OPTICS CALIBRATION DURING COMMISSIONING OF THE TAIWAN PHOTON SOURCE

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Abstract

The Taiwan Photon Source (TPS) is a 3-GeV low emittance synchrotron light machine with circumference of 518.4 m. The lattice is with 24-cell DBA structure and emittance is 1.6 nm-rad. During the commissioning in the past year, we employed MATLAB-based high level applications to calibrate the optical functions in three different operation lattice modes. In particular, we used LOCO (Linear Optics from Closed Orbit) to restore the machine optical functions and reduce emittance coupling ratio. The beam-based alignment (BBA) measurements as well as BPM and corrector errors were identified.

INTRODUCTION

The TPS is located in the NSRRC campus in Hsinchu, Taiwan. The lattice structure of the storage ring is with 24 DBA cells and the natural emittance is 1.6 nm-rad. It is a 6-fold symmetry structure, i.e., 6 long straight sections (12 m) and 18 short straight sections (7 m) for the accommodation of injection elements, RF cavities and insertion devices (IDs). There are two bending magnets, ten quadrupoles and seven sextupoles in each DBA cell and major parameters are listed in [1-2]. The lattice optical function of TPS is shown in Fig. 1. The commissioning of the TPS started in 2014 and the first synchrotron light at 3 GeV from the storage ring was observed on December 31, 2014 [3]. The optics calibration started in the beginning of 2015 and some results were reported in [3]. In the mid 2015, we installed 2 superconducting RF cavities, 10 insertion devices and 9 additional quadrupoles in three long straights to reduce the vertical betatron function in such long straights for small gap undualtors. This lattice structure is called double mini-betay (DMB) lattice [4]. The second phase commissioning started in September 2015 and 520 mA stored beam reached in December 2015.

In this paper, we give optics correction results for three operation conditions, i.e., low emittance lattice, achromat lattice, and DMB lattice as well as correction with phase-I IDs. These results include beta beatings, beta function and dispersion function measurements. These measurements are obtained by using MATLAB-based high level applications [5-7].

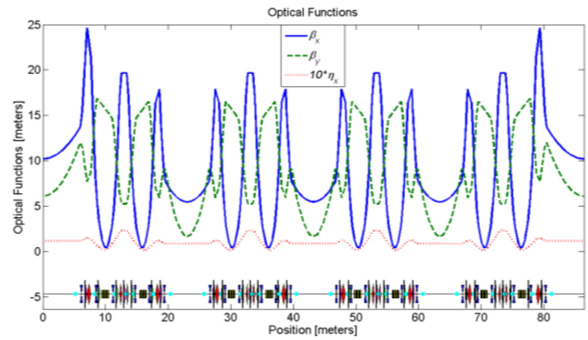

Figure 1: Optical function of the TPS storage ring.

ERROR FINDING DURING THE COMMISSIONING

During the early commissioning stage, the first measured closed orbit distortions (COD) without correction showed there were 25 oscillations in the horizontal plane as shown in Fig. 2 instead of the model prediction 26, i.e., the integer part of the horizontal tune. It was unable to correct orbit with model response matrix. The measured response matrix was employed to reduce COD. A MATLAB-based high level application LOCO [8] was then applied to restore the model optics and response matrix and as a result further reduction of COD was in good progress.

It was found that the fringe field and gain errors of the quadrupoles, especially in the long quadrupoles in high beta region, caused the distortions of the optical functions. After three LOCO iterations, the corrected gain factors in model program obtained the predicted orbit response as shown in Fig. 3.

Besides, we also used the orbit response to find some BPM (Beam Position Monitor) problems. There are two BPMs with buttons switched and two BPMs with location exchanged. After fixing the BPM problems, the orbit responses between model and measurement are almost the same.

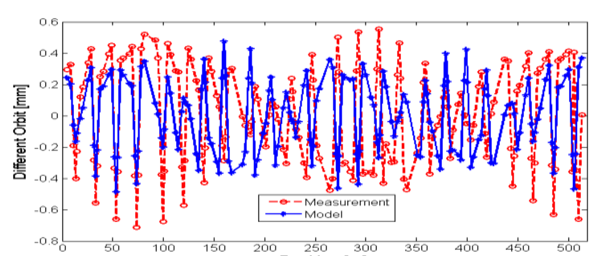

Figure 2: Measured and model orbit responses model before optics correction.

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ISBN 978-3-95450-147-2

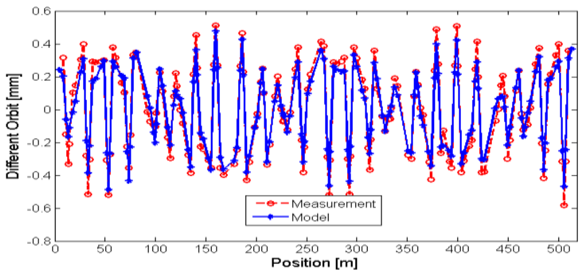

Figure 3: Measured and model orbit responses after optics correction.

