OPTIMIZATION OF LOWER EMITTANCE OPTICS FOR THE SPRING-8 STORAGE RING

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Abstract

Besides a feasibility studies of the SPring-8 II, a design work to modify the present SPring-8 storage ring optics is also in progress to provide photon beams with higher brilliance and flux density than those of the present for "current users". Accelerator physics and technology have been evolved since the beginning of use of SPring-8, and thus we can challenge the lower emittance optics than the present. The natural emittance is reduced from the nominal emittance of 3.4 nmrad to 2.4 nmrad at 8 GeV. It is noted that the optics can easily be changed from the present optics without any shutdown time. This optics has been experimentally examined, and the higher flux density due to the lower natural emittance has been confirmed by utilizing the accelerator diagnostics beamlines. This new optics design and its beam performance are presented.

INTRODUCTION

The SPring-8 storage ring is a third generation synchrotron light source with the electron energy of 8 GeV. The natural emittance is 3.4 nmrad, where the double bend lattice with the leakage of the dispersion function at the straight section is implemented in the unit cell (see Figure 1 (a)). 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 2 (a)).

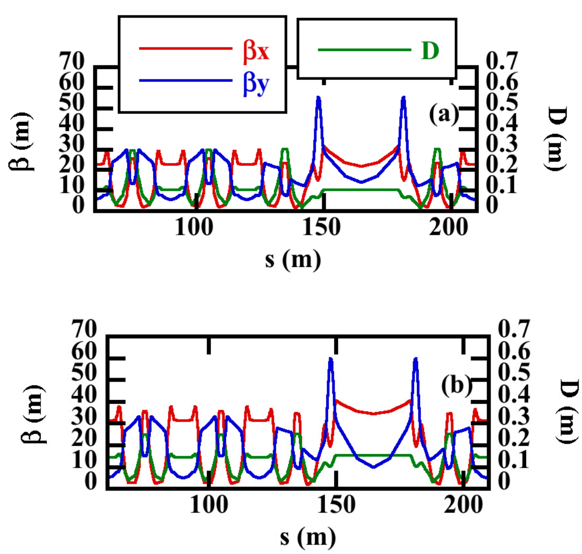

Figure 1: Lattice function of (a) present and (b) new optics.

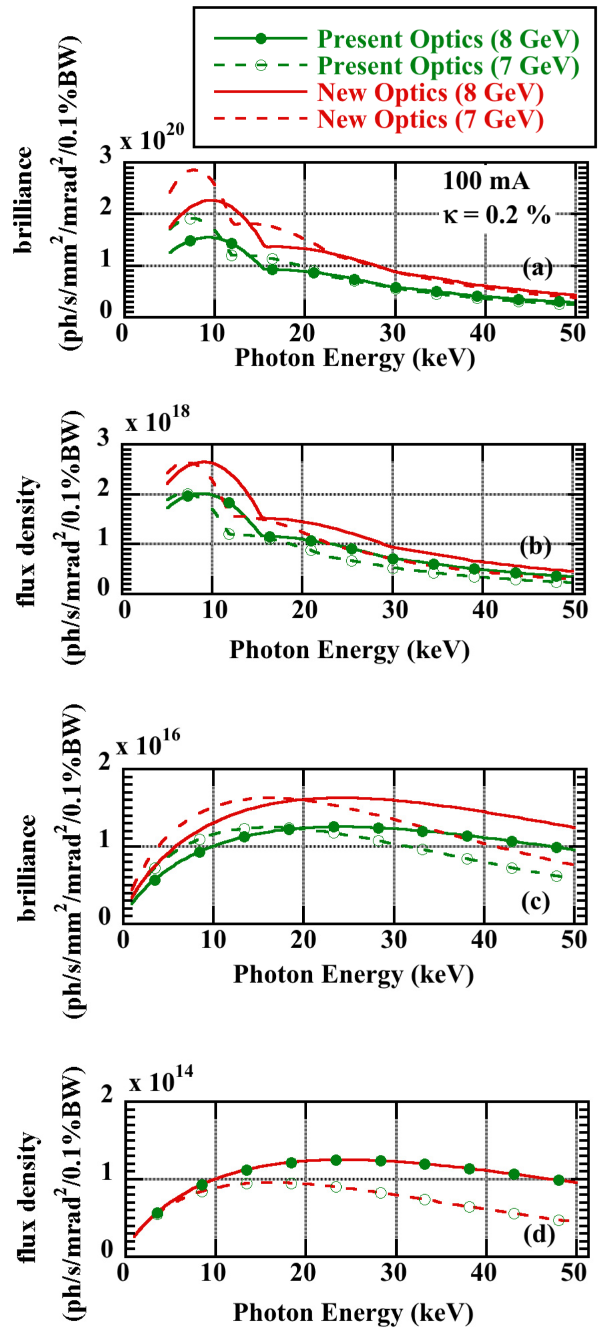

Figure 2: (a) Brilliance and (b) flux density from standard undulator (λ_u = 32 mm, L = 4.5 m, K_{max} = 2.5). (c) Brilliance and (d) flux density from bending magnet. Calculated by SPECTRA [1].

