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UPDATE OF LATTICE DESIGN OF THE SPring-8-II STORAGE RING TOWARDS 50 pmrad

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Abstract

The storage ring lattice of SPring-8-II has been under optimization towards a low emittance of around 50 pmrad, which was initially set at 150 pmrad [1]. The optimization concept is based on the effective use of extra-radiation damping by damping wigglers that can be installed in the four long straight sections each 30 m long in length. For this purpose, we have been re-optimizing the linear and nonlinear optics so as to reduce the radiation loss from the bending magnets. In parallel, since the emittance variation due to the gap change of the IDs can be an obstacle for conducting precise experiments, we are investigating a new passive method to suppress the emittance variation without any feedback system.

INTRODUCTION

As is the case with other facilities around the world, the upgrade plan for the SPring-8 storage ring is being studied with the goal of achieving an extremely low emittance [1] by adopting a multi-bend (MB) lattice with longitudinal field-gradient dipoles [2-4]. Recent advances in undulator technology make it possible to shorten the undulator period length and we lower the stored beam energy from 8 GeV to 6 GeV. This also contributes to lower the emittance since it is proportional to the square of the beam energy. In our previous studies [1, 5], bending magnets of separate-function type were used and the target emittance was set around 150 pmrad. However, users have asked for more emittance reduction and we decided to introduce new concepts to reach the 50 pmrad level in user operation.

Our lattice design is characterized by the following features. (i) The combined-function dipoles are used to increase the horizontal damping partition number and hence to reduce the emittance. (ii) The dipole field distribution within a unit cell is optimized to reduce the total radiation loss. This enhances the effectiveness of radiation damping. (iii) The lattice nonlinearity is well suppressed by adjusting the betatron phase between two arc sections where sextupoles are localized. (iv) Damping wigglers (DWs) are planned to be installed in some of long straight sections (LSSs) to lower the emittance further. (v) Matching conditions of optical functions at the boundary of LSS are met for on- and off-momentum electrons. This allows us to redesign the LSS lattice locally according to users' requirements. (vi) A transparent beam injection is possible without giving perturbation to the stored beam.

For the newly designed lattice, the natural emittance is 108 pmrad, and by using DWs the emittance is expected to be reduced to the level of 50 pmrad in user operation. By doing nonlinear optimization we have a large enough dynamic aperture (DA) for off-axis beam injection and momentum acceptance (MA) of about 3%. As for the beam injection, the SPring-8 has an advantage that we have an XFEL facility SACLA on the same campus and its linac has already been used as a high quality beam injector in the top-up operation of the present SPring-8 storage ring [6]. With only a few modifications, this high quality beam injection system can be used for the SPring-8-II.

LATTICE DESIGN

Emittance Reduction

In Fig.1 we show the design of a unit cell of the SPring-8-II storage ring. The cell structure is of the five-bend achromat type, and dipoles with longitudinal field-gradient are used to achieve a target emittance value [3], except for the one in the center of the cell. This central dipole is for generating hard x-rays and its field strength is fixed at 0.953 T. The field distribution of other dipole segments are optimized so that the lowest possible emittance are obtained under a given magnet arrangement. At the same time, we take care to minimize the radiation loss as much as possible, which is important for enhancing the effects of radiation damping. The dipole segment on the side near the peak of the dispersion (blue filled squares in Fig.1) is of the combined-function type by which the horizontal damping partition number is increased from 1.0 to 1.39. The maximum values of the quadrupole, sextupole and octupole fields are 55.7 T/m, 2.7e3 T/m^2 and 8.0e4 T/m^3, respectively, and these can be realized with ordinary electromagnet technologies. In Table 1 we compare machine parameters of the new storage ring with those of the present SPring-8 storage ring.

