LATTICE DIAGNOSTICS USING SINGLE KICK CLOSED ORBIT AT KEKB

Y. Ohnishi, K. Akai, N. Akasaka, A. Enomoto, J. Flanagan, H. Fukuma, Y. Funakoshi, K. Furukawa, S. Hiramatsu, K. Hosoyama, N. Huan, T. Ieiri, N. Iida, T. Kamitani, S. Kato, M. Kikuchi, E. Kikutani, H. Koiso, M. Masuzawa, S. Michizono, T. Mimashi, T. Nakamura, Y. Ogawa, K. Ohmi, S. Ohsawa, N. Ohuchi, K. Oide, D. Pestrikov, K. Satoh, M. Suetake, Y. Suetsugu, T. Suwada, M. Tawada, M. Tejima, M. Tobiyama, N. Yamamoto, M. Yoshida, and S. Yoshimoto
High Energy Accelerator Research Organization(KEK), Tsukuba, Ibaraki, Japan

Abstract

We have measured beta functions using single kick closed orbit at KEKB. The measured beta functions were compared with the model lattice and gradient errors were extracted from the result in a beta beat. The gradient errors were also obtained by changing strength of steering magnets and measuring beam positions as the second method. The methods of the error estimation and preliminary results will be reported.

KEKB[1] is an asymmetric-energy, double-ring, electron-positron collider. The beam energy is 3.5 GeV for positron(LER) and 8.0 GeV for electron(HER), respectively. The requirement of the peak luminosity is $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ for study of CP violation. In order to achieve such high luminosity operations, large beam current and small β_y^* which is the beta function at I.P. in the vertical plane are needed. The β_y^* = 1cm optics has been done successfully for both rings. The final focusing of two beams is provided by a pair of super conducting quadrupole magnets which are called QCS. The small β_y^* produces a large amount of chromaticity which makes the field of sextupole magnets strong. The nonlinear of sextupole magnets reduces the transverse dynamic aperture. It is, therefore, considered to use a pair of identical sextupole magnets which are connected with a -I' transformer in both the horizontal and vertical planes. The nonlinear effect due to the sextupole magnets should be compensated by the -I' transformer up to the third order in Hamiltonian.

Diagnostics of the lattice has been studied since the commissioning of KEKB started in December 1998. Measurements of the closed orbit distortion(COD) give us a large amount of information for a lattice.

The formula for the closed orbit distortion, Δx, induced by a single steering magnet is

$$\Delta x_i = R_{ij}\theta_j, \tag{1}$$

where θ_j is a kick angle of the j-th steering magnet. The response coefficient, R_{ij} of the j-th steering magnet to the i-th BPM is calculated by

$$R_{ij} = \frac{\sqrt{\beta_i\beta_j}}{2\sin\frac{\mu}{2}}\cos\left(\frac{\mu}{2} - \mid \psi_i - \psi_j \mid\right) - \frac{\eta_i\eta_j}{\alpha C}, \tag{2}$$

where $\mu = 2\pi\nu$ is the betatron tune, ψ is the betatron phase advance, β is the betatron function, η is the dispersion function between two locations, α is the momentum compaction factor, and C is the circumference of the ring. If the last term of eq.(2) can be ignored and the location at a pair of the steering magnet and the BPM is considered, the beta function is obtained from

$$\beta_j = 2\left(\frac{\Delta x_j}{\theta_j}\right)\cdot\tan\frac{\mu}{2} \tag{3}$$

When the beta functions have been measured and a significant discrepancy between the measurement and the model has been found, the sources of the discrepancy can be specified. If the error sources come from a gradient error in one or more of quadrupole magnets, the difference of measured from the model beta functions are described as follows:

$$\Delta\beta_j = \sum_m \frac{\beta_j\beta_m}{2\sin\mu}\cos(\mu - 2 \mid \psi_j - \psi_m \mid)\cdot\Delta K_m, \tag{4}$$

where ΔK_m is the gradient error of the m-th quadrupole magnet(method-1).

On the other hand, assumed that the error is the gradient error of the quadrupole magnets, the measured COD induced by a single steering magnet is written by

$$\Delta x_i^{meas.} = \Delta x_i^{model} + \sum_m R_{im}\Delta K_m \Delta x_m^{model}, \tag{5}$$

where

$$\Delta x_i^{model} = R_{ij}\theta_j \tag{6}$$
$$\Delta x_m^{model} = R_{mj}\theta_j, \tag{7}$$

where R_{ij} and R_{mj} are the response coefficients from the j-th steering magnet to the i-th BPM or the m-th quadrupole

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magnet, respectively. The last term of eq. (5) is the correction term due to the gradient errors of the quadrupole magnets against the model(method-2).

