XY-Coupling Correction at KEK Photon Factory

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Abstract

XY-Coupling of the KEK Photon Factory was corrected by utilizing auxiliary windings on sextupole magnets, which are capable of producing skew quadrupole fields. The observed reduction of Touschek lifetime indicated that the vertical beam size was reduced down to 60% of the uncorrected one. The tilt of the beam profile was reduced as well.

1 Introduction

The Photon Factory (PF) storage ring at KEK has been operated since 1982. The ring was reconstructed in '97 towards lower emittance [1]. The users operation with the new low emittance optics was successfully started in May, '98 [2]. The smallest emittance achieved in machine studies is 29 nm-rad, which is smaller than before by a factor of 4. At present, the ring is operated for users with a moderately small emittance of 36 nm-rad.

The horizontal emittance was successfully reduced as described above. The smaller emittance has made some improvements on the user experiments [3]. On the other hand, small vertical emittance is as well or more important for some of the user experiments. Since the strengths of the sextupoles, which are the major source of the XY-coupling, became larger in the new optics by factors of 5 to 10 than those in old one, the coupling was expected to become larger. Actually, soon after the start of the low-emittance operation, a user group requested to reduce the vertical emittance [4].

We decided to apply a correction scheme [5], in which XY-coupling is corrected by many skew quadrupole magnets distributed around the ring. Their strengths are determined so as to minimize vertical closed orbit displacements produced by horizontal steerers.

This scheme is suitable to PF ring for two reasons. The first is that it does not cause large changes on the closed orbit, which may require re-alignment of the photon beam lines. The second is that we have all the necessary hardware. We have 65 beam position monitors and 28 horizontal steerers (auxiliary windings on bending magnets) to measure the coupling. We can utilize auxiliary windings on sextupole magnets to produce skew quadrupole fields.

We tested the correction scheme in machine studies and obtained a good result. Soon after, we introduced it to the users operation.

In this paper, we describe the correction method and the result. More detailed analysis on the results will be presented in future papers.

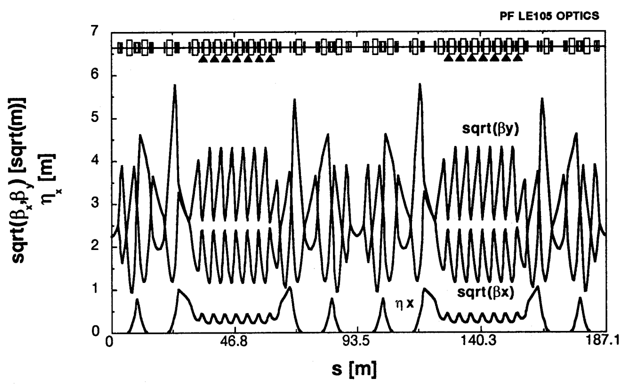

Figure 1. Magnetic lattice and optical functions of KEK-PF. Locations of the 14 sextupoles used for the correction are indicated by black triangles.

Table 1. Parameters of auxiliary windings on sextupoles

Number of Coils	4
Number of Turns	500 turn/coil
Maximum Electric Current	3 A
Maximum Field Gradient (skew Q)	0.8 T/m
Bore Radius	45 mm
Core Length	0.2 m

2 Method

The XY-coupling is measured by exciting 28 horizontal steerers one by one to produce a few-mm horizontal orbit displacement. The vertical displacement produced by the horizontal kick, which is typically a few hundred μm, is measured at 65 beam position monitors for each steerer and recorded. A few examples are shown in Figure 2. These displacements originate either from tilting errors of the horizontal steerers or skew quadrupole-like error fields in the ring. We should treat the latter. The influences of the former would be smeared out by using data for many steerers [5].

Vertical dispersion was also measured and recorded. It is shown in Figure 3. Its correction is important to reduce the effective emittance in vertical as well as the coupling correction.

There are 32 sextupole magnets in the ring and all have auxiliary windings [6]. Although they are normally used for vertical steerers, just by changing the connection of the electric cables, they can be used for skew quadrupoles. Leaving 18 sextupoles near defocusing quadrupoles for vertical steerers, the remainders 14 were converted to skew quadrupoles. The parameters of the magnets are shown in Table 1. Since all the skew quadrupoles are in dispersive section, they can produce vertical dispersion. Thus, they can be used for dispersion correction as well as the coupling correction

The strengths of the skew quadrupoles are determined so as to minimize the following function.

$$S=\sum_{i,j}\left(y_{ij}^{uncor}+y_{ij}^{sq}\right)^2+w_\eta\sum_{i}\left(\eta_{y_i}^{\ uncor}+\eta_{y_i}^{\ sq}\right)^2 \quad (1)$$

