ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWA064

# STUDY OF INHERENT POTENTIAL FOR EMITTANCE REDUCTION AT THE SPRING-8 STORAGE RING

Yoshito Shimosaki #, JASRI / SPing-8, Hyogo, Japan

*Abstract*

A design study for an upgrade project of the SPring-8, the SPring-8-II, is in progress, which is a full-scale major lattice modification. Besides the design study for the SPring-8-II, an inherent potential of achieving much higher brilliance than that of the present SPring-8 has been explored for the general evaluation. In this paper, the evaluation of the inherent potential for the SPring-8, not for the SPring-8-II, in terms of increasing the brilliance is discussed.

## INTRODUCTION

The SPring-8 storage ring is the third generation type synchrotron radiation facilities with the circumference of 1436 m in Hyogo, Japan. The basic super-period of the ring is 4, and one super-period consists of 9 unit cells, 2 matching cells and a long drift of 30 m (see Figure 1). The natural emittance for the user operation has been reduced from 6.4 nm.rad to 2.4 nm.rad, step by step [1, 2]. The present user-optics with 2.4 nm.rad was opened since 2013, which was optimized for the equilibrium emittance not to be changed drastically by the radiation excitation and the radiation damping due to insertion devices (IDs) in order to provide the stable photon-flux during the user-time [1, 2]. The top-up injection has been utilized to store the electrons of 99.5 mA with the beam energy of 7.976 GeV. The brilliant hard X-ray of the order of $10^{20}$ photons / sec / mm$^2$ / mrad$^2$ / 0.1 % B.W. has been provided.

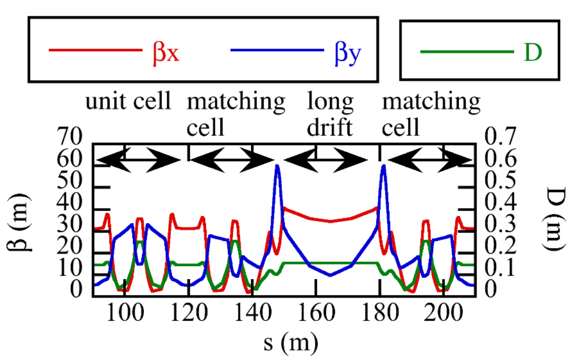


Figure 1: Lattice function of present user optics at the SPring-8 storage ring.

In order to advance promising science and to support industrial innovations, the design study for an upgrade project of the SPring-8, the SPring-8-II, is in progress [3]. In order to increase the brilliance, the electron emittance will be reduced by a multi-bend scheme [4] with a longitudinally varying dipole field [5], by a lower energy operation (6 GeV) than that of the present (8 GeV) and by utilizing a radiation damping by IDs.

Besides the design study for the future SPring-8-II, an inherent potential of achieving much higher brilliance than that of the present user optics has been explored for the SPring-8 storage ring, in order not only to provide brilliant photon beams for "current users" but also to verify a strategy of the lattice design for the SPring-8-II before switching the optics to the SPring-8-II in 2019-2020. Here, the double bend (DB) lattices have theoretically and experimentally been examined at 6 GeV and 8 GeV, and the mixture of both "DB optics" and "double bend achromat (DBA) optics with the damping wigglers" has theoretically been examined. In these designs, it is noted that magnet positions are unchanged and magnetic fields are optimized within the specifications. In this paper, the evaluation of the inherent potential for the SPring-8, not for the SPring-8-II, is presented.

## OPTIMIZATION OF DB OPTICS

In general about an optics design, freedoms of the quadrupole and sextupole magnetic fields normalized by beam energy can be expanded by lowering beam energy even within the specifications of the power supplies. From this point of view, DB optics specialized particularly for increasing the brilliance, not the flux density, has been examined at 6 GeV (see Figure 2) in order to explore a potential of the SPring-8 storage ring [6].

