OPTIMIZATION OF SEXTUPOLE STRENGTHS IN A STORAGE RING FOR TOP-UP OPERATION

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Abstract

To suppress leakage of an injection bump orbit having sextupole magnets inside, a scheme using minimum condition for the injection bump leakage was proposed [1]. Based on this scheme, we investigated optimal sextupole strengths for the SPring-8 storage ring by changing a unit structure of the ring, i.e., the number of sextupole families. The results showed that addition of two sextupole families sufficiently enlarges dynamic aperture of the storage ring. To realize a newly optimized distribution of the sextupole strengths, cabling of the sextupole magnets was partly changed in the summer 2003. The new strengths successfully improved the injection efficiency up to 80~90% with all gaps of in-vacuum insertion devices (IDs) closed [2]. In this paper, we present obtained results of the bump leakage suppression and improvement of injection efficiency and beam lifetime, comparing with the simulations.

INTRODUCTION

In top-up operation of a light source, electron beams are frequently injected to keep the stored current constant. Closing an injection bump orbit is thus critically important not to disturb precise experiments. On the other hand, high injection efficiency is also crucial to prevent injected electron beams from colliding with permanent magnet-arrays of in-vacuum IDs and from demagnetizing the permanent magnets. However, in the SPring-8 storage ring sextupole magnets are arranged within the injection bump orbit to attain large dynamic aperture (DA) for high injection efficiency and long beam lifetime. The bump orbit thus never closes all over the bump amplitude due to the sextupole nonlinearity, and in this stage closing the bump orbit is inconsistent with maximizing DA. To proceed to the top-up operation, a practical solution for this antinomy is strongly required, which satisfies the small bump leakage and sufficiently large DA.

CHEME FOR SUPPRESSION OF BUMP LEAKAGE

When we set only the sextupole strengths within the bump orbit zeros, the bump leakage vanishes completely. However, this simple treatment breaks symmetry of the sextupole magnet arrangement and excites lots of harmful resonance lines driven by the sextupoles. As shown in Fig. 1, DA is drastically shrunken by this treatment.

In the case where linear optics is optimized, the minimum leakage condition is simplified and expressed by

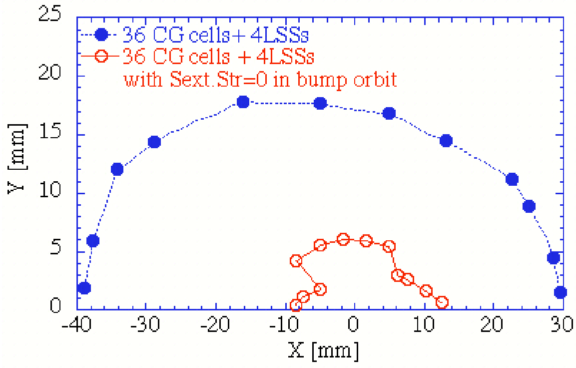

Figure 1: Reduction of DA by setting the sextupole strengths zeros only within the injection bump orbit. The unit structure is one Chasman Green (CG) cell and DA was calculated at the injection point with no magnetic errors.

$$\Delta x'_{end} = -\frac{\alpha_{end}}{\beta_{end}}\cdot\Delta x_{end}\,,\quad \alpha_{\mathrm{end}} \equiv \frac{-1}{2}\cdot\frac{d\beta_{end}}{ds}\,,\quad (1)$$

where ΔX_{end}, $\Delta X'_{end}$ are the displacement and angle of the bump leakage caused by the sextupoles at the exit of the last sextupole within the bump orbit and β_{end} is the betatron function at the last sextupole [1]. Assuming that the bump field pattern is a completely synchronized half-sine, the bump leakage is reduced down to about ~40μm in rms under the minimum condition [1].

Equation 1 gives a linear relation among all of the integrated sextupole strengths within the bump orbit. This means that when two families of sextupoles are within the bump orbit, Eq. 1 imposes a constraint only on the ratio of these strengths. By this loose constraint, recovery of DA is possible by introducing a small number of additional sextupole families keeping the minimum leakage condition.

OPTIMIZATION OF SEXTUPOLE STRENGTHS

We modified CATS [3], which is the computer code for the correction of harmful resonance harmonics of the sextupole magnets [4] so as to utilize fitting functions in MINUIT package [5]. By this modification, we can optimize the sextupole strengths to enlarge DA imposing various constraints, e.g., the condition for the minimum bump leakage and the linear chromaticity correction. DA is calculated at the injection point of the storage ring and the tracking revolution number is 1000 turn.

