij} / \sigma_i \right)}{\partial k_q} \Delta k_q \right]^2 \tag{10}$$

3 CORRECTION PROCEDURE

At first, the lattice optics of the real machine are calibrated experimentally using the measured orbit response matrix with W20 wiggler magnetic gap fully open[5]. In the measurement of orbit response matrix, the kick size was usually of a size to create an rms orbit distortion of 1 mm so as to have good noise-to-signal level and eliminate the nonlinear effects in the BPMs. Based on the measured data, we can calculate the quadrupole gradients and the gain factors of steering magnets and BPMs. With the wiggler magnetic gap fully closed, the vertical effective gradient of W20 can be analyzed from the measured orbit response matrix and compared with the model value. It shows that these values are consistent with each other. Therefore, the modeling of the wiggler elements in this linear calculations can be approximated with the effective vertical focusing.

To restore the periodicity of the lattice as well as the desired working betatron tunes when the wiggler gap was closed, we imposed the constraints on the optics close to the one with wiggler gap open in the finding of a set of quadrupole settings in the ring. The 36 matching quadrupoles were grouped into 18 pairs. Therefore there were 19 variables including Q4 family in the fitting. As showed in the Fig. 1, it turned out that the Q4 values was unchanged. The calculated quadruple settings were used to predict the corrected lattice optics. Fig. 2 shows the

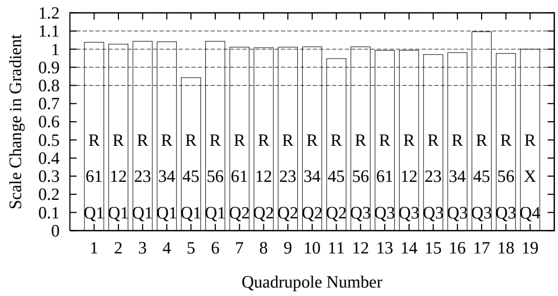

Figure 1: The correction factors of quadrupole families Q1, Q2, Q3, and Q4.

betatron functions without the insertion device W20 and Fig. 3 and 4 present the beta-beats when wiggler W20 is closed in the horizontal and vertical plane, respectively. Each shows the beta-beats before and after the lattice optics corrections. From the simulated results, the vertical twiss

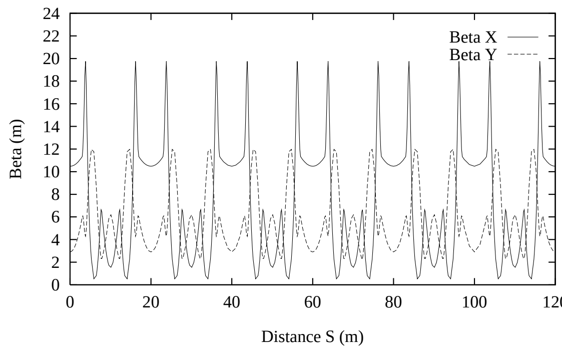

Figure 2: Horizontal and vertical betatron functions without the wiggler W20.

functions and the 6-fold periodicity are mostly recovered under the constraints of our installed quadrupole power supplies. What we need to check and test is the tune shift happened in our correction scheme.

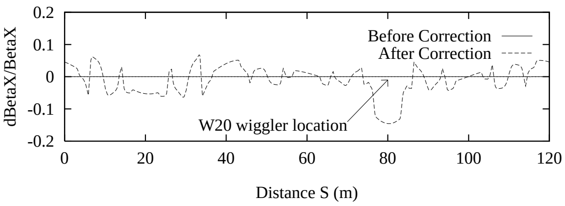

Figure 3: Horizontal beta-beats before and after correction of modeling lattice optics with wiggler W20 gap closed.