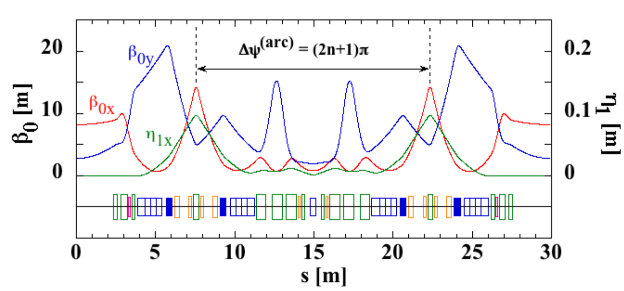

Figure 1: The optics and magnet arrangement of a unit cell. The squares shown at the bottom of the figure represent bending (blue), quadrupole (green), sextupole (orange) and octupole (red) magnets. Blue filled squares are bending magnets of the combined-function type.

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Table 1: Machine Parameters of the Ring

Parameter	SPring-8-II	SPring-8
Lattice Type	Five-bend	Double-bend
Energy [GeV]	6	8
Circ. [m]	1435.44	1435.95
Emittance [nmrad]	0.108 ~0.05 w/DW	6.6 (Achromat) 2.4(Non-Achr.)
Tune (H/V)	108.10/42.58	40.15/18.35 (A) 41.14/19.35 (NA)
Nat. Chrom.	-154/-149	-90/-41 (A) -117/-47 (NA)
Beta at ST [m]	8.2/2.8	24.4/5.8 (A) 31.2/5.0 (NA)
Mom. Cmpct. Factor	4.14e-5	1.46e-4 (A) 1.60e-4 (NA)
E. Spread [%]	0.097	0.109
Rad. Loss [MeV/turn]	2.6	8.9

Nonlinear Optimization

As shown in Fig.1, the betatron phase difference $\Delta\psi^{(arc)}$ between two arc sections are basically set to $(2n+1)\pi$ with n being an integer to cancel dominant nonlinear effects of sextupoles. In our design, this phase difference is used as a knob to suppress the ADTS [7] and is set to 2.976π and 0.990π for horizontal and vertical directions, respectively. The cancellation of the nonlinear sextupole kick is not perfect and the residual effect is mitigated by weak sextupoles placed near the center of the cell [8]. As an additional knob to control the ADTS, we also placed octupoles in the straight sections.

USE OF LONG STRAIGHT SECTIONS

Matching of Optics

At SPring-8 we have four LSSs in the ring and some LSSs will be used for installing DWs to reduce the emittance. These DWs are also usable as a source of high-flux photon beamlines in the hard x-ray region. Other LSSs can be used specifically for R&D of future innovative light sources. Then, it is important to take optics matching for not only on-momentum but also off-momentum electrons in order to fully utilize each LSS independently. Figure 2 shows such an example of the transparent LSS insertion where the matching conditions are fully satisfied. At the boundary of the LSS, the on- and off-momentum betatron functions $(\beta_{0x}, \beta_{1x}, \beta_{0y}, \beta_{1y})$ and dispersion functions (η_{1x}, η_{2x}) are matched, where

$$\beta_x(s) \equiv \beta_{0x}(s) + \beta_{1x}(s)\delta$$
$$\beta_y(s) \equiv \beta_{0y}(s) + \beta_{1y}(s)\delta$$
$$\eta_x(s) \equiv \eta_{1x}(s) + \eta_{2x}(s)\delta$$

with $\delta \equiv \Delta p/p$, and the betatron phase increases by 2π in both horizontal and vertical directions when passing through this section. Once we have an optimized LSS lattice as shown in Fig. 2, the matching conditions are always satisfied regardless of the setting of sextupoles, since the linear optics only within the LSS are modified [9]. Figure 3 shows the on- and off-momentum optical functions before and after inserting the LSS. We see that the matching conditions are satisfied and the LSS is transparent for off-momentum electrons up to the first order of δ. By tracking simulations, we confirmed that by imposing the off-momentum matching conditions at the boundary of the LSS, the stability of off-momentum electrons is improved. As long as the matching conditions are met, the LSS lattice can be changed independently according to what light sources will be needed there in the future.

