NEW OPTICS WITH EMITTANCE REDUCTION AT THE SPRING-8 STORAGE RING

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Abstract

The machine tuning of a new optics has been examined at the SPring-8 storage ring. The natural emittance is reduced to 2.41 nmrad from the past value of 3.49 nmrad without any change of magnet positions. The flux density 1.3 times higher than that of the 3.49 nmrad optics was observed at the diagnostics beamline. The nominal injection efficiency of the order of 80 % has been achieved (the 3.49 nmrad optics: 92 %) by correcting the error of the optics function, by adjusting the strength of the injection magnets and by optimizing the sextupole magnetic fields. The beam lifetime was 13 h at 1 mA / bunch (the 3.49 nmrad optics: 22 h), and the momentum aperture estimated from the measurement of the Touschek lifetime was 2.3 % (the 3.49 nmrad optics: 2.8 %). As verifying the photon beam performance at beamlines, this new optics has been applied to the user operation.

INTRODUCTION

The SPring-8 is a third generation synchrotron light source with the electron energy of 8 GeV. The natural-emittance of 3.49 nmrad was used up to now from 2002 [1]. The ring stores a nominal current of 100 mA and has provided brilliant hard X-rays of the order of 10^{20} photons / sec / mm^2 / mrad^2 / 0.1 % B.W. (see Figure 1 (a)). In order not only to provide brilliant photons for current users but also to study a strategy of a lattice design and a tuning scenario for the upgrade project SPring-8 II, a new optics of the SPring-8 storage ring has been examined [2]. The design emittance of the new optics is reduced from 3.49 nmrad to 2.41 nmrad at 8 GeV. It is predicted by SPECTRA [3] that the 2.41 nmrad optics can provide 1.5 times higher brilliance and 1.25 times higher flux density for 10 keV photons with the SPring-8 standard undulator than those of the 3.49 nmrad optics. It is noted that, in the 3.49 nmrad optics, magnet positions and polarities are unchanged and magnetic fields are optimized within the specifications, so that the shutdown time is not required for switching from the 3.4 nmrad optics to the 2.4 nmrad.

OPTICS DESIGN

The main parameters of the double bend achromat (DBA) optics, the double bend optics of 3.49 nmrad (DB-3.49) and the new double bend optics of the 2.41 nmrad (DB-2.41) at the SPring-8 storage ring are listed in Table 1, and these lattice functions are shown in Figure 2. The DB optics with the leakage of the dispersion function has been modified to suppress the natural emittance from 3.49 nmrad to 2.41 nmrad. In order to provide the stable photon beam intensity during the user-time, the beta function and the dispersion function of the DB-2.41 at each straight section are optimized for the emittance not to be changed drastically by the radiation excitation and damping due to insertion devices (IDs). The brilliance and flux density predicted by SPECTRA [2] are shown in Figure 1. Figure 1 shows that the DB-2.41 can provide 30 ~ 45 % times higher brilliance and flux density for the hard X-ray region than those of the DB-3.49 at 8 GeV.

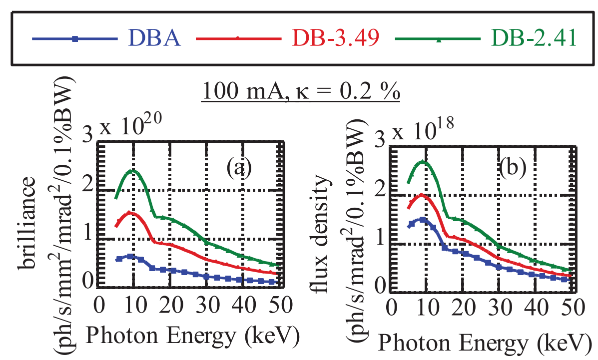

Figure 1: (a) Brilliance and (b) flux density from standard undulator (l_u = 32 mm, L = 4.5 m, K_{max} = 2.5) calculated by SPECTRA [3].

Table 1: Main Parameters of the SPring-8 Optics

	DBA (~2002.11)	DB -3.49 (2002.11 ~ 2013.5)	DB -2.41 (2013.5 ~)
Natural emittance	6.67 nm.rad	3.49 nm.rad	2.41 nm.rad
Effective emittance	6.67 nm.rad	3.77 nm.rad	2.79 nm.rad
s_E / E	0.11 %		
Tune (Q_x, Q_y)	(40.14, 19.35)	(40.14, 19.35)	(41.14, 19.35)
Natural chromaticity	(-91, -42)	(-88, -42)	(-117, -47)

In the DB-2.41 the horizontal dispersion leaked in the straight section is increased as seen from Figure 2, and the horizontal tune is increased by 1 as shown in Table 1. These allow us to approach an optics with the minimum emittance condition and a smaller natural emittance can be obtained. When we first tested the optics with

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dispersion leakage in 2002, the beam injection efficiency and the Touschek lifetime were not sufficient for the optics having the natural emittance below 3.4nmad. One reason for this is a stronger sextupoles required for chromaticity corrections, since the dispersion peak in the arc becomes lower (Figure 2) and the natural chromaticity becomes larger in the horizontal direction (Table 1) as we increase the leakage of dispersion into straight sections for reducing the natural emittance. To enlarge the dynamical stability of the ring, we then installed counter-sextupoles [4] and, together with the improvement of an optimization technique of sextupoles, this enabled us to realize a lower emittance optics having 2.41 nmrad.