Here, y_{ij}^{uncor} is the measured vertical orbit displacement at i-th BPM produced by j-th horizontal steerer, η_{yi}^{uncor} the measured vertical dispersion at i-th BPM. The y_{ij}^{sq} and η_{yi}^{sq} are the vertical orbit displacement and vertical dispersion produced by skew quadrupoles. They can be written in forms,

$$y_{ij}^{sq}=\sum_{n}R_{ij}^{n}k_{n}^{sq} \quad (2)$$

$$\eta_{y_i}^{\ sq}=\sum_{n}H_{i}^{n}k_{n}^{sq} \quad (3)$$

where R^n_{ij} and H^n_i are response matrices and k_n^{sq} is the strength of n-th skew quadrupole. The w_η is a weight factor, which would be determined empirically such that both the coupling and the vertical dispersion were reduced to satisfactory levels. The response matrices (R^n_{ij} and H^n_i) were measured in prior to the correction. The results agreed well with the calculation.

The strengths of the skew quadrupoles (k_n^{sq}) are obtained by solving a set of linear equations,

$$\frac{\partial S}{\partial k_n^{sq}}=0 \quad (4)$$

by using singular value decomposition. The number of eigen values is determined so as to give a satisfactory result with moderate strengths of skew quadrupoles.

3 Results

Strengths of 14 skew quadrupoles were calculated as described in the previous section. The r.m.s. value of their strengths is 0.0025 T/m*m, that is well within their abilities.

After the skew quadrupoles were excited, the vertical orbit displacements produced by horizontal steerers were reduced as shown in Figure 2. The vertical dispersion was also reduced as shown in Figure 3, although it is less remarkable.

A reduction of the beam lifetime was observed which could be attributed to the enhanced Touschek effect caused by the reduction of the vertical beam size. A change of the beam lifetime in single bunch mode before and after the correction is shown in Figure 4. It was indicated that the vertical beam size was reduced on average to 60 % of the uncorrected one.

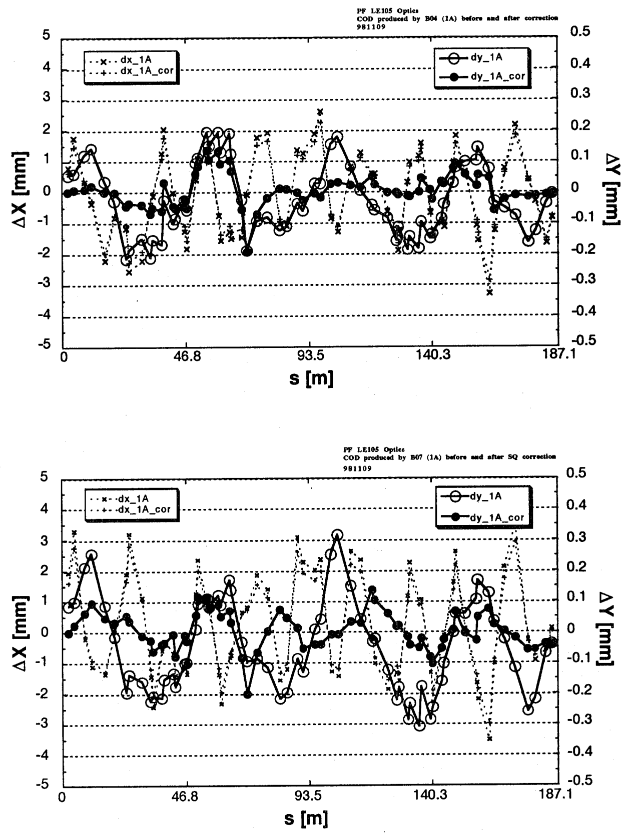

Figure 2. Examples of the vertical orbit displacements produced by kicks of horizontal steerers. The dotted lines are horizontal orbit displacements, the solid lines with white circles are the vertical orbit displacements before correction and those with black ones after correction.

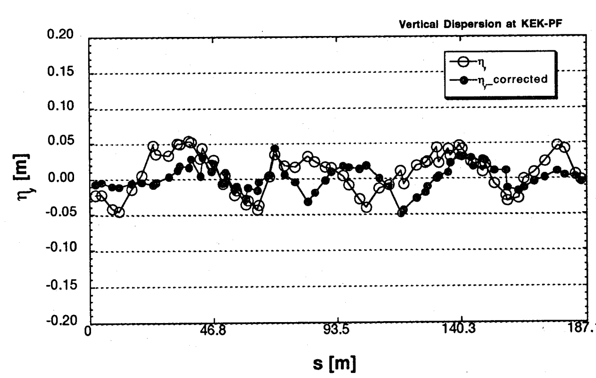

Figure 3. Change of the vertical dispersion. The solid line with white circles is before correction and that with black circles is after correction.