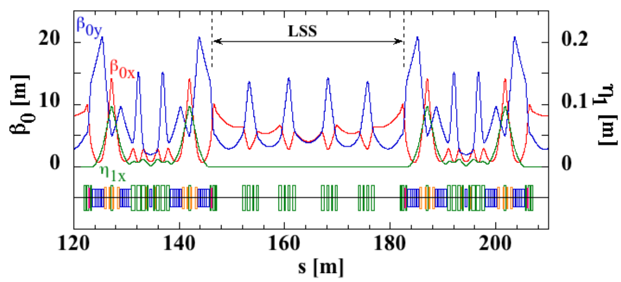

Figure 2: An example of the optics and magnet arrangement of a long straight section.

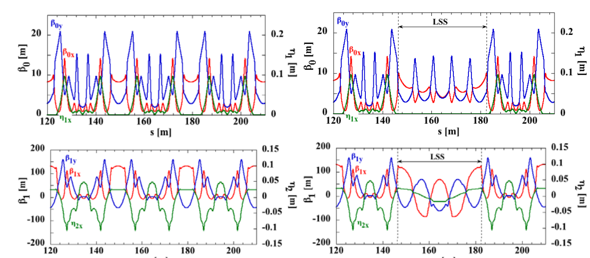

Figure 3: Matching of on- and off-momentum optical functions at the LSS. The energy-independent part (β_{0x}, β_{0y} and η_{1x}: upper) and the first-order energy dependence ($\beta_{1x}, \beta_{1y}, \eta_{2x}$: lower) are shown before (left) and after (right) inserting the LSS.

Effects of Damping Wigglers

As mentioned above, we are planning to install high-field DWs in LSSs to reduce the emittance. Parameters of the DW we assumed are as follows [10]: the period length is 100mm, the peak magnetic field is 1.8 T, and the number of periods is 144 per LSS. We then estimated the effects of radiation damping by taking account of the undulators installed in the normal straight sections. The results are shown in Fig. 4, where the emittance and the relative energy spread are plotted as a function of the undulator peak field in normal straight sections. In these calculations we assumed that the number of undulators is 34 considering the current operating conditions of SPring-8, and all undulators were assumed to be of the same standard type with the period length of 22 mm [1]. We see that for the case of using two LSSs, the emittance can be reduced to the 50 pmrad level in user experiments when undulator gaps

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are closed to the typical range indicated in the figure. We also see that

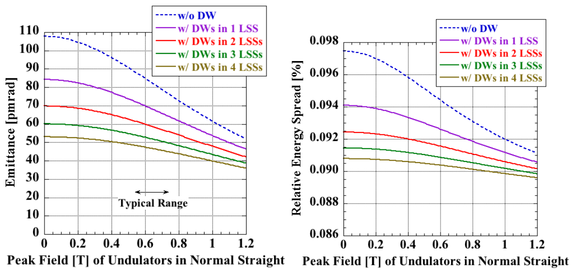

Figure 4: The emittance (left) and the relative energy spread (right) as a function of the undulator peak field. The dashed curve is for a bare ring without DW. The solid curves are for the ring with DWs and four curves are shown depending on the number of LSS used.

the number of LSSs used is sufficient up to 2 and increasing its number is not effective.

TRANSPARENT BEAM INJECTION

Today, top-up operation to maintain a constant stored current is an essential requirement for synchrotron radiation users, and a transparent beam injection scheme that does not perturb the stored beam is needed. We will adopt a transparent off-axis beam injection scheme and are considering two possibilities to implement it: one is a conventional scheme with pulsed bump magnets and the other is with a pulsed nonlinear kicker magnet (NLK) [11,12]. We first consider the former.