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Dynamic Aperture for On-Momentum Particle

We have investigated how DA is enlarged as the additional sextupole families increase by using three unit structures shown in Fig.2. In the case A, B and C where the unit structures are composed of 1-, 2- and 3-CG cells, respectively, degrees of freedom for the optimization are 1, 4 and 8 under two constraints for the leakage suppression and linear chromaticity correction.

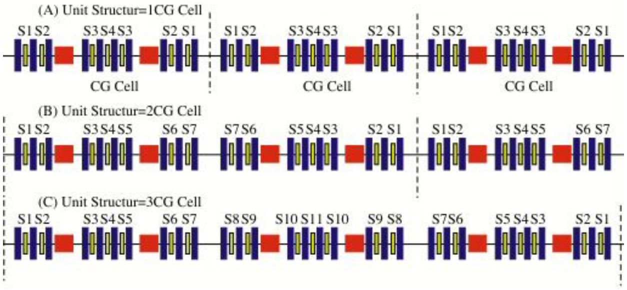

Figure 2: Three kinds of unit structures used for the DA calculation. The dashed lines show the boundary between the unit structures. The blue, red and yellow rectangles represent quadrupole, bending and sextupole magnets, respectively. The symbols S1~S11 represent the different sextuple families.

Figure 3 shows the results obtained by the optimization. DA was calculated with no magnetic errors and no synchrotron oscillation. The linear horizontal and vertical chromaticities are adjusted to +2 and +2, respectively. In the calculations, we used two kinds of optics: the achromatic optics with natural emittance of 6.6nmrad (5.3nmrad with IDs closed) and the non-achromatic optics with 3.4nmrad (2.8nmrad with IDs closed) [6]. We see that DA increases as the number of CG cells in the unit structure increases for the two kinds of optics. This shows that DA can be recovered by using the sufficient degrees of freedom even when the symmetry is lowered.

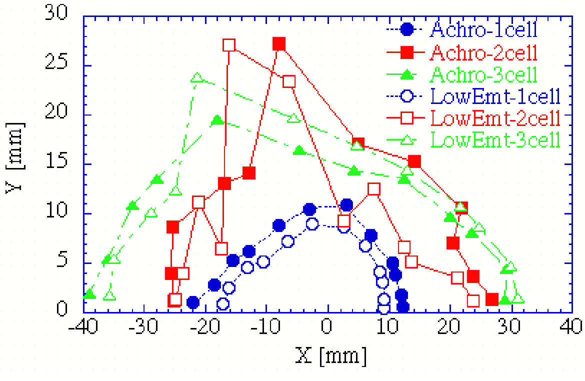

Figure 3: DAs for the ring comprising of three kinds of unit structures. The curves with circles, squares and triangles represent the calculations for the cases A, B and C in Fig.2, respectively. The solid and open symbols represent calculations for the achromatic and non-achromatic optics, respectively.

Dynamic Aperture for Off-Momentum Particle

The SPring-8 storage ring has four phase-matched magnet-free long straight sections (LSSs) [7]. These LSSs are transparent for the on-momentum particles with design energy, but for the off-momentum particles, the phase matching is broken. For the case B of the non-achromatic optics, we have investigated the effect of local chromaticity correction on DA for the off-momentum particle. As shown in Figs. 4(A) and (B), the focusing sextupoles at LSSs (SFLs) enlarge the horizontal aperture for particles with large momentum errors. However, the horizontal aperture without the momentum error decreases as the strength of SFL increases. By setting the strength of SFL=-0.3m^{-2}, we calculated the practical DA with the normal and skew error fields obtained by the response matrix analysis [8]. The synchrotron oscillation was also considered. Figure 5 shows the calculation results. Although the DA reduction due to the symmetry-break of the linear optics is found, DA of 15mm is kept at the beam injection side, the negative side of the horizontal axis.

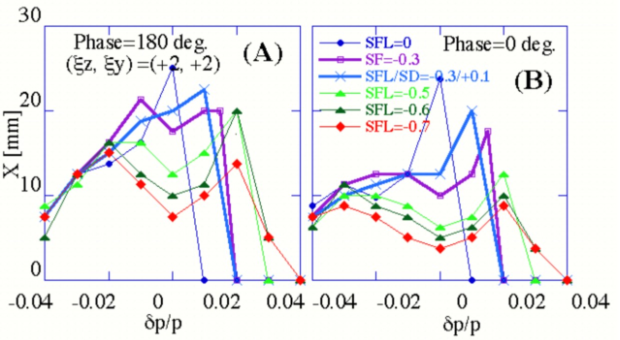

Figure 4: The effects of the local chromaticity correction on the horizontal aperture with the betatron phase of 180deg. (negative side: A) and 0deg. (positive side: B), respectively.