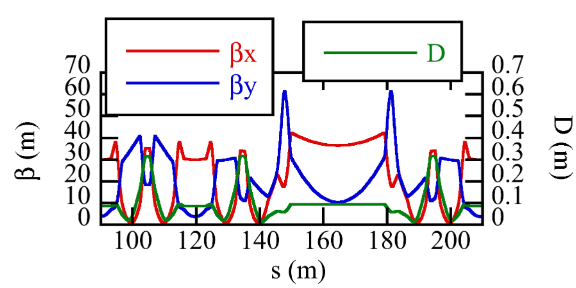


Figure 2: Lattice function of DB optics optimized for 6 GeV at the SPring-8 storage ring.

$\beta_x$, $\beta_y$ and $D$ at the ID positions in Figure 2 are optimized (1) to enhance the emittance damping by IDs, and (2) to decrease the effective photon emittance by matching between the 30 keV photon beam size and the electron beam size at the ID position. The effective photon emittance of 10 keV photon in Figure 2 (6 GeV)

#shimosaki@spring-8.or.jp

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWA064

becomes 1 / 2.5 times smaller than that of the present optics (8 GeV) with the help of emittance damping from 1.8 nm.rad to 1.3 nm.rad by the IDs. SPECTRA [7] predicts that, if the stored current is normalized at 100 mA for both 6 GeV and 8 GeV, the above optimization results in 2.4 times higher brilliance and 1.25 times higher flux density for 10 keV photons than those of the present (see Figure 3), where it is noted that, in order to estimate them around the comparable X-ray region, an undulator of $\lambda_u$ = 35 mm, $L_u$ = 4.5 m and $K_{max}$ = 2.5 (= the standard undulator of the SPring-8) is assumed in the calculation at 8 GeV and one of $\lambda_u$ = 23 mm, $L_u$ = 4.5 m and $K_{max}$ = 2.3 [6] is assumed at 6 GeV.

The beam tests have experimentally been carried out at 6 GeV [6]. The normal injection efficiency of 74 % and the beam lifetime of 63.3 hours at the stored current of 54.4 mA and 160 bunch trains x 12 were achieved [6].

.

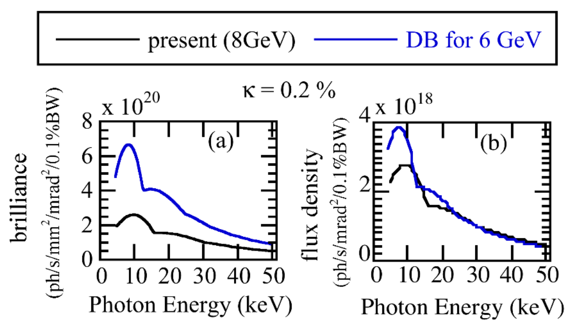


Figure 3: (a) Brilliance and (b) flux density at present optics (8 GeV) and 6 GeV optics.

While the brilliance and flux density from the IDs are intense if an appropriate ID for 6 GeV can be introduced, the reduction of the critical energy from the bending light source at 6 GeV should be serious at some bending beamline. So, to accommodate the users at the bending beamline, the low-beta optics (DB) at 8 GeV specialized for increasing the brilliance has also been examined within the specifications of the power supply (see Figure 4). The natural emittance of 2.3 nm.rad is achieved, and ($\beta_x$, $\beta_y$, $D$) at the ID positions are lowered from (31.2 m, 5.0 m, 0.15 m) to (29.9 m, 3.8 m, 0.15m).

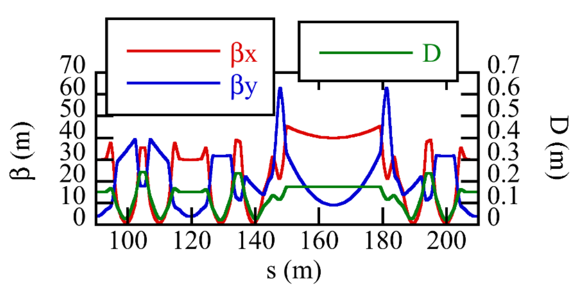


Figure 4: Lattice function of low- beta optics (8GeV).

The brilliance and flux density at the low-beta optics with 2.3 nm.rad are shown in Figure 5. The brilliance of the low-beta optics is 15 % higher than that of the present, and the flux density is almost same between the present and the low-beta. It seems that the present optics pulls out the almost performance at 8 GeV.