Another constraint to determine the errors of the lattice is

$$\Delta K_m = \pm\frac{2}{\beta_m}\{\cot\mu(\cos\Delta\mu - 1) + \sin\Delta\mu\}, \qquad (8)$$

where $\Delta\mu$ is defined by $\mu^{meas.} - \mu^{model}$, and the $\pm$ sign refers to the horizontal and vertical planes, respectively. If the tune changes small and not close to the half integer or integer resonances, eq. (8) can be simplified as follows:

$$\Delta\mu \simeq \pm\frac{1}{2}\sum_m \beta_m \Delta K_m \qquad (9)$$

with taking all gradient errors into account.

In order to extract the gradient errors of the lattice, there are two methods as described above. The beta function at I.P, $\beta_y^* = 1$ cm optics was utilized. The horizontal-vertical coupling has been neglected. Before the measurements of the COD, orbit corrections with the steering magnets were performed. There are 462 horizontal and 456 vertical steering magnets available in LER. In this analysis, 87 horizontal and 88 vertical steering magnets were chosen to measure the single kick closed orbit. The dispersion functions at those steering magnets are less than 0.1m in order to avoid the uncertainties of dispersion functions between the model and the real machine.

There are 449 BPMs available to measure the beam positions. The beam positions are determined by an average of 8 measurements and the resolutions of the BPMs are typically less than 5μm. The closed orbit has been measured at BPMs before and after changing every steering magnets along the ring to minimize effects of orbit drifting. The orbit drifting at large beta function was less than 200μm in horizontal and 1 mm in vertical plane during this measurement, respectively. Each steering magnet is set to the kick angle of 50μrad added to the original setting.

The beta functions were measured by the beam position and a single kick angle from eq. (3). Measured transverse tunes were used in eq. (3). Difference between the beta functions at the steering magnet and those of the nearby BPM is typically less than 10% which is estimated from the model calculation. We used SAD program[2] to calculate twiss parameters of the lattice model. Figure 1 shows the beta functions at BPMs nearby the steering magnet. A significant discrepancy between measured beta functions and those of the model without corrections can be found(fig. 1(a)). In most cases, the difference from the model beta function will be a beta beat which is an oscillation of the measured beta function around the design beta function at twice the betatron frequency. The gradient errors were estimated by eq. (4) using an iterative procedure(Micado[3]). In eq. (4) measured transverse tunes are utilized and betatron phase advances are also scaled by the ratio of measured to the model tunes. The error source is identified

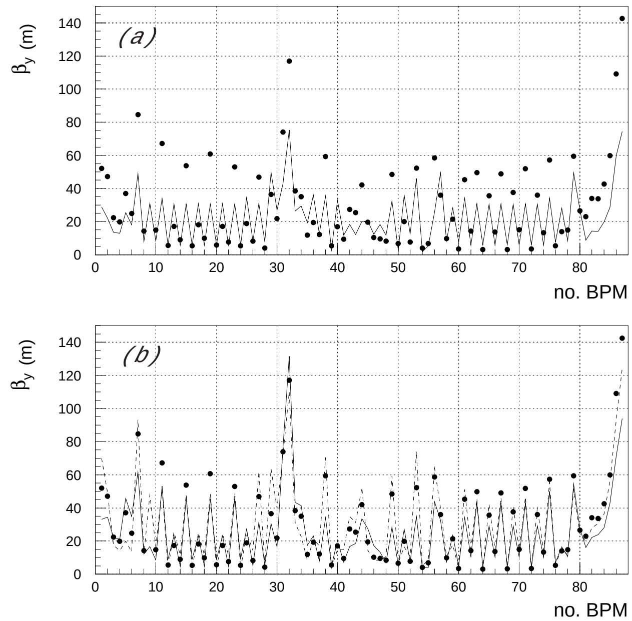

Figure 1: The β functions at BPMs nearby the steering magnet which induces a single kick closed orbit. The measured beta functions(plots) and the model calculations for (a) no correction and (b) after corrections in the vertical plane. The solid line in fig. (b) shows only correction of QCS magnet identified from method-1 and the dashed line shows correction of the QCS and other quadrupole magnets from method-2.

with QCS magnets which locate at vicinity of the interaction point. The strength of magnetic field was stronger than the expected value by 0.47%. Figure 1 (b) shows the corrected model for the QCS(solid line) and the beta functions from the model lattice can well reproduce the measured beta functions. After the correction of QCS, measured vertical tune is different from the model by 0.18, on the other hand, the difference before the correction was 0.25.

Figure 2 represents the typical single kick closed orbit in the vertical plane at LER. The model calculation after the correction of QCS agrees with the measured beam positions at BPMs.

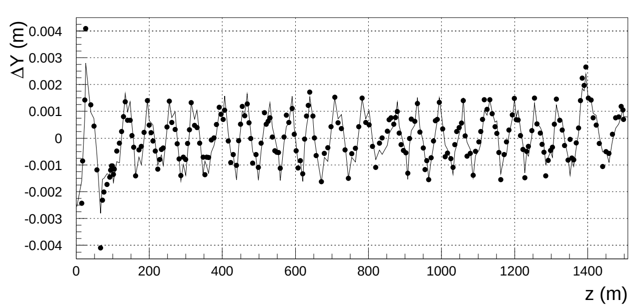

Figure 2: The single kick closed orbit in the vertical plane for a half of circumference at LER. The plots shows measured beam positions by BPMs and the solid line shows those of the lattice model with corrections of the gradient errors for the QCS magnet.

