OPERATIONAL PERFORMANCE OF THE SPRING-8 STORAGE RING

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Abstract

The SPring-8 storage ring is usually operated with the cycle of three-weeks. The full operation time in one cycle is about 400 hours and three fourth, about 300 hours are dedicated to users. Since 2001, the cycle of four-weeks is also usually used. Up to now the storage ring completed user service operation of about four years. Over this period the storage ring was operated stably and the total user time reaches more than 12,400 hours, 70% of whole operation time. In order to obtain more brilliant X-rays, we have realized four magnet-free long straight sections (LSS's) of 27 meters in the storage ring in the summer shutdown of the year 2000. Via smooth machine tuning, the user service operation was successfully started from the beginning of October 2000, keeping almost the same beam performance as that before the LSS's installation: The estimated horizontal emittance is about 6 nm·rad and the vertical one is at most 14 pm·rad. Beam lifetime is longer than 110 hours in multi-bunch operation. The operational status and recent beam performance of the SPring-8 storage ring will be presented, comparing with that before the LSS's installation.

1 OPERATIONS

1.1 Operation Statistics in 2000

During the year 2000 a total operation time of the storage ring was 4,973 hours, and 3,264 hours (65.6%) has been delivered to the users. The down time was 89 hours, 1.8% of the user time. The remaining 1,620 hours (32.6%) were used for the machine tuning, for the photon beamline tuning and for the commissioning of new photon beamlines. Three weeks (about 500 hours) were used for the beam commissioning after the installation of four magnet-free long straight sections (LSS's).

1.2 Filling Modes

In 2000, 1,748 hours (53.5% of the total user service operation) was delivered in the multi-bunch mode operation. In first half of 2000, a 24/29-filling mode was used for the user service operation. After the summer shutdown of 2000, a dispersed filling pattern of which eleven 160-bunch trains are distributed was used to avoid the beam size increase due to an ion trapping effect. Recently various several-bunch and hybrid filling modes were used. In 2000, eight different types of the several-bunch modes and four different types of the hybrid-filling mode were used. Operation times were 1,003 hours (30.8%) and 513 hours (15.7%), respectively. For example of a several-bunch mode and a hybrid-filling mode, the 9-bunches train mode (29 equally spaced 9-bunches trains) and the partially filled multi-bunch with single bunch were used. In isolated bunches, 1 or 1.5 mA/bunch were stored, and purities in the 10^{-7} range were routinely achieved in the user. The stored beam was usually refilled or accumulated at a repetition of once or twice a day.

2 BEAM PERFORMANCE

2.1 Magnet-Free Long Straight Sections

The initial lattice structure of the SPring-8 storage ring was based on the Double-Bend Achromat with 48 unit cells, which is called a 'Phase-I lattice'. There were four long straight cells with missing-bend. In first two years, the storage ring had been operated with Hybrid optics (horizontal beta function takes a large value and a small value alternately in the straight section for insertion devices). In 1999 the Hybrid optics was changed to HHLV optics (optics with High Horizontal and Low Vertical betatron functions in all straight sections)[1]. In summer shutdown of 2000, it was in progress that four magnet-free LSS's, which were about 27 m long, were going to be realized by rearranging quadrupole and sextupole magnets in the LSS's. New lattice structure is called a 'Phase-II lattice'.

Four LSS's inevitably breaks the symmetry of optics, especially of the sextupole fields. Additional harmful resonance lines also appear near a working point. Then, a new optics must be optimized by considering the stability of circulating electrons with large amplitudes and momentum deviations. To solve this problem, we proposed a new concept of "Quasi-Transparent Matching of sextupole-fields (QTMS)"[2]. The QTMS concept simultaneously manages both symmetry restoration of sextupole fields and the local correction of the chromaticities in a proper way. To apply the QTMS concept to the Phase-II lattice, we adopted a matching section of about 90 meter, which was composed of LSS's and neighboring Chasman-Green (CG) unit cells. Each matching section has nine quadrupole and four sextupole families, which are independent of those for normal CG unit cells. It is important to consider a betatron phase advance in the matching section. If the betatron phase

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advance in the matching section is equal to $2\pi n$, where n is an integer, and there is no sextupole field in this section, circulating electrons do not feel any perturbations in this section. This means the matching section becomes transparent [3] for circulating electrons. In the case where the rest of the ring is unchanged, symmetry of the optics is recovered for on-momentum electrons and the Phase-II lattice with four LSS's becomes effectively equivalent to the Phase-I lattice. Figure 1 shows typical optical functions for Phase-I and Phase-II lattice.