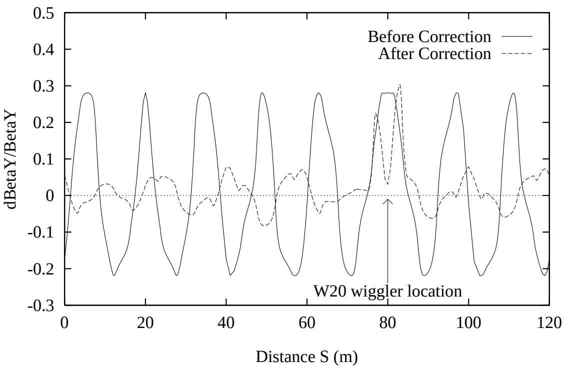

Figure 4: Vertical beta-beats before and after correction of modeling lattice optics with wiggler W20 gap closed.

4 EXPERIMENTS AND RESULTS

To perform the above analytical results to the operational lattice, we transferred the calculated quadrupole strengths before and after correction to the quadrupole power supply settings with the excitation current and magnetic field mapping tables. Using the same process of energy ramping to adjust the driving current of the eighteen quadrupole power supplies, we could achieve the corrected lattice without any beam loss. The experiments showed that the correction of lattice optics with LOCO was a feasible method. The corrected optics of the ring was measured again using orbit response method and the measured data were re-analyzed with LOCO program. The analyzed results after lattice optics corrected are presented as following. As shown in Table 1, the analytical tunes obtained from LOCO are in good agreement with the measured tunes. Fig. 5 and 6 show the beta-beats after correction. It shows that the vertical beta-beat is obviously reduced after correction but there is still a little difference between the model lattice optics and the LOCO lattice optics which is caused by the small residual quadrupole gradient errors.

Tune	analytical	measured
ν_x	7.2032	7.2034
ν_y	4.1615	4.162

Table 1: The analytical tunes and measured tunes after optics correction.

5 DISCUSSION AND CONCLUSION

Although the tunes are changed, the experiments have proved that the correction of lattice optics by using the LOCO program can be done in the operational machine. The global matching of LOCO can recover the periodicity of lattice possibly under some constraints of hardware structure. Two detailed techniques should be noted for applying the correction method to normal operation of machine. Small systematic residual quadrupole gradient errors may come from the different operational paths of quadrupole magnet hysteresis such that the convergent and operational driving paths of quadrupole power supplies should be found after several iterations of the correction and analytical process. In order to obtain a more well-corrected lattice optics, the small individual residual quadrupole gradient errors should be adjusted by the installation of the fully independent quadrupole power supplies for every quadrupole magnet.

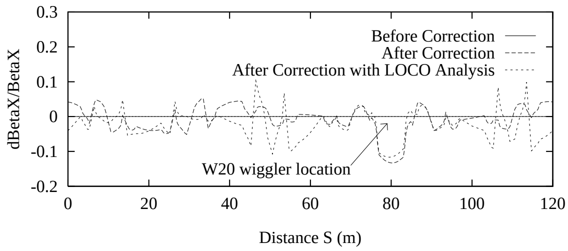

Figure 5: Horizontal beta-beats before and after correction of the real machine lattice with wiggler W20 gap closed.

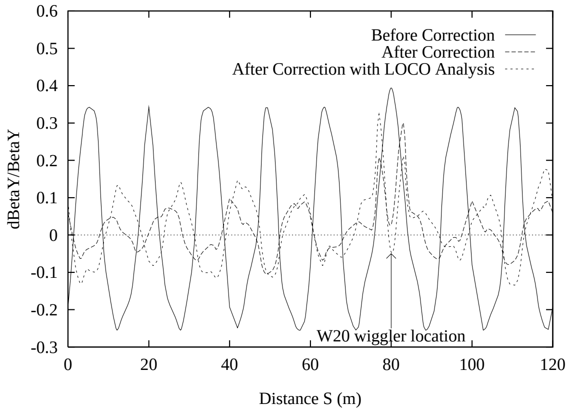

Figure 6: Vertical beta-beats before and after correction of the real machine lattice with wiggler W20 gap closed.

6 REFERENCES

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