The design study for an upgrade project of the SPring-8, the SPring-8-II, is in progress [2-4]. Its ultimate goal is to provide a superior brilliance of photons by $10^2 \sim 10^3$ times

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higher than the present by reducing emittance of electrons until a diffraction limit. A full-scale major lattice modification will be performed, and the shutdown time is planned about a year for this purpose.

Besides the feasibility studies of this SPring-8 II, a design work to modify the present SPring-8 storage ring optics is also in progress to provide photon beams with higher brilliance and flux density than those of the present for “current users” [5]. Accelerator physics and technology have been evolved since the beginning of use of SPring-8, and thus we can challenge the lower emittance optics than the present. It is noted that, in this optics, magnetic positions and polarities are remained and magnetic fields are optimized within the specifications, so that the optics can easily be changed from the present optics without any shutdown time. In this paper, this new optics design and its beam performance are presented.

OPTICS DESIGN

The lattice function of the new optics is shown in Figure 1 (b), and the main parameters are listed in Table 1. The double bend optics with the leakage of the dispersion function has been modified to suppress the natural emittance from 3.4 nmrad to 2.4 nmrad. In order to provide the stable photon beam intensity during the user-time, the beta function and the dispersion function at the straight section are optimized for these emittances not to drastically change by the radiation excitation and damping caused by the insertion devices (IDs).

Table 1: Main Parameters of Present Optics and New Optics

	Present Optics	New Optics
Beam energy	8 GeV	8 GeV
Natural emittance	3.4 nmrad	2.4 nmrad
Energy spread σ_p	0.11 %	0.11 %
Tune (Q_x, Q_y)	(40.14, 19.35)	(41.14, 19.35)
Natural chromaticity (ξ_x, ξ_y)	(-88, -42)	(-117, -47)
Effective emittance @ ID center	3.8 nmrad	2.8 nmrad
Lattice function @ ID center (β_x, β_y, D)	(22.5 m, 5.6 m, 0.11m)	(31.2 m, 5.0 m, 0.15m)

In the design of the Spring-8 II, 12 sextupole families are utilized for correcting (1) the linear chromaticity and (2) dominant terms of nonlinear resonances [3]. On the other hand, in the case of this new optics, 6 sextupole families are implemented in the unit cell. This means that the number of the families is less than the degree of freedom for correcting them, and the dominant nonlinear resonances cannot be corrected, strictly. Therefore, a genetic algorithm for CETRA [6] has been developed for not strictly but globally and approximately optimizing the (non-)linear optics with avoiding a local minimum. The sextupole fields have been numerically surveyed with the genetic algorithm to enlarge the dynamic aperture until the present level (see Figure 3) and to suppress the amplitude-dependent tune shifts (see Figure 4). An example of the survey result is shown in Figure 5. Figure 5 shows that the survey point of the sextupole magnetic field was wandering without trapping in the local minimum.

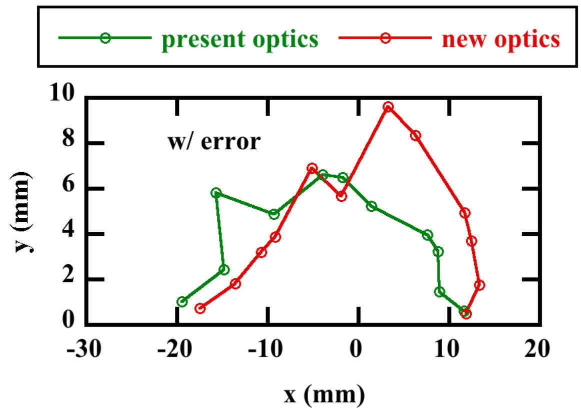

Figure 3: Dynamic aperture (CETRA).

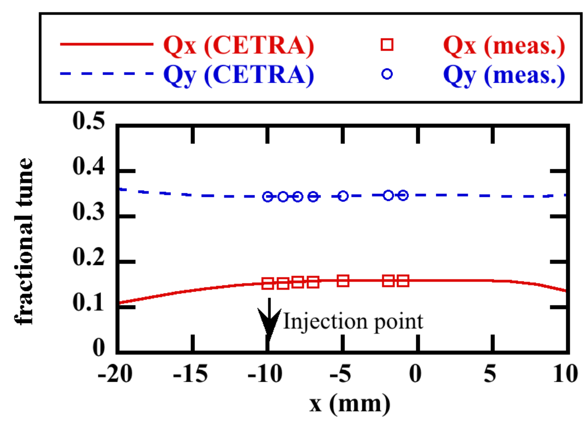

Figure 4: Amplitude dependence of tune.