OPTICS CORRECTION RESULTS

Low Emittance Lattice

More iterations in LOCO procedure can further reduce the optics errors. Before the optics correction, the beta beating was 8.91% rms in the horizontal plane and 10.94% rms in the vertical plane, respectively, as shown in Fig. 4 and 5. After three iterations, the beta beating was reduced to 1.44% rms in horizontal and 0.68% rms in vertical. Figure 6 depicts the relative deviations with respective to the ideal settings in 240 quadrupoles (8 different ideal settings). The maximum value of the errors is about 4%, and the rms value is 1.53%.

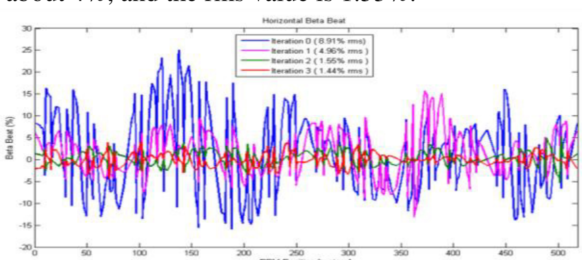

Figure 4: Beta beating in the horizontal plane.

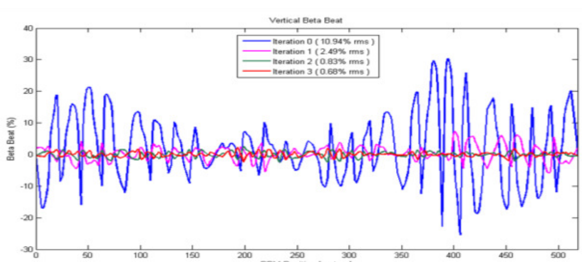

Figure 5: Beta beating in the vertical plane.

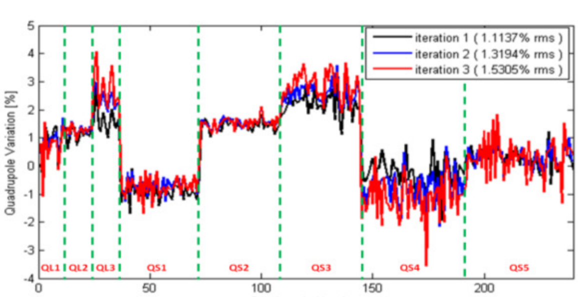

Figure 6: Quadrupole error.

We also used MATLAB-based high level applications to measure the beta and dispersion functions after LOCO procedure as shown in Fig. 7-8.

The vertical dispersion in real machine is mainly due to coupling. To correct the horizontal and vertical dispersion simultaneously, we need use coupled-plane correction with skew quadrupoles in LOCO procedure. After correction, the dispersion symmetry was restored and the vertical dispersion was smaller.

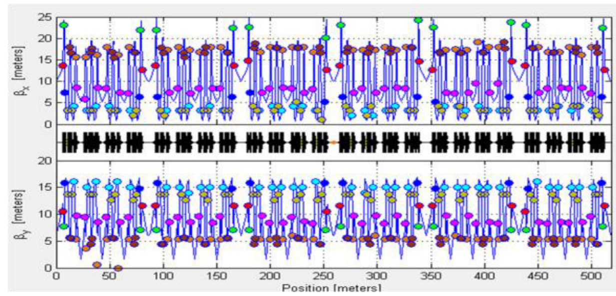

Figure 7: Beta function measurement after optics correction (color circle: measured data, blue line: LOCO result).

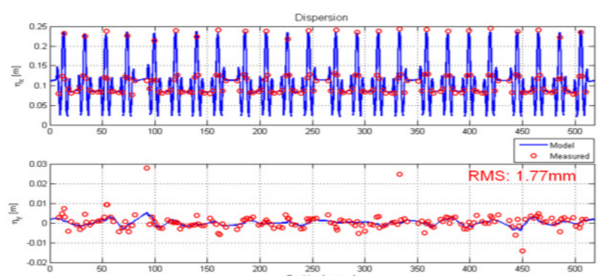

Figure 8: Dispersion function measurement after optics correction (red circle: measured data, blue line: LOCO result).

Achromat Lattice

After the commissioning of the low emittance lattice, we switched the lattice to achromat mode. The emittance is 4.9 nm-rad and the optical function is shown in Fig 9. We used LOCO to reduce the beta beating to 1.59% rms in the horizontal plane and 1.39% rms in the vertical plane.

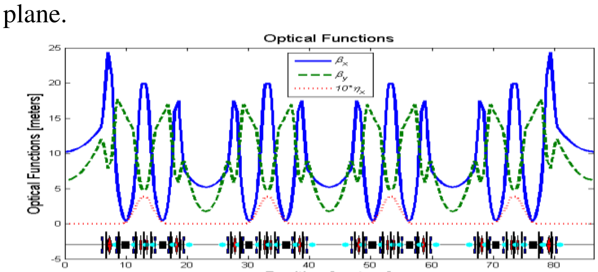

Figure 9: Optical function of the TPS storage ring.

