RECENT PROGRESS OF OPTICS CORRECTION AT KEKB

A. Morita, H. Koiso, K. Oide, Y. Ohnishi, KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

Chromaticity correction is a part of optics corrections, which takes an important role to control both the dynamic aperture and the strength of synchro-beta resonance. Whenever the linear optics is changed to control the emittance, etc, the chromaticity correction i.e. sextupole settings must be re-optimized. In this paper, we present new method to find chromaticity correction parameters to maximize the dynamic aperture and minimize the synchro-beta resonance.

INTRODUCTION

KEKB B-Factory[1] is an asymmetric energy double-ring e^+e^- collider, which consists of an 8GeV high energy electron ring (HER) and a 3.5GeV low energy positron ring (LER). In order to achieve both large dynamic aperture and larger momentum acceptance, the 2.5π-cell with non-interleaved chromaticity correction sextupoles is selected as a unit cell in the arc of KEKB as shown in Fig.1. The total number of sextupole families in the arc section is 52 families per ring. The LER has additional 2 sextupole families for the local chromaticity correction around the interaction point (IP).

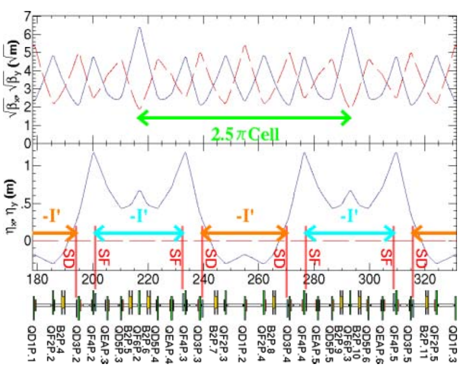

Figure 1: The non-interleaved 2.5π cell of the KEKB LER. The HER has almost same structure expect the length of bending dipole magnets. The transformation between the sextupole pair for the chromaticity correction is quasi negative identity transformation $-\mathbf{I}'$. The blue solid lines and red dashed lines show the horizontal and vertical optics function, respectively.

In order to obtain the large dynamic aperture for a longer beam lifetime and to control the linear chromaticity $\xi \equiv \partial\nu/\partial\delta$ for suppressing the head-tail instability, the chromaticity correction by using sextupoles is necessary. In the luminosity run, the linear optics is fixed and the sextupole parameters are improved by the adiabatic tuning. But a new sextupole parameter set is required for trying either machine study or new operating mode with changing the arc cell, because the natural chromaticity of the arc cell is changed by adjusting either the horizontal emittance ϵ_x or the momentum compaction factor α_c. For performing the such studies efficiently, the more effective solution finding a new sextupole parameter set is required.

CONVENTIONAL METHOD

In the conventional sextupole optimization for chromaticity correction, two tools are used mainly. One is the sextupole adjuster controlling 6 kind of linear chromaticity parameters $\xi_{x,y} \equiv \partial\nu_{x,y}/\partial\delta$, $\partial\alpha^*_{x,y}/\partial\delta$ and $(\partial\beta^*_{x.y}/\partial\delta)/\beta^*_{x,y}$ by solving the linear response matrix between linear chromaticity parameters and sextupole strength parameters, where asterisk * denotes the value at the IP. The other is parameter matching so called the finite-bandwidth chromaticity correction with the finite-amplitude matching[2]. The finite-bandwidth chromaticity correction minimizes the chromaticities in betatron tunes, $\alpha^*_{x,y}$, $\beta^*_{x,y}$, etc. within the finite-bandwidth $-\Delta < \delta < +\Delta$. In the finite-amplitude matching, the target function of the finite-bandwidth chromaticity correction is extended to the optics function on the one-turn orbit starting at a particular location in a ring with finite-amplitudes in the transverse directions.

At first, we adjust the linear chromaticity ξ and expand the dynamic aperture by using the finite-amplitude matching. This process is iteratively performed by trial and error changing either 6 linear chromaticity parameters or matching conditions. The obtained sextupole parameter set is applied to the real machine and it is improved by trial and error adjusting both linear chromaticities and individual sextupole strengths in daily operation.

OPTIMIZATION BY USING TPSA

The conventional finite-bandwidth chromaticity correction needs a suitable initial condition to avoid local minimum. And the dynamic aperture is not directly optimized by the conventional method. In some cases, the chromaticity curves are getting smoother, however, the dynamic aperture is decreased.

To avoid such a problem, the method directly maximizing the dynamic aperture is desirable. In order to maximize the dynamic aperture in global parameter space, we try to use the Temperature Parallel Simulated Annealing (TPSA) method[3] combining with the dynamic aperture estimation.

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Algorism and Implementation

TPSA method is a parallel version of a simulated annealing method. Its algorism is constructed by 2 parts. One is the parallel simulated annealing processes in the independent thermal baths that has different temperature with each other. The other is the stochastic swapping between the different thermal baths.