A change of the beam profile was observed at the optical monitor station on a beam line, BL27 [7], as shown in Figure 5. It is obvious that the tilt of the profile was reduced as well as the vertical beam size.

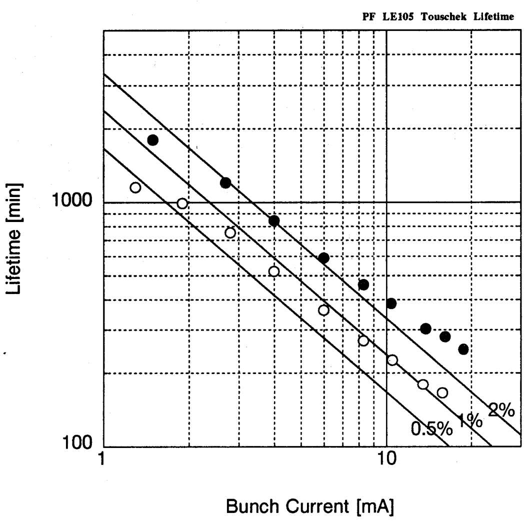

Figure 4. Change of the beam lifetime in single bunch mode. The black circles are the lifetime before correction and the white ones after correction. The solid lines are Touschek lifetime calculated for three cases of emittance coupling as indicated in the figure. Here the vertical dispersion is assumed to be zero.

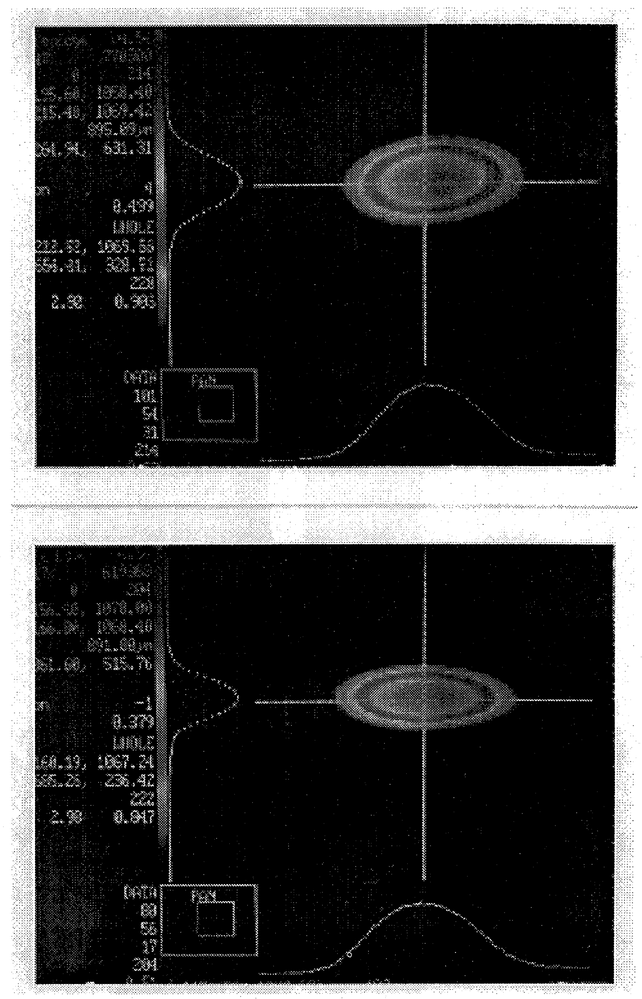

Figure 5. Change of the beam profile before (upper) and after (lower) the correction observed at the optical monitor station on BL27.

4 Summary and Discussions

We successfully corrected the XY coupling at KEK-PF. We utilized the auxiliary windings on the sextupole magnets to produce skew quadrupole fields for the correction. We observed a reduction of Touschek lifetime, which indicated a reduction of vertical beam size to 60% of the uncorrected one. The tilt of the beam profile was corrected as well.

We have introduced this correction method to the users operation. The user group, who had requested the coupling correction, reported some improvements in their experiment [4].

Although, we have many skew quadrupoles, they are concentrated in the normal cell sections (see Figure 1). This may limit the performance of the correction scheme, in particular, that of the vertical dispersion correction. This point will be investigated in future.

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