MACHINE TUNING

The machine tuning for the DB-2.41 has been carried out at the machine study run. The beam injection efficiency has been improved step by step. The injection efficiency was only 8% at the initial tuning stage. This value is quit lower compared with an efficiency of 92% achieved at the DB-3.49. The machine study result showed that the horizontal tune crosses the integer at around the injected beam horizontal amplitude due to the amplitude-dependent tune shift. We first suppressed the horizontal amplitude-dependent tune shift by adjusting strengths of the harmonic sextupoles. This counter measure improved the injection efficiency up to 34%. Then, we performed successively precise tuning of the injection beam orbit together with the bump orbit, lattice function symmetry-restoration with the beam response analysis, re-adjustment of sextupole strengths under the linear optics distortion, and so on. The injection efficiency finally has reached about 90%.

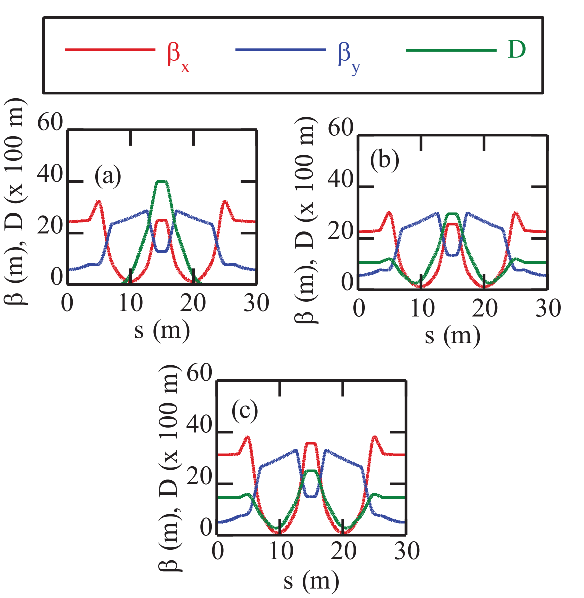

Figure 2: Lattice function of (a) DBA optics, (b) DB-3.49 and (c) DB-2.41: b is the betatron function and D is the horizontal dispersion.

Suppression of the stored beam oscillation is important for stable top-up operation. In the top-up injection the leakage of an injection bump orbit causes X-ray axis fluctuation through the stored beam oscillation. In order to reduce the axis fluctuation at the beam injection we performed the sextupole strength adjustment [5], the leakage suppression by fast kicker magnets [6], and the tilt-correction of bump magnets [7]. Figure 4 shows the achieved stored beam oscillations in the horizontal and vertical planes. The vertical oscillation amplitude is almost the same as the DB-3.49, but the horizontal amplitude is still larger. We have continued efforts on suppressing the horizontal stored beam oscillation.

Reduction of H-V coupling ratio is a key issue in synchrotron radiation light sources. At the beginning of the beam tuning stage, the vertical emittance was rather high, 31.5 pmrad after applying the coupling correction scheme developed at SPring-8 [8]. The developed scheme is based on the transverse oscillation exchange locally observed by using a single pass BPM. However, the sensitivity to the energy exchange depends on the optics and this scheme was not effective for reducing the coupling ratio at the new optics. In order to improve the coupling correction performance, we changed an objective function in the correction scheme from the local exchange rate to the global one, which treats with transverse oscillation exchange over the ring by using all available single-pass BPMs. By this change the correction performance was improved and the vertical emittance has been reduced to 13.82 pmrad. The ratio of the vertical emittance to the horizontal in the DB-2.41 is about 0.55 %, which is almost the same value as the DB-3.49.

ACHIEVED PERFORMANCE

To check the beam performance of the DB-2.41, we measured the momentum acceptance and compared it with the present one. Dependence of the beam lifetime on an RF acceleration voltage was measured at the Touschek dominant condition, i.e., 21-isolated bunches each of which beam current is 1 mA. Figure 3 shows the result, which gives a momentum acceptance of 2.4% in a normalized energy deviation. Though this value is smaller compared with 2.8% at the DB-3.49, it is sufficient to continue the top-up operation. Further optimization of sextupole strengths will be tested in the future.