The annealing part is the iteration process of the standalone simulated annealing. In this iteration process, the next solution candidate is randomly selected from the neighborhood of the current solution candidate, which is accepted stochastically. The neighborhood for the next solution candidate is given by

$$x'_i = x_{i\,\mathrm{cur.}} + (x_{i\,\max} - x_{i\,\min})\sigma r, \quad (1)$$

where x'_i and $x_{i\,\mathrm{cur.}}$ are the next and current value of i-th parameter, respectively. $x_{i\,\max}$ and $x_{i\,\min}$ are the maximum and minimum value of parameter x_i, respectively. σ is the width of neighborhood and r is a uniform random number generated in the range $[-1, 1]$. The transition probability toward the next solution candidate is given by Metropolis rule:

$$\begin{cases} 1 & \text{if } E_{\mathrm{next}} - E_{\mathrm{cur.}} < 0: \\ \exp\left(-\frac{E_{\mathrm{next}} - E_{\mathrm{cur.}}}{T}\right) & \text{otherwise,} \end{cases} \quad (2)$$

where E_{next} and $E_{\mathrm{cur.}}$ are the target function value of the next and current solution candidates, respectively. T is the temperature of the thermal bath.

In the stochastic swapping part, the solution candidates are stochastically swapped between neighborhood temperature thermal baths every N_{anneal} annealing iterations. The swapping probability between i-th thermal bath and j-th thermal bath is given by

$$\begin{cases} 1 & \text{if } (E_i - E_j)(T_i - T_j) < 0: \\ \exp\left(-\frac{(E_i - E_j)(T_i - T_j)}{T_i T_j}\right) & \text{otherwise,} \end{cases} \quad (3)$$

where E_i and T_i are the target function value and the temperature of i-th thermal bath, respectively. After many annealing and swapping processes, the minimized solution is obtained from the lowest temperature thermal bath.

The TPSA algorism is implemented on SAD[4] by using process forking and inter-process communication via shared memory. It's running on both quad-core PowerMac G5 and quad-core Mac Pro. In our implementation, the temperature of i-th thermal bath T_i is given by

$$T_i = T_{\min}\left(\frac{T_{\max}}{T_{\min}}\right)^{\frac{i-1}{N_{\mathrm{temp}}-1}} \quad (i = 1, 2, \ldots N_{\mathrm{temp}}), \quad (4)$$

where $T_{\max}$ and $T_{\min}$ are the maximum and minimum temperature of the thermal bath, respectively. N_{temp} is number of the thermal bath. The maximum temperature $T_{\max}$ has to be selected enough high to escape local minimum. The minimum temperature $T_{\min}$ has to be selected enough low to keep good solution candidate. In the lower temperature thermal bath, the big parameter changes would be almost rejected by Metropolis rule Eq.2. In order to improve accepting probability, we introduce a temperature dependence of neighborhood width as follows:

$$\sigma_i = \sqrt{T_i/T_{\max}}, \quad (5)$$

where σ_i is the neighborhood width of i-th thermal bath. The adaptive neighborhood method proposed in the paper[3] is not used, because the convergence of the neighborhood width is not expected for short term calculation.

Optimization Recipe and Results

In KEKB rings, the beam blowup around the synchrobeta resonance line $2\nu_x + \nu_s = n$ is observed and this resonance exists nearby the operating betatron tune. In the computer simulation, this resonance line results in both reducing the dynamic aperture and diverging the anomalous emittance[5]. In order to expand the dynamic aperture on the resonance condition, the horizontal betatron tune is adjusted to satisfy $2\nu_x + \nu_s = n$.

At first, we try to maximize the dynamic aperture. The target function for TPSA is given by -1 times the score of the dynamic aperture. To estimate the dynamic aperture, we track particles starting from the grid points on both the momentum error δ and the transverse amplitude axis and count the number of remaining particles after specific turns. The initial grid points are given by

$$(x, x', y, y', z, \delta) = (\sigma_x i, 0, \frac{\sigma_x}{3} i, 0, 0, \sigma_\delta j), \quad (6)$$

where σ_x and σ_δ is the horizontal beam size and the momentum spread, respectively. i and j are positive integers and integers to specify the transverse and longitudinal grid points, respectively. In order to reduce the evaluation cost of the target function of TPSA, the particle tracking is truncated at 500 turns and odd number grid points in the longitudinal direction are thinned out from the aperture estimation. The control parameters of TPSA $T_{\max}$, $T_{\min}$, N_{temp} and N_{anneal} are chosen to 50, 0.5, 6 and 7, respectively. In order to control the linear chromaticity, ξ_x and ξ_y are manually adjusted by using the sextupole adjuster between TPSA batches if needed.

