

RECENT PROGRESS OF OPTICS MEASUREMENT AND CORRECTION AT KEKB

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Abstract

In the regular operation of the KEKB B-Factory, the on-momentum optics correction has been working well for years. As the next step of the optics correction, we have studied the off-momentum correction scheme besides the regular optics correction procedure. In this paper, we present the off-momentum correction scheme under development as well as the preliminary results of the measurement and the correction.

INTRODUCTION

The KEKB B-Factory is an asymmetric energy double ring collider, which has an 8GeV high energy electron ring(HER) and a 3.5GeV low energy positron ring(LER)[1]. In the rings of the KEKB, the error of the beta function $\Delta\beta/\beta_0$ is mitigated within 10% by using the global beta correction. On the other hand, the disagreement of the tune chromaticity between the model optics and the real machine has been observed. We sometimes found that the beam lifetime was shorter in the real machine than we expected, although we optimized the strength of the sextupole magnets to make the dynamic aperture large in the model optics. It implies that the momentum dependence of the real optics is different from the model optics. In order to understand the disagreement, we have performed the measurement of the beta function with changing the momentum of the ring and corrected the momentum dependence of the optics by adjusting the strength of the sextupole magnets.

OFF-MOMENTUM BETA MEASUREMENT

In the on-momentum beta measurement, we measure six sets of the closed-orbit response induced by the dipole steering kick in the horizontal(x) and vertical(y) direction. In the linear approximation, above closed-orbit response is described as follows:

$$\Delta\chi(s) = \frac{\sqrt{\beta_\chi(s)}}{2 \sin \pi\nu_\chi} \Delta\theta_\chi \sqrt{\beta_\chi(s_{kick})} \cos(|\phi_\chi(s) - \phi_\chi(s_{kick})| - \pi\nu_\chi), \quad (1)$$

where χ indicates either x or y , and $\Delta\chi(s)$, $\beta_\chi(s)$, $\phi_\chi(s)$, ν_χ , $\Delta\theta_\chi$, and s_{kick} are the displacement of the close-orbit, the beta function, the betatron phase advance, the betatron tune, the kick angle of the dipole steering magnet, and the location of the dipole steering magnet, respectively. The betatron tune and the displacement of the closed orbit are measured by the tune meter and the beam position monitors(BPMs). The KEKB has about 450 BPMs

in each ring, and we use all of them for this measurement. From the monotonicity of the betatron phase, the sign of $(\phi_\chi(s) - \phi_\chi(s_{kick}))$ is automatically given by the order of the beam line element. The kick angle $\Delta\theta_\chi$ is given by the measurement condition of the closed-orbit response. The unknown variables, $\beta_\chi(s)$ and $\phi_\chi(s)$, are obtained by fitting the single dipole kick model Eq. 1 to the measured closed-orbit responses. The detail of the fitting scheme is found in the proceedings of PAC'05[2].

In order to measure the beta function with the momentum shift $\Delta p/p_0$, we shift the momentum of the beam by changing the RF frequency of the ring. The relationship between the momentum and the ring RF frequency is given by

$$\frac{\Delta f}{f_0} = - \left(\alpha_c - \frac{1}{\gamma^2} \right) \frac{\Delta p}{p_0}, \quad (2)$$

where f , α_c , γ and p are the ring RF frequency, the momentum compaction factor, the Lorentz factor and the momentum, respectively. The typical slippage factor, $(\alpha_c - \gamma^{-2})$, of the KEKB ring is 3×10^{-4} and the nominal frequency of the ring RF cavity is 508.886MHz. In our measurement, the beta measurement was performed with five different frequency shifts of -400 , -200 , ± 0 , $+200$, and $+400$ Hz. The range of $\Delta p/p_0$ is $\pm 2 \times 10^{-3}$ that corresponds to above frequencies.

OFF-MOMENTUM BETA CORRECTION

The KEKB has 54 independent families of sextupole magnets in the LER and 52 in the HER, respectively. We assume the deviation of the sextupole field as the error source of the off-momentum optics. In this assumption, the off-momentum correction becomes the problem to find a parameters of the sextupole strength so as to minimize the residual error between the model optics and the measurement. This residual error is described by the function of the measured betatron tune, beta function, and betatron phase advance.

In the magnet power supply system of the KEKB rings, the magnetic field strength $B^{(n)}$ is adjusted as the following equation:

$$B^{(n)} = \frac{a_f B\rho K_n + b_f}{L}, \quad (3)$$

where a_f and b_f are fudge factors. L and $B\rho$ are the effective length of the magnet and the magnetic rigidity of the beam, respectively. K_n is the normalize magnetic field strength defined by $\tilde{B}^{(n)}L/B\rho$, where $\tilde{B}^{(n)}$ is the $2(n+1)$ -pole magnetic field component of the model. We perform

the off-momentum optics correction by embedding the calculated correction factor into the a_f fudge factor of the sextupole power supply.