After optics correction and coupling correction, the beta function was more symmetric and the dispersion function was very close to the design value (see Fig.10-11).

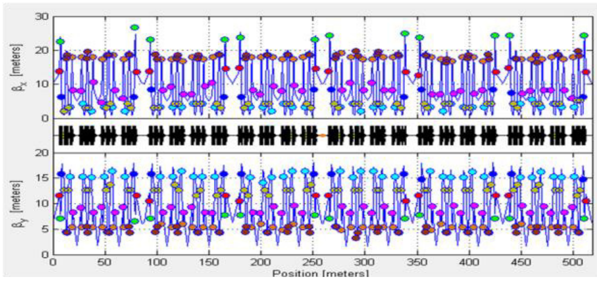

Figure 10: Beta function measurement after optics correction (color circle: measured data, blue line: LOCO result).

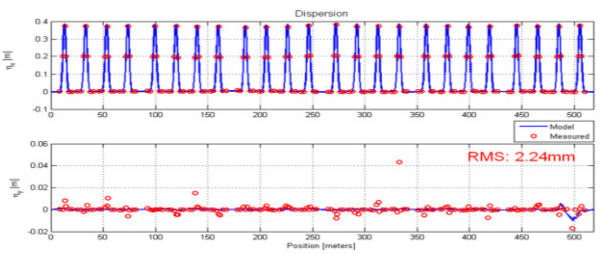

Figure 11: Dispersion function measurement after optics correction (red circle: measured data, blue line: LOCO result).

Double Mini-Betay Lattice with small gap IDs

We started commissioning of DMB lattice in September 2015. Further LOCO procedure was needed because extra 9 quadrupoles were added. After three iterations, the beta beating was reduced to 1.23% rms in horizontal and 0.54% rms in vertical, respectively.

We also repeated the Beam-Based Alignment (BBA) [9-10] measurements to find the BPM offsets, especially the new ones in the long straights. The measured BPM offsets with respective to nearby quadrupole centers were 0.34 mm rms in horizontal and 0.35 mm rms in vertical, respectively. After BBA and orbit correction, the residual orbit was reduced to 69.89 um rms in horizontal and 36.99 um rms in vertical as given in Fig. 12.

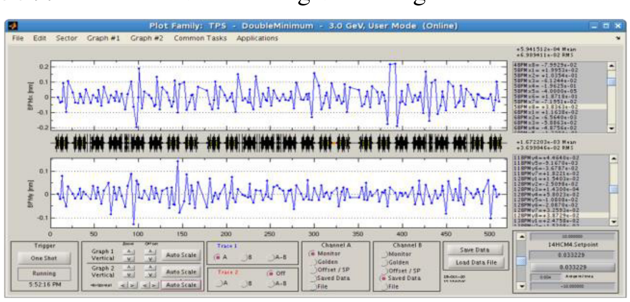

Figure 12: Residual orbit after BBA and orbit correction.

The commissioning of insertion devices started in October 2015. The perturbation of the beta beating in the horizontal plane was larger than in the vertical plane before optics correction. After optics correction, the beta beating was reduced to 0.73% rms in horizontal and 0.13% rms in vertical. The tune shift due to IDs was in good agreement with model prediction and can be restored with global quadrupoles.

Due to the strong skew quadrupole fields in the elliptical undulators (EPUs), we also used skew quadrupoles to reduce the coupling strength. The measured betatron coupling strength was 0.88% before correction and near zero after correction. The overall emittance coupling was then dominated by the residual vertical dispersion.

As shown in Fig. 13, the vertical beam size was reduced from 30.1 um to 23.1 um after coupling correction and the tilt angle of the beam profile was reduced from -7.96 degree to 0.04 degree. Moreover, the injection efficiency was improved after optics and coupling correction.

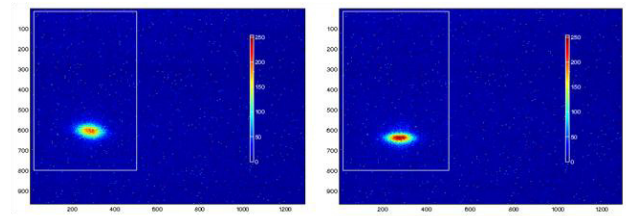
Figure 13: Beam profile before coupling correction (left) and after correction (right).

SUMMARY

LOCO is a very useful tool for the TPS machine commissioning in finding the error sources and corrections. The TPS machine performances were much improved after such corrections. In the future, LOCO will be employed for routine operations and optimization and further ID commissioning.

ACKNOWLEDGMENT

We would like to thank the operations staff and Instrumentation and Control Group for their help in this study.

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ISBN 978-3-95450-147-2