STATUS AND RECENT PROGRESS OF SPring-8

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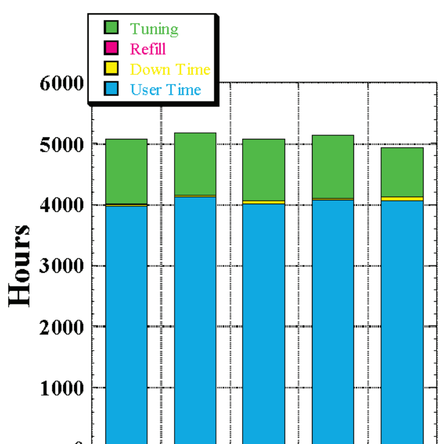
Abstract

The operational status and recent progress overview of SPring-8 is presented: the local lattice modification of 30-m long straight section for installing small gap (min. gap is 5.8 mm) in-vacuum undulators, the emittance coupling correction for the vertical beam size reduction, the test operation of low energy operation for the energy saving, and the study of lower emittance optics for the present SPring-8 storage ring. An outline of a future upgrade with a full-scale major lattice modification is also presented.

OPERATIONAL STATUS

The SPring-8 is an 8GeV synchrotron radiation facility that has been in operation since 1997. The SPring-8 has been operated well and total user time has reached more than 53,700 hours, 75 % of the total operation time. The average user time per year is about 4,000 hours. The average availability is about 98 % in the past 15 years.

The operation statistics for last five fiscal years are shown in Fig. 1. In FY2011, the total operation time of the accelerator complex was 4918.6 hours. The operation time of the storage ring was 4904.2 hours, of which 82.8% (4058.5 hours) was made available for SR experiments. The downtime resulting from failure accounted for 1.4% (57 hours) of the total user time; in November 2011, a great loss of user time was incurred



	FY2007	FY2008	FY2009	FY2010	FY2011
Acc. Operation Time	5063.6	5150.1	5150.1	5125.6	4918.6
Sr Operation Time	5056.3	5133.3	5035.4	5096.3	4904.2
Tuning& Study (Acc. &BL)	1065.0	1008.2	1019.1	1026.6	803
Refill	9.5	10.1	6.3	5.0	4.4
Down Time	29.2	31.0	34.8	27.5	57
Mean Time Between Fa	148.4	143.2	122.9	178.4	117.7
Achieved User Time	3969.3	4110.9	4014.9	4071.6	4058.5
Planning User Time	4008.0	4152.0	4056.0	4104.0	4120.0
Availability (%)	99.0	99.0	99.0	99.2	98.5

Figure 1: Operation statistics for last five fiscal years.

due to cooling water leak from the cooling pipe to vacuum vessel of the in-vacuum undulator, consequently, user time of 27.15 hours was cancelled for the suspension of machine operation. Since FY2004, top-up injection was introduced. Concerning user service operation, a high availability (ratio of net user time to planned user time), e.g., 98.5%, was achieved in FY2011. The total tuning and study time of 803 hours was used for machine tuning, for the study of the linac, booster synchrotron and storage ring, and also for the beamline tuning and study.

Operations in two different filling modes were provided for the following user time: 62.5% in the several bunch mode, such as the mode of 29 equally spaced trains of 11 bunches and 37.5% in the hybrid filling mode, such as the mode of 1/14-partially filled multi-bunch with 12-isolated bunches. In FY2011, there was no operation in multi-bunch mode. The several bunch mode was the dominant filling mode. The 203-bunch mode and the mode of 29 equally spaced trains of 11 bunches reached 30.3% and 32.2% of the total user time, respectively. For the hybrid filling mode, 1.0 mA, 1.4 mA, 1.6 mA, or 3.0 mA is stored in each isolated bunch. An isolated bunch impurity better than 10^{-10} is routinely maintained in the top-up operation. Table I shows a summary of the beam filling patterns for user time operation.

Table 1: Filling Patterns

Filling Pattern	Bunch Current	Lifetime
203 bunches	0.5 mA	25 ~ 30 hr
11 bunch-train × 29	0.3 mA	35 ~ 50 hr
1/7-filling + 5 single bunches	3.0 mA (single)	18 ~ 25 hr
1/14-filling + 12 single bunches	1.6 mA (single)	18 ~ 25 hr
2/29-filling + 26 single bunches	1.4 mA (single)	18 ~ 25 hr
4/58-filling + 53 single bunches	1.0 mA (single)	18 ~ 25 hr

LOCAL LATTICE MODIFICATION OF LONG STRAIGHT SECTION FOR ADVANCED SOURCE

In one of four long straight sections of the SPring-8 storage ring, the lattice was modified locally to install small gap in-vacuum undulators with a short period (Fig. 2) [1]. Although the symmetry of the ring was lowered by this modification, the dynamic aperture and the momentum acceptance could be kept large. This is owing to our scheme of lattice design of the LSS: we imposed the betatron phase condition to this section to make it transparent for on momentum electrons, made a local chromaticity correction with weakly excited sextupole

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magnets to enlarge the off-momentum dynamic aperture, and introduced "countersextupole" magnets to cancel a dominant effect of the nonlinear kick due to sextupole magnets. The beam commissioning of the new lattice has successfully been finished and, after checking the beam performance, it is now used in user operation. One undulator has been installed in the middle sub-section and at present the minimum gap of 5.8 mm is allowed. The other two undulators are going to be installed for achieving the design goal of the beamline.

