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CORRECTION OF THE HIGHER ORDER DISPERSION FOR IMPROVING MOMENTUM ACCEPTANCE

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Abstract

May 2013 we lowered the emittance of the SPring-8 storage ring from 3.5 nm·rad to 2.4 nm·rad to enhance the brilliance. At the optics change the momentum acceptance shrunk from 3.2 % to 2.4 %. Then, by carefully correcting the second order dispersion, we recovered the momentum acceptance up to 2.8 %, which results in doubling the Touschek beam lifetime. Although the injection efficiency decreased by more than 10 % by the dispersion correction, we restored it by means of suppressing the amplitude dependent tune shift. Here we describe these improvements of the nonlinear dynamics of the SPring-8 storage ring.

INTRODUCTION

At the present light source facilities the intensity stability of the synchrotron radiation is extremely important for the precise experiments. For this end, the top-up operation, where the electron beam is injected during user experiments, is widely performed at the present light source rings. Hence the long beam lifetime and the high injection efficiency is essential for the stable top-up operation. The reduction of the beam loss is also important to protect the magnets of the insertion devise from the demagnetization by the electron bombardment.

The SPring-8 is the third generation light source facility for providing high brilliant hard X-ray to user experiments. Recently, for the purpose of improving the brilliance, we changed the optics of the SPring-8 storage ring [1], which reduced the natural emittance from 3.5 nm·rad to 2.4 nm·rad and gave rise to 1.5 times larger brilliance and flux density. The relevant parameters of the SPring-8 storage ring are listed in Table 1. The lattice structure of the SPring-8 storage is the modified double bend of 36 unit cell with 4 long straight sections (LSS) including 2 matching cells each. One of the four LSS's (LSS-D) is rearranged September 2011 by adding two quadrupole triplets to introduce the in-vacuum insertion device with the short period and the small gap. The betatron functions are shown in Fig. 1.

Table 1: Parameters of the SPring-8 Storage Ring

	~ April 2013	May 2013 ~
Energy	8 GeV	
Betatron Tune (H/V)	40.14 / 19.35	41.14 / 19.35
Chromaticity (H/V)	2 / 2	
Natural Emittance	3.5 nm·rad	2.4 nm·rad
Coupling Ratio	0.2 % – 0.4 %	

The optics change brought not only these profits but also the reduction of the momentum acceptance from 3.2 % to 2.4 %. The beam lifetime, especially the Touschek lifetime, is reduced further by the narrow momentum acceptance in addition to the reduction of the beam lifetime due to the decrease of the bunch volume. In order to improve the momentum acceptance, we performed the machine studies and found that the higher order dispersion of the 2.4 nm·rad optics is larger than that of the 3.5 nm·rad optics. So, suppressing the second order dispersion, we could enlarge the momentum acceptance. This is reported in detail in the following sections.

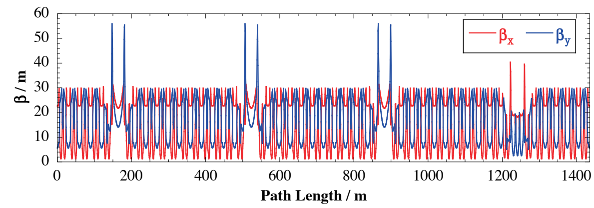

Figure 1: The betatron functions of the LSS-D modified optics.

TOUSCHEK LIFETIME AND MOMENTUM ACCEPTANCE

Beam Loss Mechanism

The present user operation of the SPring-8 is carried out in the several bunch filling mode, so the Touschek effect dominates the beam lifetime despite the relatively high energy 8 GeV. Although the Touschek lifetime is primarily determined by the RF bucket height due to the large momentum deviation by the energy exchange at the electron-electron collision in a bunch, it is also strongly limited by the transverse dynamics [2].

If the collision of the electrons occurs at a non-zero dispersion, the electrons with exchanging the momentum start to oscillate with an amplitude proportional to the dispersion. This is because the dispersion orbit is the central one for the electron with a momentum deviation. The electron with large enough amplitude to reach the transverse aperture, *e.g.* the vacuum chamber is lost, thus the momentum acceptance is restricted by the transverse dynamics. The horizontal aperture is enough large as to accept the injected beam of a large horizontal amplitude, which in the case of the SPring-8 storage ring is 10 mm. However the horizontal oscillation is converted to the vertical one by means of some betatron coupling, and hence the electron with vertical oscillation growing is lost at the vertical aperture narrower than the horizontal. Thus the momentum acceptance is determined by the following dynamical parameters.