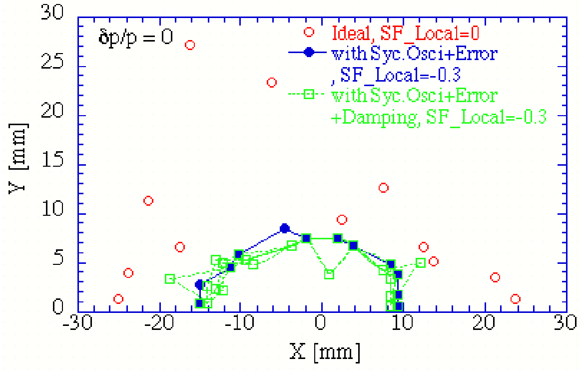

Figure 5: The solid circles and open squares represent DA at SFL=-0.3m^{-2} without and with radiation damping, respectively. The linear field errors and synchrotron oscillation is taken into account. The open circles represent ideal DA with no errors and SFL=0 as a reference.

EXPERIMENTAL RESULTS

Among the three cases shown in Fig. 2, the case C requires a modification of power supplies of sextupole magnets on a large scale. On the other hand, the case-B can be attained by a minor change of the cabling. In consideration of the calculation results and the modification scale, we adopted the case B. The cabling of sextupole magnets was changed so that periodicity of the sextupole strengths in the unit structure comprising of two CG cells can be kept over LSSs, which are inserted between the CG cells.

Injection Efficiency

Before the modification, the injection efficiency was less than 10% with sextupole arrangement of the case A under the minimum condition for the bump leakage. Though we collimated the injection beam [9], we could not obtain the injection efficiency at high level. After the modification, however, the injection efficiency increased up to ~80% due to the enlargement of DA even without injection beam collimation. By cutting the horizontal tail of the injection beam at 7 1σ with a collimation system, we could achieve the injection efficiency of 90%.

Stored Beam Oscillation

We measured the stored beam oscillation caused by the sextupole magnets within the injection bump by changing the sextupole strengths and compared the results with the calculations. Figure 7 shows the comparison between the experimental and calculation results for the two cases with small and large stored beam oscillations. As indicated by the arrows in the figure, we could reduce the beam oscillation due to the nonlinearity within the bump by adjusting the sextupole strength to the minimum condition. The calculations agree well with experimental results.

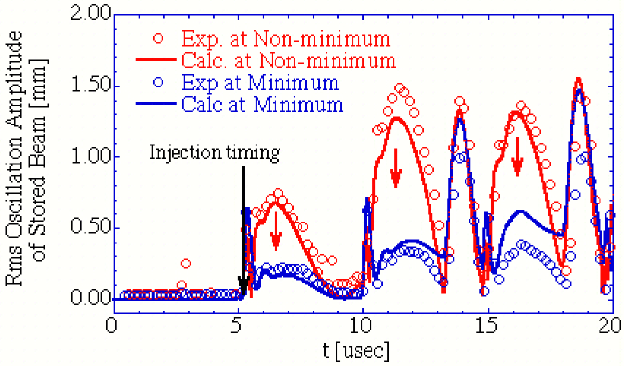

Figure 6: Comparison between the measured and calculated stored beam oscillations. The solid line and open circles represent the calculation and measured data, respectively.

Beam Lifetime

Since the introduction of the focusing sextupoles SFLs at LSSs enlarges the horizontal aperture for off-momentum particles, the Touschek-dominant beam lifetime also increases. In Fig. 7 we show the measured beam lifetime at 1mA/bunch as a function of the strength of SFL. As we can see, the measured beam lifetime becomes longer as the SFL becomes stronger. The value of SFL for user-time operation was fixed in consideration of the beam lifetime and injection efficiency.

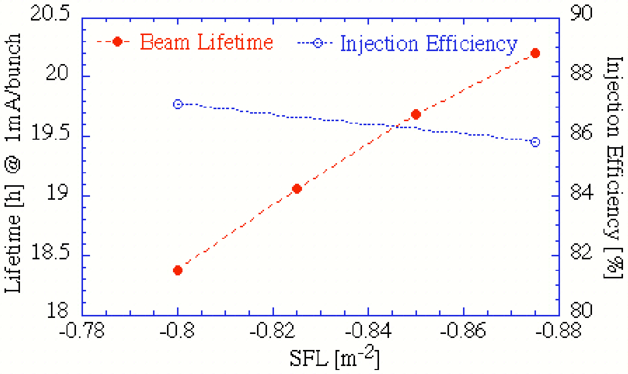

Figure 7: Touschek-dominant beam lifetime as a function of the strength of focusing sextupoles at LSSs.

CONCLUSION

By using the suppression scheme based on the minimum condition of the injection bump leakage, we have succeeded in increasing the injection efficiency up to 90% suppressing the stored beam oscillation due to sextupoles magnets.

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