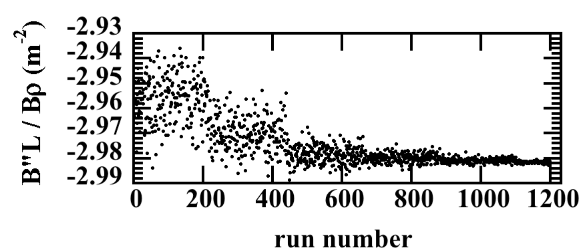

Figure 5: Survey results of a sextupole magnetic field.

The brilliance and flux density predicted by SPECTRA [1] is shown in Figure 2. Figure 2 (a), (b) and (c) show that the new optics can provide 30 ~ 45 % times higher brilliance and flux density for the hard X-ray region than those of the present optics at 8 GeV. Figure 2 (b) also suggests a possibility that if we operate the ring at a lower energy of 7 GeV for saving the electric power, we can use the new optics to recover the flux density from the

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standard undulator. Figure 2 (d) implies that, for recovering the photon flux density from the bending magnet at 7 GeV, the stored current should be increased at 7 GeV; the stored current of 170 mA at 7 GeV is equivalent with 100 mA at 8 GeV from the viewpoint of the acceptance of the heating on the crotch absorber [7].

MACHINE TUNING

The beam tests have been carried out with the new optics at 8 GeV. The machine conditions, such as the injection efficiency, the bump orbit for the injection and the vertical dispersion function, have been tuned. The normal injection efficiency of 74 % was achieved. Concerning the top-up injection, the top-up injection efficiency was 89 % and the beam lifetime was 191 hours, when the stored current was 100 mA, the bunch filling was 160 bunch trains x 12, and the gaps of all IDs were fully opened.

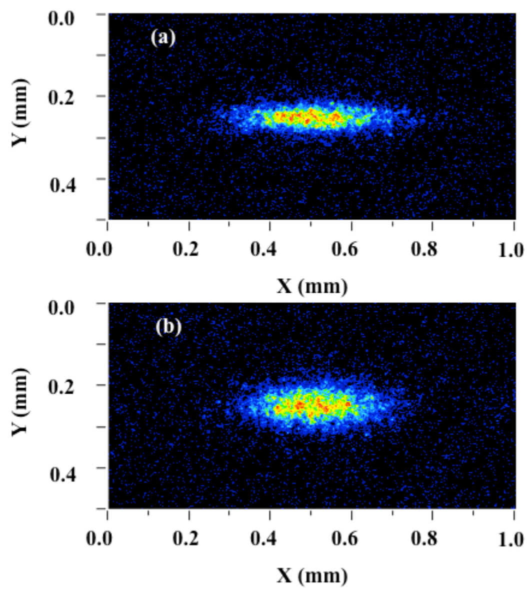

Figure 6: X-ray beam image. (a) Present and (b) new optics.

Table 2: Comparison of Emittance

	Present Optics	New Optics
ε_x (nmrad) design / measurement	3.46 / 3.59	2.40 / 2.32
ε_y (pmrad) measurement	12.55	31.46

The photon beam performance was observed 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, and by using the lattice functions estimated from the response matrix analysis. The results of the X-ray beam imager are shown in Figure 6, and the evaluated emittance is summarized in Table 2. The resulting value of the horizontal emittance shows a good agreement with the design. The vertical emittance was found to be larger than the present optics, though the vertical dispersion function and the linear coupling resonance were corrected by the skew quadrupole magnets. From a measurement of the betatron oscillation spectrum, it seems that a vertical emittance growth is caused by a coupling resonance induced by skew sextupole magnetic fields. We will suppress the vertical emittance by avoiding the resonance.

The flux density of 10 keV photons from the ID was measured at the diagnostics beamline II. The flux density of the new optics was 1.3 times higher than that of the present (see Figure 7), and this result is consistent with theoretical calculation by SPECTRA, in which the above determined emittances and estimated lattice functions are assumed.

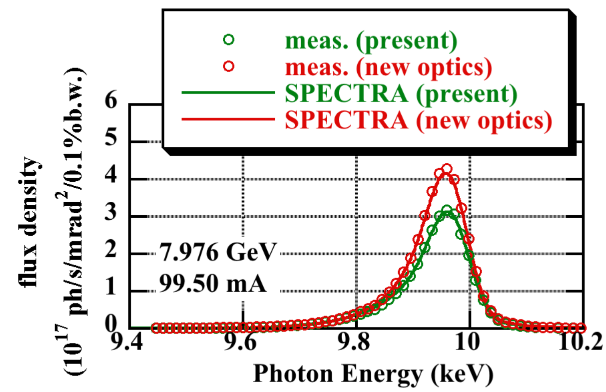

Figure 7: Flux density at the diagnostics beamline II.

After optimizing the machine conditions (the vertical emittance, the top-up injection efficiency, the beam life time, etc) and verifying the photon beam performance at beamlines, the new optics will be applied to the user operation. In addition, a lattice with much lower natural emittance is under designing to provide much brilliant photon to "near future users", where the short shutdown time may be planned.

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