After maximizing the dynamic aperture, the minor improvement of the anomalous emittance is achieved. The target function to minimize is the average of the anomalous horizontal emittance in nano-meter unit calculated at 41 sample points in synchrotron tunes around the resonance condition. The evaluated width of the synchrotron tune is $\pm 3 \times 10^{-3}$. The control parameters of TPSA $T_{\max}$, $T_{\min}$, N_{temp} and N_{anneal} are chosen to 5, 0.05, 6 and 7, respectively.

Figure 2 and 3 show the dynamic aperture and anomalous horizontal emittance before and after the sextupole optimization by TPSA, respectively. These optimization

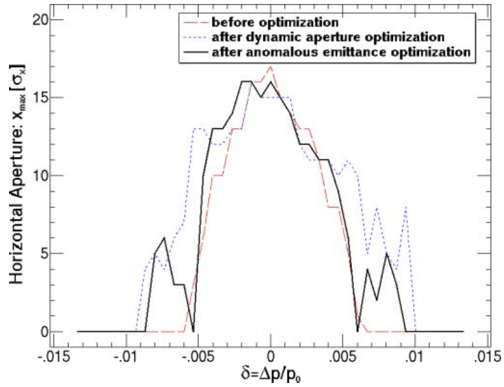

Figure 2: The dynamic aperture before and after sextupole optimization. These are estimated by particle tracking for 1000 turns with synchrotron motion, and initial ratio of the transverse actions was fixed as $J_x/J_y = 9$. The red dashed line, blue dotted line and black solid line show before optimization, after maximizing the dynamic aperture and after suppressing the anomalous emittance, respectively.

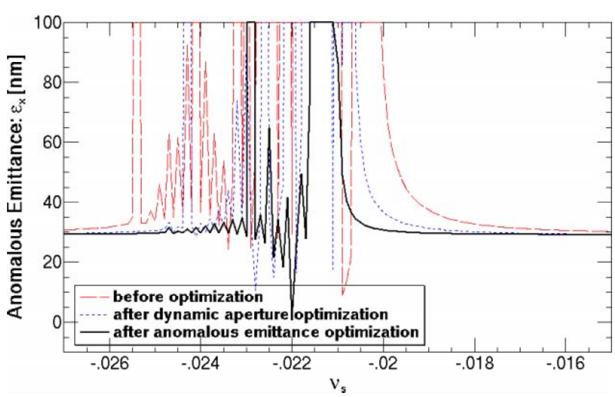

Figure 3: The synchrotron tune dependence of the anomalous horizontal emittance before and after sextupole optimization. The horizontal betatron tune is adjusted to 44.51053 and $2\nu_x + \nu_s = n$ resonance appears around $\nu_s = 0.021$. The red dashed line, blue dotted line and black solid line show before optimization, after maximizing the dynamic aperture and after suppressing the anomalous emittance, respectively.

are performed for the high emittance HER optics dedicated to the crab crossing study, whose horizontal emittance is adjusted to 29nm. (The nomial horizontal emittance of HER is 24nm) The red dashed line shows the initial dynamic aperture and anomalous emittance before optimization. In order to shrink the height of the vertical closed-bump around sextupoles using for xy-coupling and dispersion correction knob[6], this initial sextupole parameters are prepared by increasing the strength of weak sextupoles from yet another optimized optics. The blue dotted line shows the aperture and emittance after maximizing the dynamic aperture. The dynamic aperture shown by blue dotted line is expanded from the red dashed line. The black solid line shows the aperture and emittance after suppressing the anomalous emittance. The dynamic aperture shown by black solid line is shrink from the blue dashed line, however, both strength and width of the synchro-beta resonance line are reduced. The chromaticity curves of the optimized sextupole parameter set, which is shown in Fig.2-3 by the black solid line, is shown in Fig.4. This optimized sextupole parameter set is applied to the real machine operation. The HER has been stably operated with this optimized parameter.

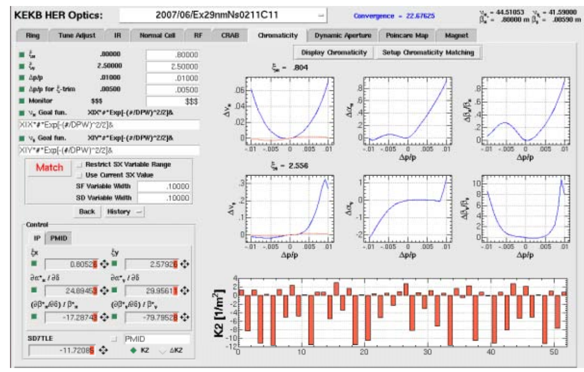

Figure 4: An example of the chromaticity curves and the distribution of the sextupole strength applied to the real machine.

SUMMARY

We apply this sextupole optimization recipe using TPSA to create the new optics for the machine study at June, 2007. In the computer simulation model, different sextupole parameters, which have large dynamic aperture, are found within one day. Trying to use obtained sextupole parameters on the real machine, several of them achieve enough beam lifetime and operation stability. This method is useful to reduce the time of the sextupole parameter tuning by trial and error on the real machine.

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