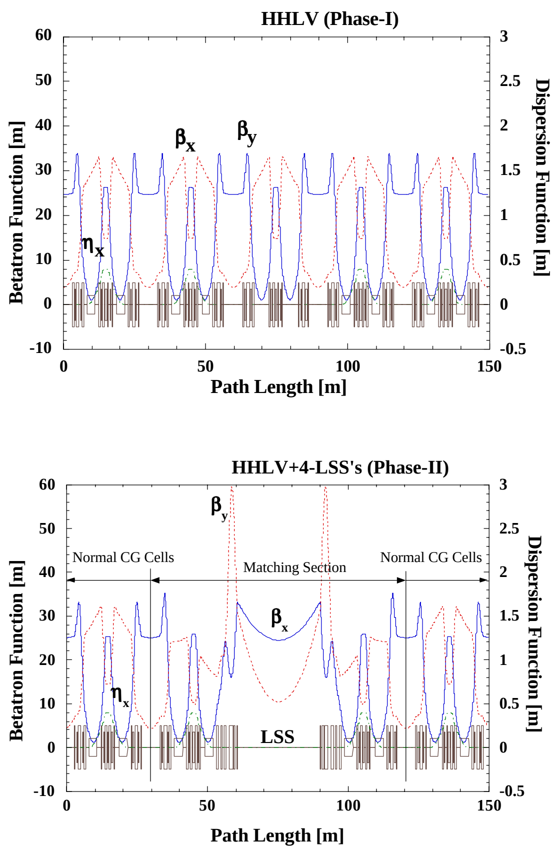

Figure 1: Phase-I and Phase-II optics.

The beam commissioning of the Phase-II lattice was successfully accomplished for about three weeks. The beam commissioning was started from August 28 and within the first day stored beam current of 0.22 mA was achieved by on-axis injection. Via the scheduled machine tuning (i.e., COD correction, chromaticity adjustment and so on) the stored beam current of 100 mA was achieved September 3. It takes only one week to reach to this condition. Since the beginning of October, user service operation was started on schedule. In general, beam performance of Phase-II lattice is almost the same as that in the Phase-I lattice. Horizontal and vertical emittance are estimated respectively ~6.3 nm·rad and ~14 pm·rad. Although momentum acceptance strongly depends on the chromaticity condition, the momentum acceptance of 2.1 % is kept in user service operation with +7 horizontal and +6 vertical chromaticities. One day orbit stability is ~10 µm and the same as the previous one. The over-all beam performances are listed in Table 1. The details of the beam commissioning and achieved performance of LSS's will be presented in ref.[4].

Table 1. Performance of the SPring-8 Storage Ring

	Phase-I (HHLV)	Phase-II (HHLV+4-LSS's)
Energy [GeV]	8GeV	8GeV
Circumference [m]	1436	1436
Number of bucket	2436	2436
Revolution time [µs]	4.79	4.79
Symmetry	48	4
(β_x / β_y) at ID section [m]	25/4	(24.4/5.8)/(23.4/14.4)
Current [mA]		
single bunch	16	13
multi bunch	100	100
Bunch length (FWHM) [ps]	36 [$1,$3] (32 [$2,$3])	32 [$2,$3]
Horizontal emittance [nm.rad]	6.0 [$4]	6.3 [$4]/7.3 [$5]
Vertical emittance [pm.rad]	5.5 [$6]	14.2 [$5]
Coupling [%]	≤0.09	~0.2
Tunes (ν_x / ν_y)	43.16/21.36	40.15/18.35
Operation chromaticities(ξ_x / ξ_y)	7.0 / 4.0	7.0/6.0
Momentum acceptance [%]	1.9 [$1] (2.9 [$2])	2.1 [$2]
Energy spread ($\Delta E/E$)	0.0011	0.0011
Lifetime		
100mA (multi bunch)	~140 [$2]	~110 [$2]
1mA (single bunch)	~11 [$1] (25 [$2])	~22 [$2]
COD [mm]		
horizontal (rms)	<0.1	<0.1
vertical (rms)	<0.1	<0.1
Residual dispersion at non-dispersive section [mm]		
horizontal (rms)	7.0	4.4
vertical (rms)	4.5 (1.1 [$7])	1.3 [$7]
Orbit stability (tune harmonics) [µm]		
horizontal (rms)	0.7	1.3
vertical (rms)	0.35	0.35

