# IMPROVEMENT OF BEAM STABILITY OF SPRING-8 STORAGE RING BY SYMMETRY-RESTORATION

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*Abstract*

It is known that the distortion of beam optics excites accidental resonance lines nearby an operation point and hence it limits the stability of circulating beams. Through the analysis of full transverse beam response (AFTBR) we have recently found that the optics distortion in the SPring-8 storage ring is enhanced by the modification to install four magnet-free long straight sections of 27m [1]. The rms distortion is estimated to be several percent of a design value. Particle tracking also showed that this distortion limits the beam stability especially at the large amplitude of a betatron oscillation. To improve this situation, we have investigated the correction scheme based on the error distribution obtained by AFTBR. And then, we have found that the small adjustment on strength of only twelve quadrupoles suppresses the distortion down to a few percent and recovers the beam stability sufficiently. In this paper, we present our correction scheme and discuss the obtained results compared with the simulation ones.

## 1 SYMMETRY-BREAK AND ITS IMPACT

Four magnet-free long straight sections (LSS's) of 27m were installed in the SPring-8 storage ring in the summer 2000 to make the most of potentiality of the storage ring [2]. Results obtained by AFTBR showed that the distortion of betatron functions becomes larger than that before the installation. The rms values of horizontal and vertical distortion reach respectively to ~8 and ~7%. Figure 1 shows estimated horizontal and vertical betatron functions by the dashed lines for the period of 100m from the beam injection point. The solid lines show design values as a reference.

We have investigated how this symmetry-break affects on the beam performance. Firstly we calculated the impact to the transverse emittance using the integrated error fields estimated by AFTBR, i.e., 236 normal and 132 skew quadrupole-field-errors [3]. The result showed that the symmetry-break doesn't seriously affect on the transverse emittance: (1) The horizontal emittance becomes ~ 7nmrad which is just a little higher than the design value of 6.6nmrad. (2) The vertical emittance is ~7pmrad corresponding to the coupling ratio of 0.1%.

On the other hand, particle-tracking simulation showed the symmetry-break reduces the dynamic aperture under both the on- and off-momentum condition. Figure 2 shows dependence of the dynamic aperture on the relative momentum deviation at the initial tracking phase of 180° and the initial X-Y coupling ratio of 0.01. The calculation includes effects of distributed physical aperture, synchrotron oscillation, radiation excitation and damping, error distribution estimated by AFTBR [4]. We see that the dynamic apertures for the symmetry-broken optics (circles) are small compared with those for the symmetry-restored optics (squares) obtained by the correction scheme described later.

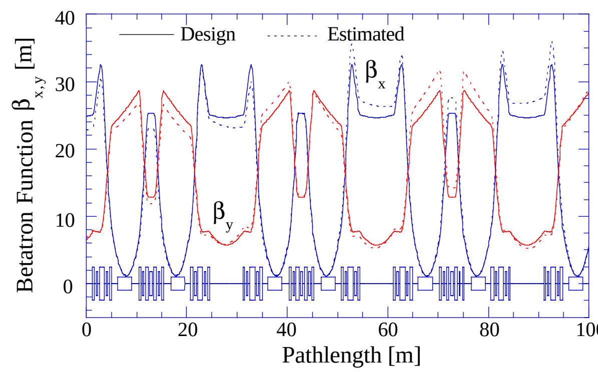


Figure 1: Betatron function distribution.

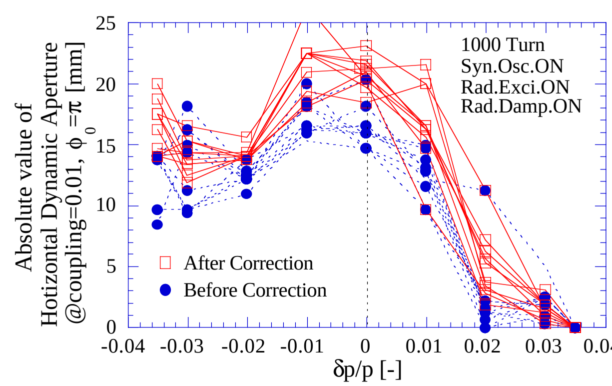


Figure 2: Dynamic aperture reduction due to symmetry-break.

## 2 CORRECTION SCHEME

The correction scheme for this symmetry-break has been investigated. In the SPring-8 storage ring, there are ten families of quadrupole magnets in one normal Chasman Green (CG) cell. For the field adjustment of an individual magnet, we adopted current-trimming power supplies (PS's) [5] but not trimming coils to make the magnets compact. Such additional PS's are thus installed as the need arises.