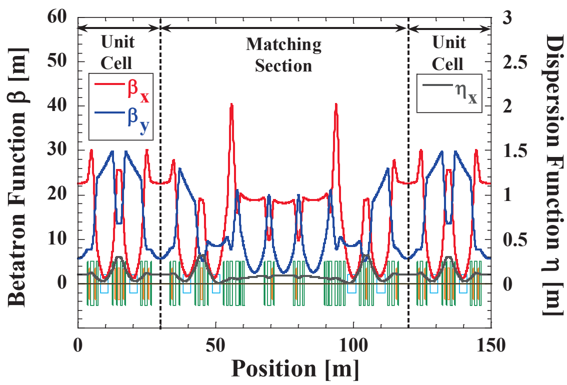

Figure 2: Lattice functions and magnet arrangement modified for small gap in-vacuum undulators [1].

IMPROVEMENT OF THE COUPLING CORRECTION [2]

By the precise alignment of the magnets and the proper COD correction, at the commissioning phase of the SPring-8 storage ring we succeeded in achieving the very small coupling ~0.2 % without correction. However, the coupling had grown large with the years, so recently we have corrected it and recovered the initial performance. The scheme of the coupling correction at the SPring-8 storage ring is the global one, which is based on the perturbation theory with single resonance approximation. The perturbation theory implies that the vertical beam size is proportional to the strength of the coupling resonance. Hence the strengths of the skew quadrupole magnets for the coupling correction are determined so as to give the minimum of the vertical beam size.

After the coupling correction based on the vertical beam size response, we find that there remains the linear coupling mode in the vertical oscillation induced by the horizontal kick by the pulse bump magnets. This is because the vertical beam spreads comes from the higher order coupling as well as the linear coupling. The strength of the higher order coupling may vary according to that of the linear coupling, so the vertical beam size is not a so suitable measure for the linear coupling correction. Then we change the way of the coupling correction to correct linear coupling mode in the vertical oscillation induced by the pulse bump magnet. As a result, we can almost completely eliminate the linear coupling of the beam motion at the SPring-8 storage ring. By changing the strength of the skew qudrupole magnets properly, we can eliminate the linear coupling mode corresponding to the peak at the horizontal betatron tune 0.15.

For the purpose of further reducing the emittance coupling, we must correct the higher order coupling as implied above. For this end, we are preparing the skew sextupole magnets, which generate the higher order coupling.

LOW ENERGY OPERATION

We tried to test a low energy operation for saving electricity at the stored electron beam energy of 7 GeV. In this operation, we confirmed that the peak consumption power for SPring-8 accelerator operation (linac, booster synchrotron and storage ring) was reduced from 17.9 MW (8 GeV) to 14.5 MW (7GeV), i. e., the amount of power-saving was 3.4 MW. Figure 3 shows the power consumption at 7 GeV operation of the SPring-8 storage ring. We also confirmed the natural beam emittance is reduced from 3.2 nm·rad (8GeV) to 2.5 nm·rad (7 GeV).

And also we have successfully increased the stored beam current from 100 mA to 170 mA at 7 GeV operation.

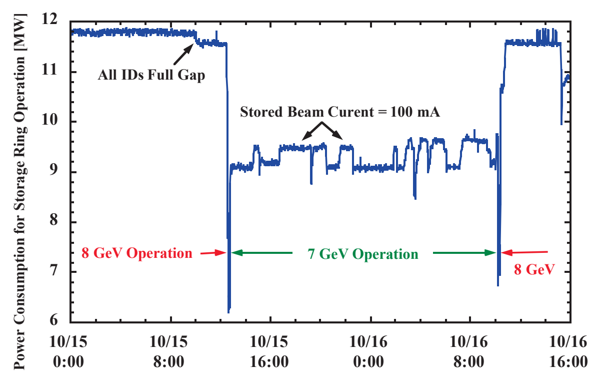

Figure 3: Power consumption of 8 GeV and 7 GeV storage ring operation.