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- The dispersion function, which gives the initial amplitude of the Touschek scattered electron.
- Linear and nonlinear coupling, which shares the initially horizontal oscillation energy to the vertical direction.
- The vertical betatron function, which regulates the vertical beam spread.

Hence, in order to enlarge the momentum acceptance and achieve longer Touschek lifetime, one may reduce the dispersion, suppress the betatron coupling, or squeeze the vertical betatron function at the narrow vertical aperture.

Momentum Acceptance Measurement

The momentum acceptance is estimated from the measurement of the Touschek lifetime as a function of the RF accelerating voltage. The synchrotron tune is measured simultaneously, from which one can calculate the bunch length and the RF bucket height. To enhance the effect of the Touschek scattering over the other lifetime effects a high current per bunch is filled in a few equidistantly spaced bunches. The low number of bunches avoids multi-bunch instabilities. The beam condition to measure the Touschek lifetime at the SPring-8 storage ring is 1 mA/bunch and 21 bunches (out of 2436) filled.

Figure 2 shows the measurement of the Touschek lifetime for the two optics with different emittances. The full circles dente the measured data, which grow according as the RF voltage increases until it reaches the transverse momentum acceptance. The dashed lines stand for the estimated Touschek lifetime under the assumption that the lifetime is limited only by the longitudinal momentum acceptance, *i.e.* the RF bucket height. For the sake of the easy comparison of the MA, the lifetime is normalized by the bunch volume, or the emittance.

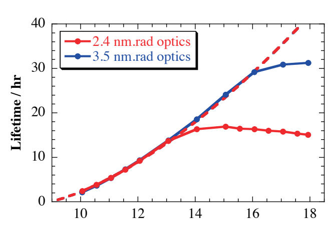

Figure 2: Touschek lifetime as a function of the RF accelerating voltage.

Figure 2 definitely shows the reduction of the momentum acceptance of 2.4 nm·rad optics compared to the 3.5 nm·rad. The estimated momentum acceptance for the former optics is 2.4 %, and that for the latter 3.2 %.

To reduce the emittance, we suppress the peak dispersion function at the arc of the storage ring. Hence the momentum acceptance of the 2.4 nm·rad optics deserves to be larger than that of 3.5 nm·rad if it were not for the drastic change of the coupling resonance and the betatron function. In practice, at the previous emittance reduction of the SPring-8 storage ring, which reduces the emittance from 6.6 nm·rad to 3.5 nm·rad by means of changing the achromat optics to the non-achromat, the momentum acceptance was enlarged by the reduction of the dispersion function from 0.4 m (peak) to 0.3 m [3]. At that time, the measured momentum acceptances are 2.2 % and 2.5 % for the achromat and the non-achromat optics, respectively. This contradiction comes from the influence of the second order dispersion as explained in the next section. Then, we improve the momentum acceptance of the 2.4 nm·rad optics by correcting the higher order dispersion.

CORRECTION OF THE HIGHER ORDER DISPERSION

Dispersion Measurement

In order to check the performance of the lattice structure of the storage ring, we regularly measure the higher order dispersion functions. The higher order dispersions up to the fourth of the 2.4 nm·rad and 3.5 nm·rad are shown in Fig. 3. The red circles denote the measured dispersion, and the blue lines represent the calculated one based on the ring model. The measured dispersion well agrees with the calculation except the fourth order dispersion of the 3.5 nm·rad optics.

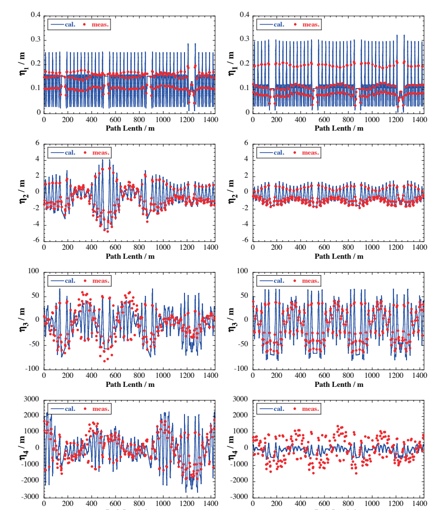

Figure 3: Higher order dispersions of the 2.4 nm·rad optics (left) and the 3.5 nm·rad (right).

As mentioned above, the linear dispersion of the 2.4 nm·rad optics has 0.25 m peak at the arc of the unit cell, which is smaller than that of the 3.5 nm·rad optics 0.28 m. On the other hand, the peak of the second order dispersion of the 2.4 nm·rad optics is three times larger than that of the 3.5 nm·rad, due to the significant modulation out of the four fold symmetry. Hence, at the momentum deviation 3 %, the peak of the total dispersion of the 2.4 nm·rad optics becomes larger than that of the 3.5 nm·rad one as shown in Fig. 4. As the result the momentum acceptance seems to become narrow as inversely proportional to the peak dispersion.