Due to the above magnet and power supply condition, local distortion of the betatron functions are not directly measured with a conventional method, i.e., tune response against a quadrupole field change. We therefore assume

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that the estimated error distribution is real one. By using this error distribution and the linear optics theory, we calculated dependence of the correction performance against the number of trimming PS's. In fitting the correction fields, we suppressed the tune shifts and distortion of the horizontal dispersion with proper weights for the fitting variables. Figure 3 shows the calculation results. We see that main harmonics of the distortion are corrected with eight trimming PS's. The correction level with the main harmonics-suppression is about 0.2m in an rms value, which is about one seventh of the rms distortion before the correction. Both the tune shifts and dispersion distortion are suppressed sufficiently by using a set of PS's of which number is larger than ten. From these results, we decided to use a set of twelve PS's for the correction. The expected rms value is one sixth of that before the correction and the maximum field change is about 1% of the design quadruple field.

We supposed that the selected magnets would concentrate in LSS's or matching sections that were newly installed in the summer 2000. However, the calculation result is opposite to our prediction. The performance obtained with the best set of twelve quadruples selected from only the CG cells is better than that with the best set selected from LSS's and matching sections. This suggests that a major part of the errors is in the CG cells. This reason is not clearly understood.

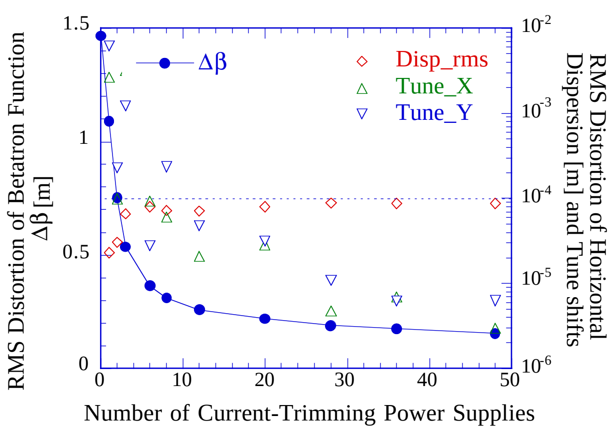


Figure 3: Dependence of correction performance on the number of correction magnets.

## 3 CORRECTION RESULTS

The quadrupole field correction with twelve trimming PS's has been applied to the user operation from the second cycle of year 2002. The beam response was measured before the user operation and the correction performance was analysed. Figure 4 shows the estimated distortion of the betatron functions before and after the quadrupole field correction by AFTBR. In the figure, the open circles show the predicted correction performance. We see that the estimated distortion well agrees with the prediction. The rms values of the horizontal and vertical distortion over 280 beam position monitors (BPM's) are about 2% and this value is almost the same as the predicted ones, 1.5% and 1.4% respectively for horizontal and vertical residues. The result shows that the error field distribution estimated by AFTBR is accurate enough for correcting the distortion down to a few % levels. We stress that the precise error distribution can't be obtained without both the good reproducibility of BPM's [6] and the accuracy of a ring model.

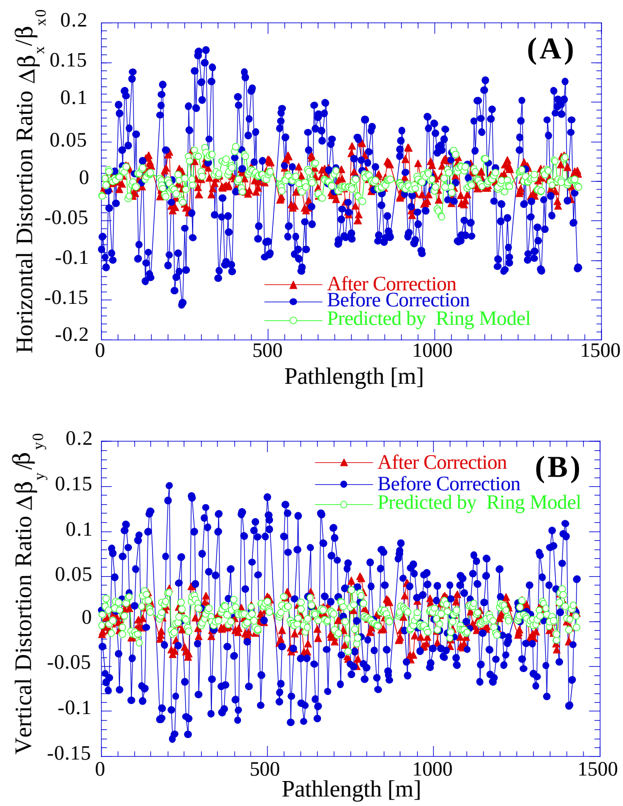


Figure 4: Distortion ratio of the horizontal (A) and vertical (B) betatron functions before and after the correction.