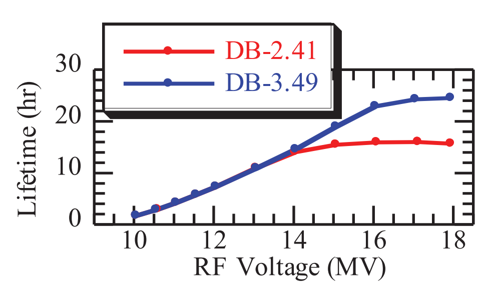

Figure 3: Touschek lifetime vs. RF voltage.

The photon beam performance was confirmed by utilizing the accelerator diagnostics beamlines I (BL38B2) and II (BL05SS). The emittance was determined by measuring the electron beam size with the X-ray beam imager at the diagnostics beamline I [9], and by using the lattice functions estimated from the response matrix analysis. The results of the X-ray beam imager are shown in Figure 5, and the evaluated emittance is summarized in Table 2. The resulting value of the natural emittance shows a good agreement with the design.

The flux density of 10 keV photons from the ID was measured at the diagnostics beamline II. The flux density of the DB-2.41 was 1.3 times higher than that of the DB-3.49 (see Figure 6), and this result is consistent with theoretical calculation by SPECTRA, in which the above determined emittances and estimated lattice functions are assumed.

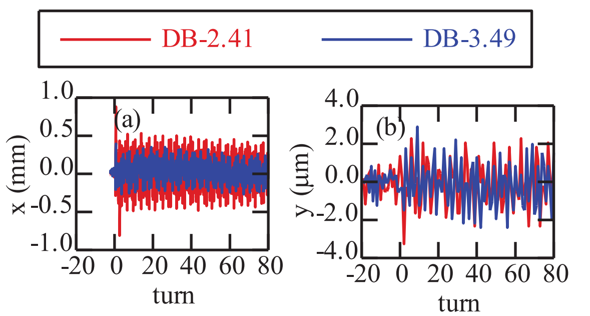

Figure 4: Oscillation of stored beam when bump magnets are tuned on in (a) horizontal and (b) vertical direction.

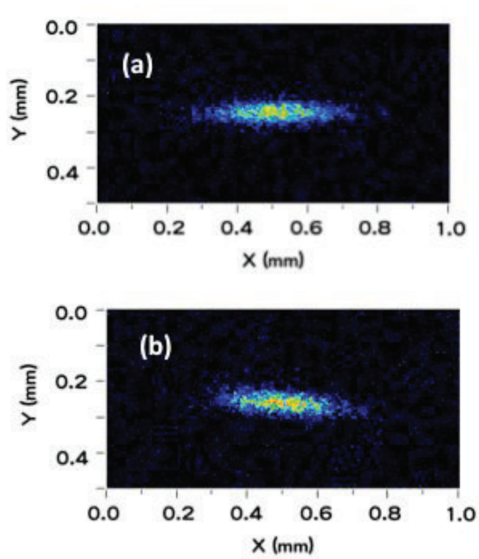

Figure 5: X-ray beam image for (a) DB-3.49 and (b) DB-2.41. The tilt of these images is not absolute and the ambiguity is mainly due to an optical system.

Table 2: Experimentally Deduced Values of the Emittance

	DB-3.49	DB-2.41
e_x (nmrad)	3.55	2.55
e_y (pmrad)	20.1	13.8
Natural emittance (nmrad) measurement / design	3.57 / 3.49	2.57 / 2.41

A test run for demonstrating the new optics was carried out on Jan. 26, 2013, and the photon beam performance was checked at 13 insertion device (ID) beamlines and 3 bending-magnet beamlines. The increment of the partial flux (~10 %), the increment of the brilliance (25 %) and the decrement of the photon beam size at the frontend slit (10 %) were observed at these ID beamlines.

After checking the photon beam performance at all beamlines, the DB-2.41 has been used in user operation from May 2013.

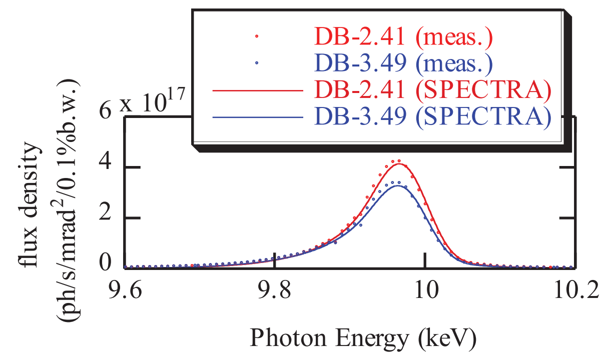

Figure 6: Flux density at the diagnostics beamline II (l_u = 76 mm, N = 51. K=1.666, 3rd harmonic).

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