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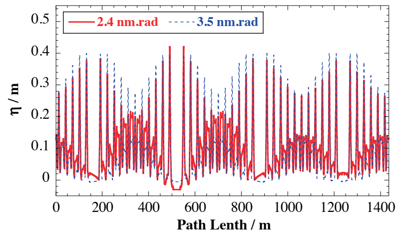

Figure 4: Total dispersions of the 2.4 nm·rad and the 3.5 nm·rad optics for the momentum deviation 3 %.

Correction of Dispersion

The second order dispersion can be corrected by the sextupole magnet, mainly ones at the arc, as given in [4]. The sextupole magnets at LSS matching cells can be controlled independently, so the local modulation of the second order dispersion is corrected freely. The higher order dispersions after the correction are shown in Fig. 5. The peak of the second order dispersion is almost halved by the correction.

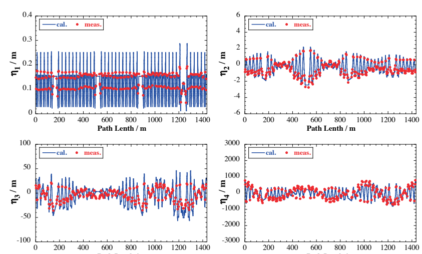

Figure 5: Higher order dispersions of the modified 2.4 nm·rad optics.

The calculated local momentum acceptances for the 2.4 nm·rad optics with and without the second order dispersion correction are shown in Fig. 6 as well as the dispersion for the momentum deviation 3 %. It is found from Fig. 6 that the dispersion correction gives rise to the enlargement of the momentum acceptance.

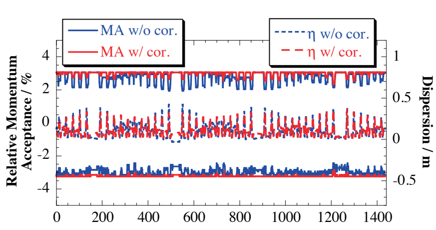

Figure 6: Local momentum acceptance and dispersion.

Figure 7 shows the measured Touschek lifetime, which implies that the momentum acceptance spreads from 2.4 % to 2.8 % by the dispersion correction.

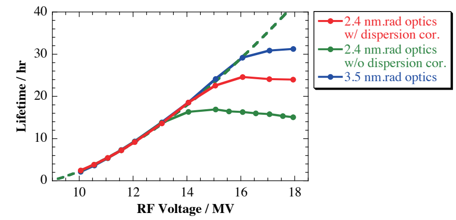

Figure 7: Touschek lifetime as a function of the RF accelerating voltage.

INJECTION EFFICIENCY

At the top-up operation the injection efficiency is another important figure of merit due to the radiation safety and the demagnetization of the magnet array of the ID's since the beam is injected with opening shutter for photon beam lines and closing gap of the ID's. For a time after improving the momentum acceptance by means of the sextupole magnet, the injection efficiency decreases by more than 10 %.

For the purpose of investigating the causes of injection efficiency decreasing, we measure the dynamic aperture and the amplitude dependent tune shift (ADTS). Then we found the amplitude dependent shift of the horizontal tune of the 2.4·rad optics so large as to approach the integer resonance as shown in Fig. 8. By suppressing the ADTS by means of tuning the harmonic sextupole magnet as conducted by the tracking simulation, we can recover the injection efficiency.

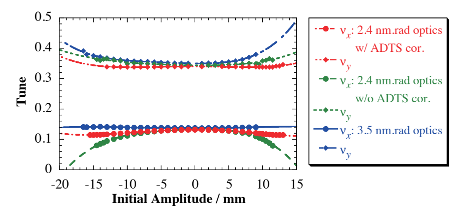

Figure 8: Amplitude dependent tune shift.

Thus we improve the momentum acceptance and the injection efficiency at the SPring-8 storage ring by means of tuning the nonlinear dynamics. The former is enlarged by the correction of the second order dispersion, and the latter is restored by the suppression of the ADTS.

REFERENCES

[1] Y. Shimosaki, et al., Proc. of IPAC'13, Shanhai, China, May 2013, 133 (MOPEA027).

[2] M. Takao, Proc. of IPAC'13, Shanhai, China, May 2013, 3981 (FRXAA01).

[3] M. Takao, et al., Proc. of EPAC'08, Genoa, Italy, June 2008, 3152 (THPC072).

[4] H. Tanaka, et al., Nucl. Instrum. Method **A 431**, 396 (1999).