For the conventional off-axis beam injection scheme, we modify the lattice of the injection section to make a high-beta straight with $\beta_{0x} = 20\ m$ at the injection point. Figure 5 shows a tentative design of the injection cell. To generate a pulsed bump orbit, we use a π-bump scheme [13], where two pulsed bump magnets driven by a common power supply are installed at two points with a horizontal betatron phase difference of π. The use of a common power supply minimizes a perturbation to the stored beam during injection.

The dynamic aperture (DA), chromaticity and ADTS for the whole ring are shown in Fig. 6. A high-quality beam from the SACLA linac is injected at $x \approx -3\ mm$, and we see that DA is large enough for off-axis beam injection. As in the LSS insertion case discussed above, the off-momentum matching condition should be met at the border of the injection cell. The current design of Fig. 5 almost satisfies the β_1-matching but the η_2-matchign is not met. We are currently evaluating the impact of the distortion of η_2.

If the higher order dispersion is largely distorted, the aborted beam will always hit a specific point of the vacuum chamber wall after the RF switch is turned off, and this could cause a serious damage to the chamber [14]. We then need to suppress the distortion of η_2 and the study for improving it is on-going. If we don't get a good solution, we will consider the possibility of adopting another scheme of using NLK without modifying the optics of the injection section. In our case of using the SACLA linac as an injector, the injected beam emittance is small, and this is advantageous in the beam injection with NLK.

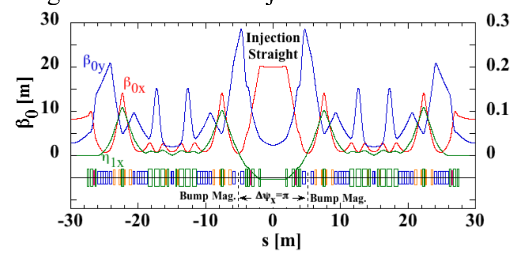

Figure 5: A tentative design of the injection cell.

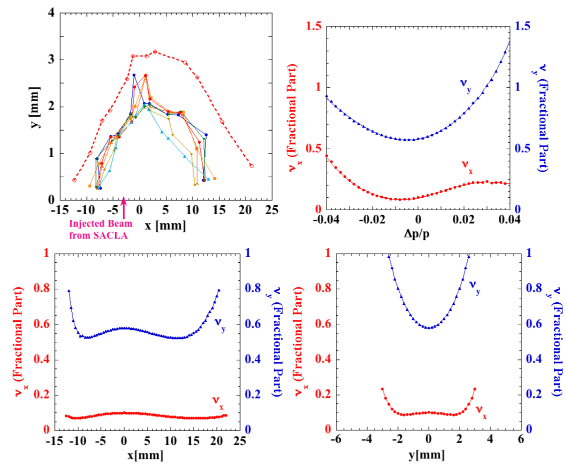

Figure 6: The DA observed at the injection point with $\beta_{0x} = 20.0\ m$ and $\beta_{0y} = 2.3\ m$ (left-upper), chromaticity (right-upper) and ADTS (bottom). In the figure of DA, the dashed line is for the ideal ring and the solid lines are for the ring with sextupole misalignment (rms 25 μm, max. $\pm 50\ \mu m$).

SUPPRESSION OF EMITTANCE VARIATION

In the next generation light source storage rings, the emittance is so small that its variation during user operation can be an obstacle for conducting precise experiments. We then developed a passive method to suppress its variation caused by the change of undulator gaps (i.e. the change of balance between damping and excitation; see Fig. 4) [15]. Our idea is to leak a small amount of dispersion to straight sections where undulators are installed and optimize its value considering actual operation range of undulator gaps. This will be examined in details in the future and in the present work we limited our discussion to the baseline design of the achromatic lattice.

SUMMARY

We have shown the updated design of the SPring-8-II storage ring lattice. The design emittance is 108 pmrad and it can be reduced to the level of 50 pmrad by using the radiation damping effects of DWs and undulators. The following issues remain to be resolved: studies of the transparent beam injection scheme, suppression of the second order horizontal chromaticity, heat load handling of the DWs, etc. These will be discussed in the future.

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