[$1] Vrf=12MV [$2] Vrf=16MV [$3] measured by streak camera
[$4] estimated with the beam size measured by a pulsed bump and scraper[5]
[$5] estimated with the beam size measured by two dimensional interferometer[6]
[$6] estimated by Touschek lifetime and systematic change of vertical dispersion[7]
[$7] with correction by 24 skew-Q's[8]

2.2 Unmatched Optics

As already mentioned the betatron phase advance in the matching section takes a value of $2\pi n$. In this "matched optics" sextupole magnets are weakly excited in the matching section so that they can be regarded as perturbation. The dynamic aperture of the matched optics is easily enlarged for on-momentum electrons but the aperture for off-momentum electrons tends to be small as their momentum deviation becomes large. This is due to their betatron phase jump in the matching section. Such a phase jump for off-momentum electrons can be made smaller by fully correcting local chromaticities with sextupole magnets in the dispersive (arc) section at both end of the matching section. In this optics the betatron function in the arc of the matching section takes the same value as other unit CG cells and the betatron phase advance in this section is no longer $2\pi n$. For this "unmatched optics" the dynamic aperture cannot be enlarged easily even for on-momentum electrons but the off-momentum behavior is improved, as expected, and the aperture for off-momentum electrons tends to be relatively large. This unmatched optics was still another candidate for beam operation and its off-momentum behavior had been checked by computer simulations and compared with the matched optics before starting the beam commissioning with LSS's.

During the course of the beam commissioning we then tried the unmatched optics in order to enlarge the momentum acceptance further. The working point of the unmatched optics was chosen by considering design values of natural emittance and the density of systematic resonance lines which come from superperiodicity of 4 on the tune map: the integer part of the horizontal and vertical betatron tunes was chose to be 40 and 19, respectively.

Through the beam commissioning of these two kinds of optics the following points were clarified: (i) from a point of view of resonance excitation the matched optics has an advantage over the unmatched optics: in the unmatched optics the stored beam was lost on every integer and half-integer resonance lines, but in the matched optics we could operate on some integer and half integer resonance lines without any corrections of resonance excitation. (ii) the momentum acceptance was almost similar and an expected larger acceptance for the unmatched optics could not be observed. From these results we selected the matched optics for user service operation: the matched optics approximately has higher symmetry than the unmatched optics around the nominal beam energy and shows good stability.

2.3 Beam Lifetime

A set of new vacuum chambers for LSS's was installed. Beam lifetime was still growing due to the beam self-cleaning effects for newly installed photon absorber in new vacuum chambers. At present, the beam lifetime is beyond 110 hours in multi-bunch mode of 100 mA current in user service operation.

Figure 2 shows the relationships of the products of the beam current (I) and the beam lifetime (τ) versus the integrated beam dose. The curve of the pressure rise per mA of the electron-beam current ($\Delta P/I$) at a new vacuum chamber region is also shown in Fig.2. The integrated beam dose has been added from restart of the storage ring operation after the installation of LSS's. The $\Delta P/I$ decreased by about three orders of magnitude after an accumulated beam dose of 50 Ah. It shows the beam self-cleaning effect on the vacuum chamber. From this figure, in the stage of beam commissioning with LSS's, $\Delta P/I$ decreases steadily with the slope of -0.67 ~ -0.74. For AB4 of the photon absorber, $\Delta P/I = 2.39\times10^{-5} D^{-0.74}$, where D is the integrated beam dose. The slope of this case is steeper than that in case of the first commissioning of four years ago[9].

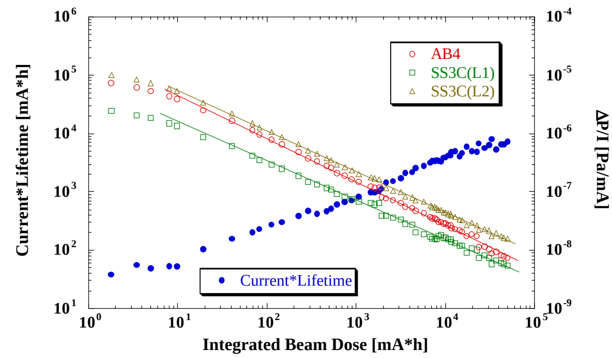

Figure 2: $I\tau$ and $\Delta P/I$ versus the integrated beam dose.

Before installation of LSS's Touschek lifetime is about 25 hours (Vrf=16MV) at the single bunch operation (1mA/bunch) of the nominal machine parameter of the SPring-8 storage ring. After the installation of LSS's Touschek lifetime is about 22 hours. As the total lifetime in the multi-bunch mode is 110 hours at the beam current of 100mA, a gas scattering lifetime is estimated τ_g=155 hours.

3 REFERENCES

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