LOWER EMITTANCE OPTICS FOR THE PRESENT SPring-8 STORAGE RING

A design work to modify the present SPring-8 storage ring optics is in progress to provide photon beams with higher brilliance to users. The new optics with the lower natural emittance of 2.4 nm·rad than the present (3.4 nm·rad) has been designed (Fig. 4) [3]. It is noted that, in this optics, magnet positions and magnetic field 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. The new optics has experimentally been examined at the machine study. The machine conditions, such as the injection efficiency, the bump orbit for the injection and the vertical dispersion function, have been tuned, and the photon beam performance has been observed by utilizing the accelerator diagnostics beamlines.

The emittance was determined by measuring the electron beam size, and by using the lattice functions estimated from the response matrix analysis. The

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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 (present: 12.55 pm·rad, new: 31.46 pm·rad), 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 optimizing the betatron tunes and by avoiding the resonance.

The flux density of 10 keV photons from the ID was measured. The flux density of the new optics was 1.3 times higher than that of the present, and this result is consistent with theoretical calculation, in which the above determined emittances and estimated lattice functions are assumed.

After optimizing the machine conditions (the vertical emittance, the top-up injection efficiency, the beam lifetime, etc.) and verifying the photon beam performance at beamlines, the new optics will be applied to the user operation.

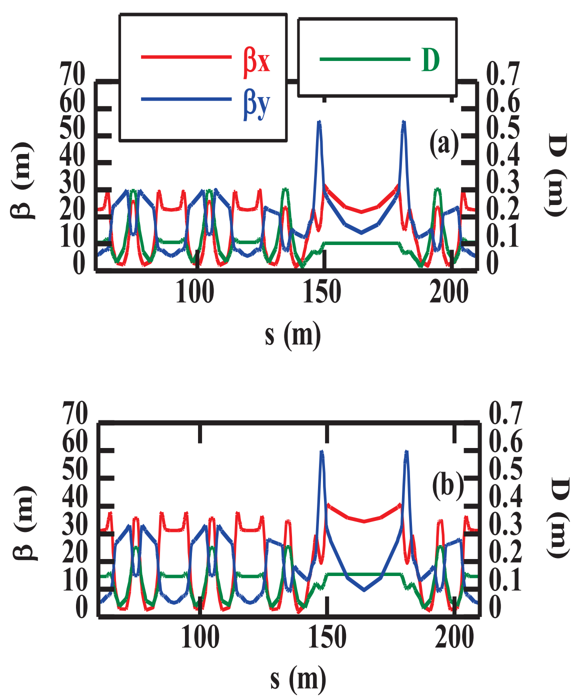

Figure 4: Lattice function of (a) present and (b) new optics [3].

FUTURE UPGRADE PLAN

We propose upgrading the SPring-8 light source within the decade. The upgrade is expected to bring fundamental changes to photon science by providing: the highest ever brilliance and user capacity via unprecedented throughput, and a unique combination with the XFEL/SACLA. In this plan, the emittance of a stored beam is reduced from 3.4 nm·rad to 10 pm·rad range, which corresponds to the diffraction limit for 10 keV photons, to provide a superior brilliance for 0.5 ~ 100 keV photons by 10^2 ~ 10^3 times higher than the present SPring-8.

For this upgrading plan, we have designed a sextuple-bend achromat lattice (natural emittance: 67.5 pm·rad at 6GeV) for an ultra-low emittance lattice of the SPring-8 II storage ring as the first candidate (Fig. 5), the rearrangement of the magnetic position to suppress sextupole magnetic fields and the suppression of the amplitude dependent tune shift were performed. And then the tolerance to the sextupole-alignment errors was enhanced. The additional enlargement of the dynamic aperture and momentum aperture will be studied with the effects of IDs. The additional emittance reduction from the natural emittance of 67.5 pm·rad to 10 pm·rad is planned by damping wigglers.

Recently, a quintuple bend lattice has been studied as the second candidate in order to enhance the feasibility, where the natural emittance is 77 pm·rad at 4.5 GeV.

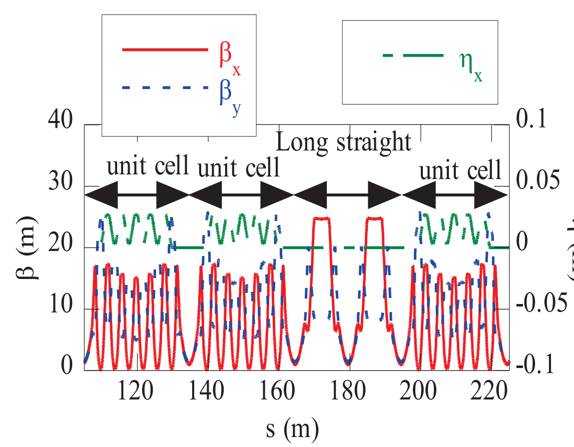

Figure 5: Lattice function of sextuple bend lattice [5].

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