The beam phenomena induce by the IDs such as the tune shift and the beam instability can be suppressed by decreasing $\beta_y$. Therefore, from a viewpoint of the stable user operation at the SPring-8 storage ring, the machine tuning for the low-beta optics has been performed at the machine study run though the brilliance and the flux density are comparable with those of the present. The normal injection efficiency was about 56 %. Further optimization of the sextupole magnetic fields and the injection bump orbit should be required.

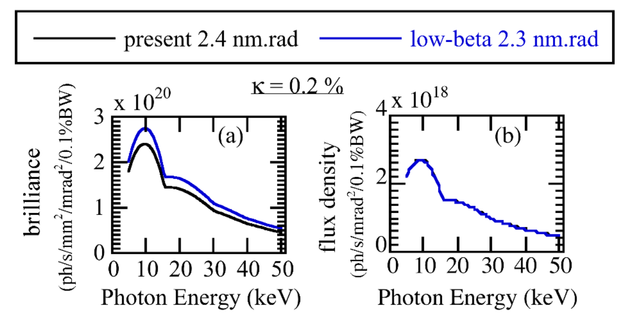


Figure 5: (a) Brilliance and (b) flux density at present optics (2.4 nm.rad) and the low-beta optics (2.3 nm.rad). 100 mA.

## MIXTURE OF “DB OPTICS” AND “DBA OPTICS WITH DAMPING WIGGLERS”

A possibility of reducing a natural emittance with a damping wiggler (DW) at the SPring-8 storage ring has also been verified, theoretically. At the Spring-8 storage ring, there are 4 long drifts of 30 m. So the DW of $\lambda_{dw}$ = 100 mm, $L_{dw}$ = 30 m, and $B_{max}$ = 1.7 T was supposed to use for the emittance reduction in this paper. The beam energy of 6 GeV was assumed because of the power loss due to the DWs and the capability of the RF voltages.

In this paper, “DBA optics with 4DWs”, and “a mixture of DB optics, and DBA optics with 2 DWs (see Figure 6) with the matching cell from DB (DBA) section to DB (DBA) section (also see Figure 7)” have been examined. In the latter, the emittance can be decreased (1) with the dispersion leakage at the DB section and (2) with the DWs at the DBA section. The estimated emittance reduction and the growth of the momentum deviation (1σ) with the DWs are shown in Figure 8. The achievable emittance with the DWs is almost same, 1 nm.rad, between the DBA optics and the mixture. However, the momentum deviation of the mixture becomes lower than that of the DBA optics with the help of the emittance reduction with the dispersion leakage at the DB section,

ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-TUPWA064

which also means the power loss caused by the DWs at the mixture is lower than that of the DBA optics.

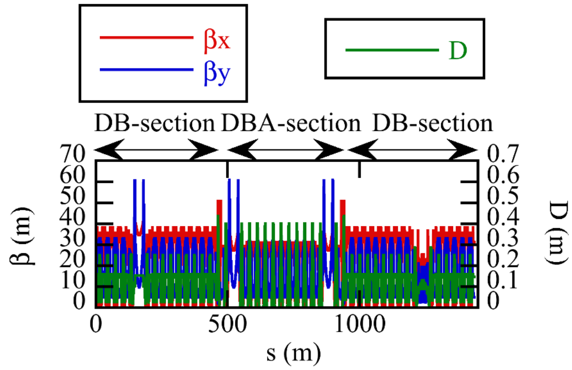


Figure 6: Lattice function for mixture of DB optics and DBA optics.

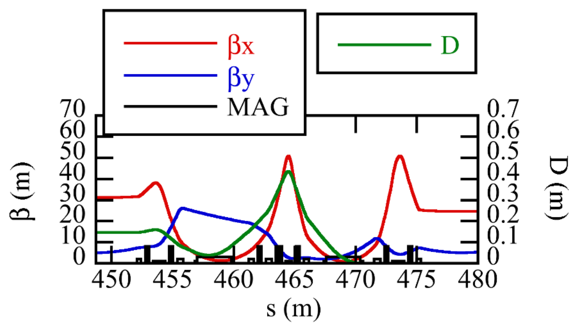


Figure 7: Matching cell from DB section to DBA section.