Figure 3 shows the gradient errors obtained from eq. (5) and eq. (9). The gradient error for all quadrupole magnets are estimated by one single kick closed orbit. In order to derive the gradient errors, the singular value decomposition(SVD)[4] is performed to solve equations described above. Because multiple error estimations for each quadrupole magnet are available, the average of errors and the standard deviations are plotted in fig. 3. Not only the gradient error of the QCS but also a series of defocusing quadrupole magnets(QD3P, QD5P) can be found. Those quadrupole magnets are connected to the same power supply. The beta functions(dashed line) calculated by the model after corrections of QCS and other quadrupole magnets are superimposed in fig. 1 (b) and also reproduce the measured beta functions well.

The error estimations between method-1 and method-2 are consistent with each other for the QCS. However, the gradient errors of quadrupole magnets besides the QCS were not clearly found by method-1 against method-2. The reason is that one BPM is used for one single kick in method-1, on the other hand, all BPMs are used for one single kick and more information can be obtained in method-2.

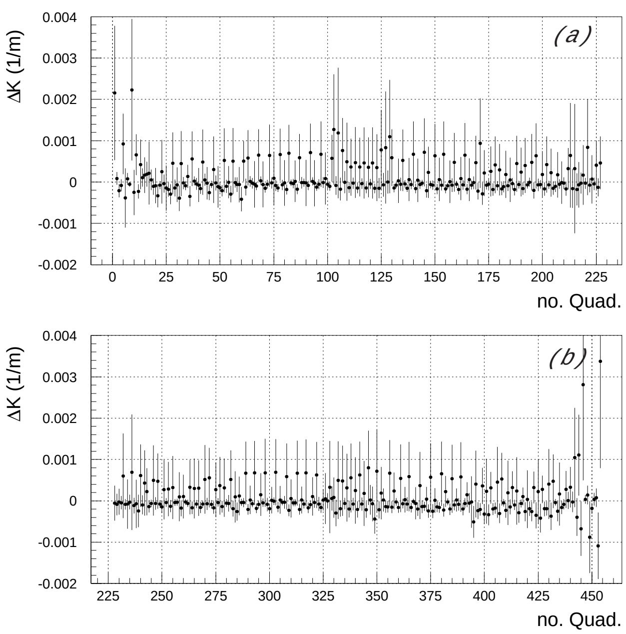

Figure 3: The gradient errors of quadrupole magnets predicted by method-2 at LER. Error bar shows the standard deviation estimated from the measurements using a single kick orbit induced by every steering magnets. The first and last number of quadrupole magnet corresponds to the QCS magnets in question. A series of quadrupole magnets which have small gradient errors are found systematically.

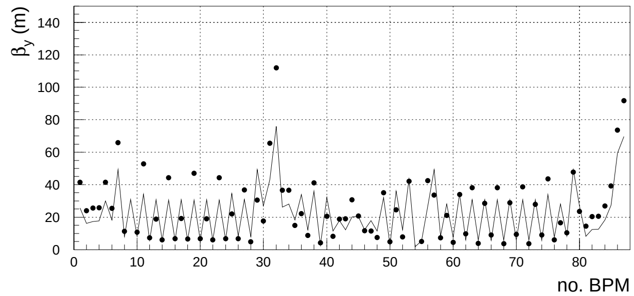

Figure 4: The β functions at BPMs nearby the steering magnet which induces a single kick closed orbit after adjustment of the real QCS. The solid line shows the beta functions calculated by the lattice model.

We have measured beta functions using the single kick closed orbit. The gradient errors of quadrupole magnets have been estimated using two methods. The gradient error of the QCS could be found by both methods. The corrected model calculations can well reproduce the measured beta functions and the measured closed orbit by BPMs. The error of the QCS was also verified from a magnetic-field measurement independent of this analysis and K value of the real QCS was corrected by 0.37%. Figure 4 shows the measured beta functions compared with the model after this correction. The errors of other quadrupole magnets were also found by method-2, however, those are still under investigation. The HER should be studied and in progress.

We would like to thank the KEKB Operations staff for their help with this experiment.

REFERENCES

[1] KEKB Design Report, KEK Report 95-7.

[2] SAD is the accelerator design tool program developed at KEK.

[3] H.G. Hereward, PS/Int. TH 59-5 (1959).
B. Autin and Y. Marti,CERN ISR-MA/73-13.

[4] W. Press, et al., “Numerical Recipes”, Section 2.9, Cambridge University Press, Cambridge(1986).