## 4 BEAM PERFORMANCE AFTER CORRECTION

We have not seen a significant change on horizontal and vertical emittance values before and after the correction as the simulation predicted.

On the other hand, we have observed clear increase of the beam lifetime under the Touschek-effect dominant condition. For the operation with equally separated 21 single bunches of 1mA, increment of the lifetime reaches to about 15%. We have then investigated whether this increment is consistent with the dynamic aperture enlargement. To this end, we calculated the Touschek lifetime using Piwinski formula [7] and the local momentum acceptance (MA) obtained by our new method [8]. Figure 5 shows the dependence of the measured (diamonds) and calculated (dashed lines) Touschek lifetime against the total RF voltage. In the figure, the solid line represents the Touschek lifetime determined by the RF bucket height. We find that both the measured lifetimes data before and after the correction agree fairly well with calculated data in the range where the RF voltage is from 10 to 16 MV.

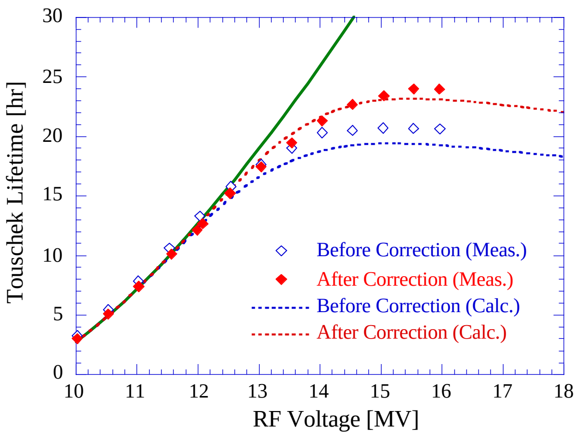


Figure 5: Dependence of Touschek lifetime on RF voltage.

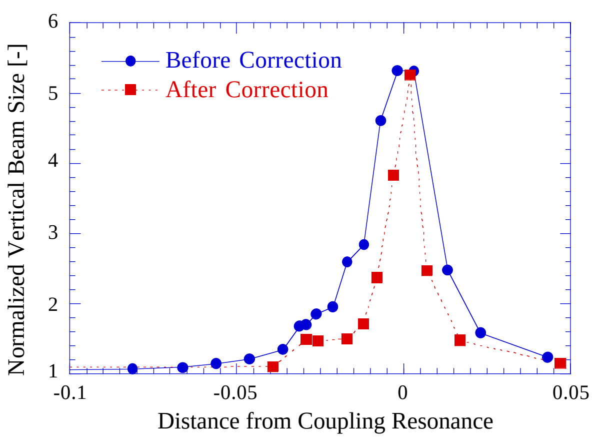


Figure 6: Difference of the bandwidth of linear coupling resonance before and after the correction.

We have also observed the difference of accidental resonance excitation nearby the operation point ($\nu_x$=40.15, $\nu_y$=18.35) before and after the correction. One big difference is that the stored beam is stable just on the horizontal and vertical half integer resonance lines, $2\nu_x$ = 81 and $2\nu_y$ = 37 after the correction even with the high chromaticity condition ($\xi_x$=+7, $\xi_y$=+6). We emphasize here that excitation of the crossing half integer resonance line is not suppressed individually in the measurement.

Figure 6 shows the difference of the bandwidth of the linear coupling resonance before and after the correction. The horizontal and vertical axes represent respectively the distance from the coupling resonance $\nu_x$ - $\nu_y$ = 22 and the vertical beam size normalized by the size at the nominal operation point. The beam sizes were measured by the two-dimensional visible light interferometer [9]. It is clear that the width of beam size blow-up reflects the width of the crossing resonance line. We find that the width of the coupling resonance line after the correction is narrower than that before the correction. These evidences show that the symmetry-restoration successfully suppresses the resonance excitation in the vicinity of the operation point.

## 5 SUMMARY

The distortion of betatron functions was corrected using the quadrupole error field distribution obtained by analysis of the full transverse beam response (AFTBR). After the correction based on this error distribution, the distortion was estimated to decrease from 8% to 2% and this reduction ratio is consistent with the prediction. In respect to the beam performance, Touschek lifetime was enlarged by 15%. This enlargement is well explained by the calculation with the expected enlargement of dynamic aperture. The resonance excitation nearby the operation point seems to be also suppressed by the symmetry-restoration. These facts show that the symmetry-break was well corrected by using the error field distribution estimated by AFTBR.

## 6 REFERENCES

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