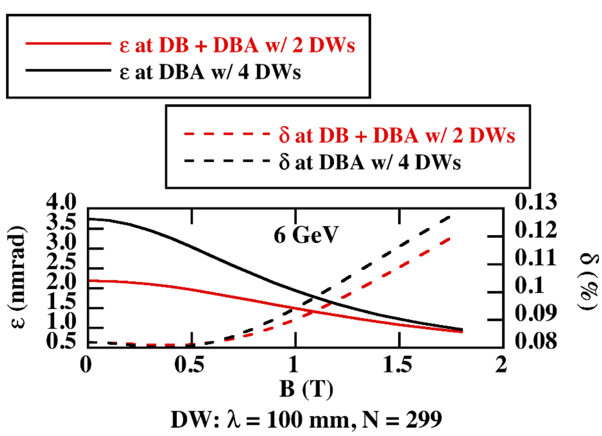


Figure 8: Emittance and momentum deviation (1σ) with DWs at DBA optics with 4DWs and mixture with 2 DWs.

The estimated brilliance and flux density by SPECTRA at the DBA optics with 4 DWs and the mixture with 2 DWs are shown in Figure 9, where the stored current of 100 mA was assumed. In these estimation, an undulator of $\lambda_u$ = 25 mm, $L_u$ = 4.5 m and $K_{max}$ = 2.3 was assumed, which were evaluated from the vertical beta functions at the ID position and Halbach's equation [8]. As shown in Figure 9, the brilliance of the DBA section at the mixture becomes higher than those of the DBA optics and the DB section at the mixture. The flux density is almost same between them. From viewpoint of a power saving, it seems that, if DWs could be utilized, the mixture of the DB and DBA may be profitable more than the DBA optics.

## SUMMARY

For the SPring-8 storage ring, the general evaluation of the inherent potential of achieving much higher brilliance than that of the present has been explored before switching the optics to the SPring-8-II in 2019-2020, where magnet positions are unchanged and magnetic fields are optimized within the specifications. The SPring8-II will provide the brilliant and coherent photon flux, and advance promising science and support industrial innovations [3].

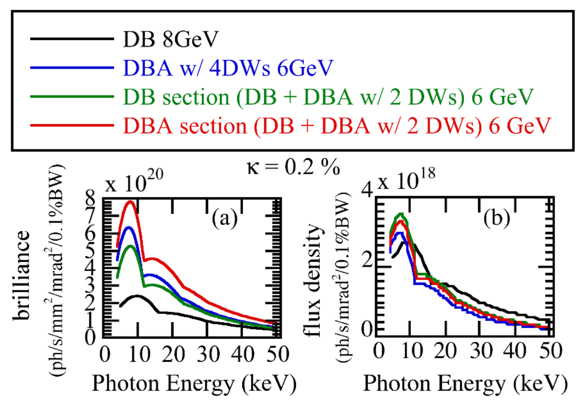


Figure 9: (a) Brilliance and (b) flux density at present optics (8 GeV), DBA optics with 4 DWs (6 GeV), and mixture with 2 DWs. 100 mA.

## REFERENCES

[1] Y. Shimosaki et al., IPAC12, TUPPC013.
[2] Y. Shimosaki et al., IPAC13, MOPEA027.
[3] SPring-8 II Conceptual Design Report: http://rsc.riken.jp/pdf/SPring-8-II.pdf
[4] D. Einfeld and M. Plesko, NIMA 335, 402 (1993).
[5] R. Nagaoka, A. F. Wrulich, NIMA 575, 292 (2007).
[6] Y. Shimosaki et al., IPAC14, MOPRO083.
[7] T. Tanaka and H. Kitamura, SPECRA code ver. 9.02 (2012).
[8] A. W. Chao and M. Tigner, "Handbook of Accelerator Physics and Engineering", World Scientific.