The change of the sextupole K_2 affects both off-momentum and on-momentum optics, because it generates the normal and skew quadrupole field depending with the horizontal and vertical displacement of the closed orbit at the sextupole magnet. In fact, we use this off-center orbit effect for correcting the on-momentum x-y coupling, dispersions and beta functions in the horizontal and vertical planes[3]. Thus, the K_2 correction fudge should be solved simultaneously with the on-momentum correction. However, it is difficult to obtain an effective correction fudge from such simultaneous equations, because the size of the matrix of the simultaneous equations is enlarged compared to those for the individual corrections.

To simplify the correction scheme, we perform the correction only for the chromatic term of the optical functions proportional to $\Delta p/p_0$, and ignore the orbit offset at the sextupoles. In order to compensate the side effect by changing the sextupole field, both on-momentum and off-momentum corrections should be performed alternatively.

One of the simplest error function for the off-momentum correction should be written as the quadratic form by the relative change of the sextupole field $\Delta K_2/K_2$. This function is obtained from the quadratic form of the error of the optical functions and the response of the optical functions as sextupole field changes.

The error function between the measured optics and the model is given by using the optical functions as follows:

$$e^2 = \sum_i \left((2\pi)^2 (\Delta \nu_{mes.}^{p_i} - \Delta \nu_{model}^{p_i})^2 + \sum_j (\Delta \phi_{mes.}^{p_i}(s_j) - \Delta \phi_{model}^{p_i}(s_j))^2 + \sum_j (\Delta \hat{\beta}_{mes.}^{p_i}(s_j) - \Delta \hat{\beta}_{model}^{p_i}(s_j))^2 \right), \quad (4)$$

where p_i and s_j are the momentum of the off-momentum optics measurement and the location of the BPMs, respectively. The momentum-dependent term of the optical functions at the momentum p are defined as follows:

$$\Delta \nu^p = \nu^p - \nu^{p_0} \quad (5)$$

$$\Delta \phi^p(s) = \phi^p(s) - \phi^{p_0}(s) \quad (6)$$

$$\Delta \hat{\beta}^p(s) = \frac{\beta^p(s)}{\beta^{p_0}(s)} - 1, \quad (7)$$

where p_0 is the reference momentum. Using the model optics of the SAD[4], the response matrix of the model optics is easily obtained by taking a numerically differential of the momentum-dependent term of the optical functions by the deviation of the sextupole field ΔK_2 . To Minimize e^2 in Eq. 4 using a given response matrix is equivalent to

solving the linear equations by the singular value decomposition(SVD). The linear equations can be written down as follows:

$$\begin{pmatrix} 2\pi(\Delta \nu_{mes.}^{p_i} - \Delta \nu_{model}^{p_i}) \\ \Delta \phi_{mes.}^{p_i}(s_j) - \Delta \phi_{model}^{p_i}(s_j) \\ \Delta \hat{\beta}_{mes.}^{p_i}(s_j) - \Delta \hat{\beta}_{model}^{p_i}(s_j) \end{pmatrix} = \begin{pmatrix} 2\pi \mathbf{I} \\ \mathbf{I} \\ \mathbf{I} \end{pmatrix} M_{s_j}^{p_i} K_2 \begin{pmatrix} \Delta a_f \end{pmatrix}, \quad (8)$$

where $M_{s_j}^{p_i}$ is a part of the response matrix for the specified momentum p_i and location s_j . The K_2 is the diagonal matrix of the sextupole filed strength. The Δa_f is the fudge to adjust the model optics to the measurement.

In order to reduce the error between the model optics and the real machine, the calculated sextupole fudge factor, Δa_f , is applied to the power supply of the sextupole magnet by the following scheme:

$$a_{f\ new} = \frac{a_{f\ old}}{1 + \Delta a_f}, \quad (9)$$

where $a_{f\ old}$ and $a_{f\ new}$ are the a_f fudge factor of the power supply before and after correction, respectively. On the other hand, the sextupole parameters are optimized for stable machine operation in the daily machine tuning. We do not want to lose the stability of the machine operation by changing the parameter of the real sextupole magnet. Thus, for keeping the excitation current of the sextupole magnet, we update the sextupole strength of the model by

$$K_{2\ new} = K_{2\ old}(1 + \Delta a_f), \quad (10)$$

where $K_{2\ old}$ and $K_{2\ new}$ are the sextupole strength before and after correction, respectively. As the results of these update scheme, Eq. 9 and Eq. 10, the sextupole parameter of the model optics should come close to the realized parameter of the real machine.

RESULTS OF MEASUREMENT AND CORRECTION

Our off-momentum correction scheme was tested on the LER of the KEKB. The typical time to measure the off-momentum optics was about 50 minutes. The SVD tolerance for the correction fudge calculation is 0.1. The first measurement result of the distribution of the off-momentum beta function is shown in Fig. 1. By applying the correction fudge using Eq. 10, the model line in Fig. 1 is modified from the blue dashed line to the green dotted line toward the red solid line of the measured one. The correction fudge calculation of the model optics is successfully performed.

Figures 2 and 3 show the trend of the distribution and the L^2 -norm of the correction fudge for the sextupole. These L^2 -norm which would be correlated with the correctable residual error of the sextupole field show a decreasing tendency except for the measurement at January 13, 2006. The

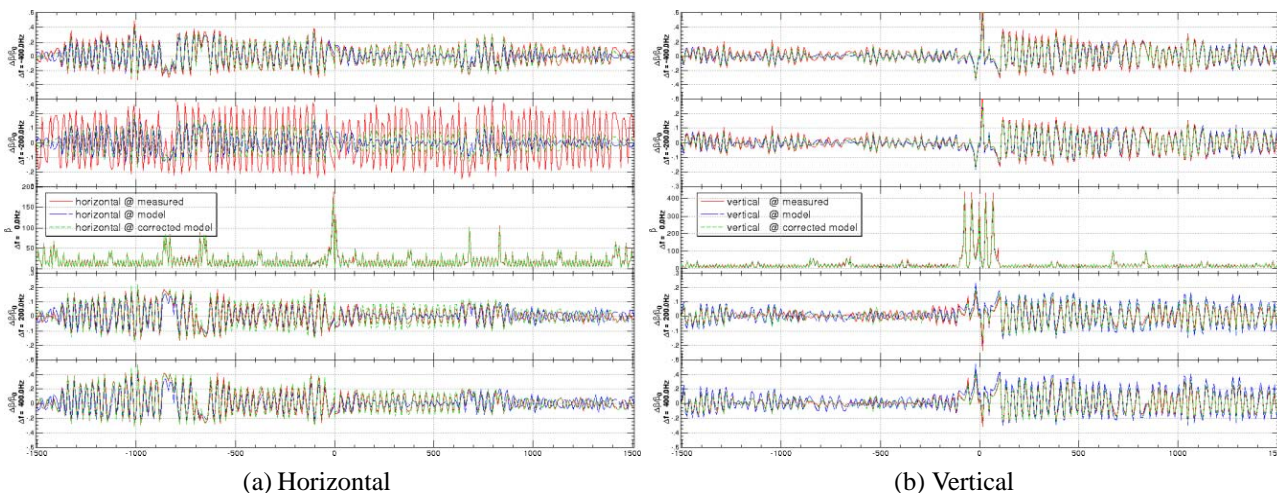


Figure 1: Measured and model beta function on November 12, 2006. The beta function is shown in the 3rd column of graphs. The other columns show the chromatic displacement of the beta function. In these plots, red solid line, blue dashed line, and green dotted line correspond with the measurement, model optics before correction, and model optics after correction, respectively.

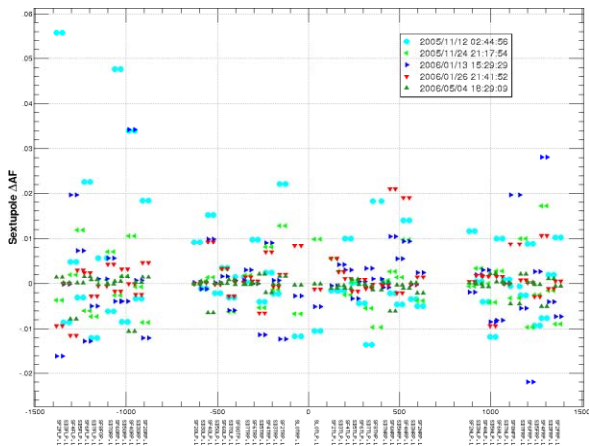


Figure 2: Distribution of sextupole correction fudge Δa_f obtained from measurement.

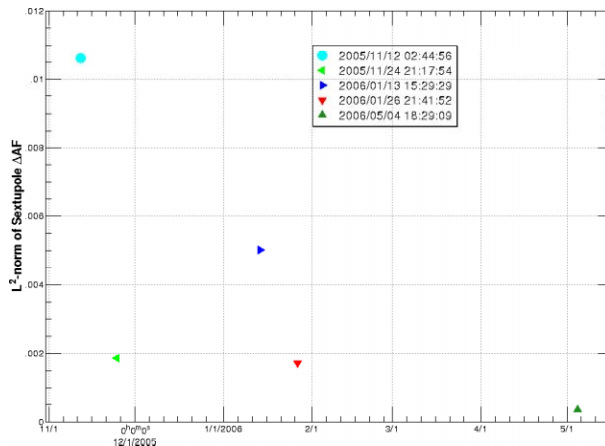


Figure 3: Trend of L^2 -norm of sextupole correction fudge Δa_f .

KEKB had a short winter shutdown from December 26, 2005 to January 13, 2006. The exceptional point would come from the change of the machine condition during the short shutdown. The correction series looks like converging.

SUMMARY

The off-momentum beta correction looks like to work fine. In order to make the correction effective, we consider to expand the momentum range of the measurement. Our regular optics correction is performed within one hour per ring. For introducing the off-momentum correction into the regular correction procedure, the reduction of the measurement time is necessary. For example, if the betatron phase measurement of the whole ring was available by introducing the single-pass BPMs, the off-momentum optics

measurement could be speeded up. As a feasible plan for present measurement system, we investigate the speed up by reducing the number of the single kicks to measure. It may sacrifice the reliability, however, the measurement time would be reduced almost half at the maximum.

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