Beam Performance

Since the beam commissioning of the storage ring in March 1997, machine performance has been intensively evaluated, and the beam performance achieved up to now is shown in Table I together with the storage ring specifications. It became clear that the storage ring provided a much higher performance than that we had expected in the design phase.

Table I : Performance of the SPring-8 Storage Ring

	Designed	Achieved
Cell type	Chasman-Green	
Number of cells (normal / straight)	44 / 4	
Circumference	1435.948 m	
Energy	8 GeV	
Stored current multi / single	100 mA / 5 mA	100 mA / 12 mA
Tunes (ν_x,ν_y)	51.22 / 16.16	51.16 / 16.31
Chromaticities (ξ_x,ξ_y)	0 / 0	3.21 / 3.93
Emittance	7 nm·rad	6.8±0.5 nm·rad
Coupling ratio	$\leq$ 10%	$\leq$ 0.06%
Bunch length	35 psec	36 - 40 psec
Energy spread ($\Delta E/E$)	0.0011	0.0012
Lifetime		
100 mA (full fill)	24 hr	60 hr
1 mA (single bunch)		6 hr
Impurity		$< 10^{-6}$
COD		
horizontal (rms)		$\leq$ 0.1 mm
vertical (rms)		$\leq$ 0.1mm
Residual dispersion at non-dispersive section		
horizontal (rms)	0	1.4 cm
vertical (rms)	0	0.4 cm

Beam Lifetime

In the 2/3 filling mode, total beam lifetime is about 70 hours at 70 mA. This lifetime is determined not only by the dynamic vacuum pressure but also by the Touschek effect, even in multi-bunch mode. In the case of 2/3 filling mode (0.043 mA/bunch), gas scattering lifetime and Touschek lifetime are 140 hours and 120 hours, respectively.

In the full filling mode, beam lifetime is about 60 hours at 100 mA, which is significantly longer than that of the partial filling mode at the same intensity. It seems that the electron beam size grows as a result of an instability due to an ion-trapping effect.

In single-bunch mode, lifetime decreases rapidly with the bunch current as shown in Figure 1. Lifetime at 1 mA/bunch is about 6 hours, and that at the design value of 5 mA/bunch is shorter than 2 hours. The dependence of lifetime on bunch current is mainly attributed to the Touschek effect.

Bunch Length

In the SPring-8 storage ring, the bunch length measured by a streak camera increases rapidly with bunch current as shown in Figure 1. At a bunch current of 12 mA, the bunch length becomes 2.5 times longer than that at the low current. This increase in bunch length is consistent with the simulation results for bunch lengthening due to the inductive impedance of vacuum elements.

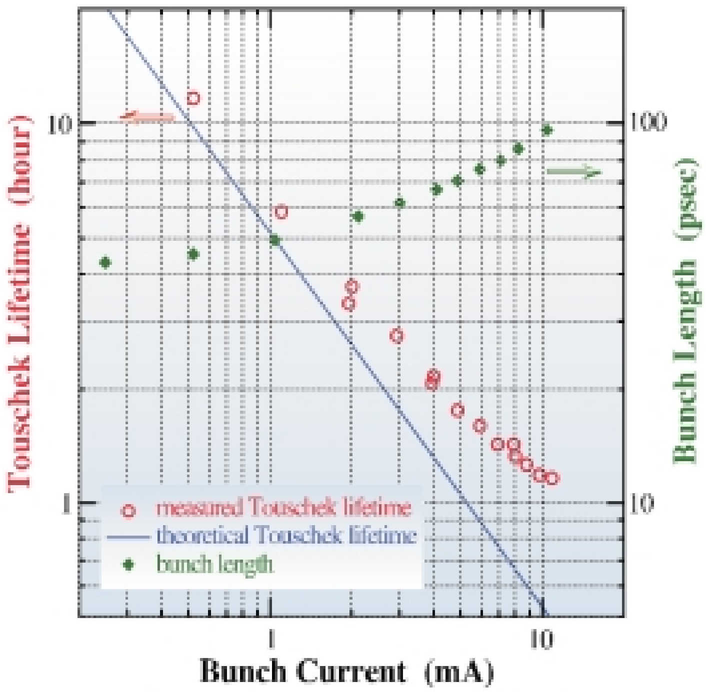

Figure 1: Beam lifetime and bunch lengthening as a function of bunch current.

Emittance

The horizontal emittance was estimated from the horizontal beam size and a beta function at the position of the size measurement. The horizontal beam size was measured from the relation between the electron loss rate and the amplitude of injection bump orbit with a half-sine shape of 8 msec width, assuming a transverse distribution of electron beam as Gauss distribution. The measured horizontal emittance was 6.8–0.5 nm·rad.

The vertical emittance depends on the coupling between the horizontal and vertical betatron oscillations. The coupling ratio of the SPring-8 storage ring is extremely low without the use of skew correction due to good magnet alignment and appropriate COD correction. The coupling ratio was estimated from the following four measurements:

1. <u>Coupling measurement from mode frequencies</u>

The operation point (ν_x,ν_y) of the SPring-8 storage ring is (51.16, 16.32). The betatron coupling is mainly induced by the resonance difference of ν_x-ν_y=35. The width on the resonance difference in single resonance approximation is estimated from the relation (Figure 2) between the unperturbed tunes and the measured ones neighboring the resonance. The coupling ratio, calculated by using the measured width (of less than 0.005) and the distance from the resonance difference, is about 0.06% at the normal operation point (ν_x=51.16, ν_y=16.32).

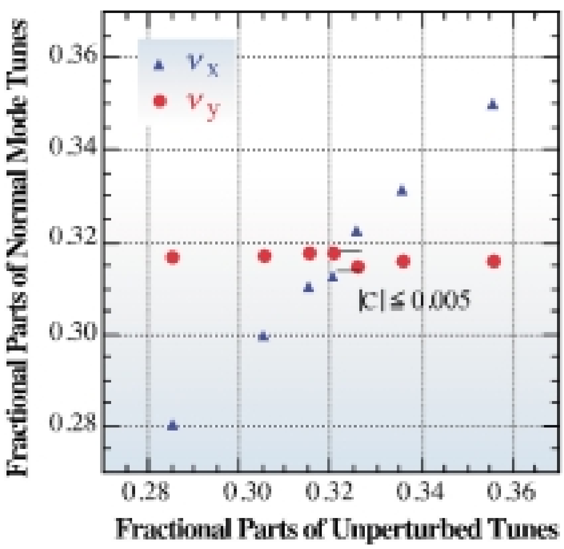

Figure 2: Tune separation for resonance difference; the resonance width (|C|) is about 0.005.

2. <u>Coupling Measurement from Coherent Oscillations</u>

The coupling ratio (κ) can also be directly measured from the form of the coupled oscillation following a dipole kick in the horizontal direction. The coupled oscillations (Figure 3) were measured turn-by-turn with beam position monitors (BPM) for five coupling ratios estimated from the measurement of the frequency mode together with the beam lifetime. At the normal operation point corresponding to κ=0.06% (upper most graph), the coupled oscillation in the vertical direction cannot be observed by BPM within a resolution of a few μm. From these data, the coupling ratio was recalculated from the ratio of the minimum to the maximum horizontal oscillation and the beat period of the oscillations. The coupling ratios obtained by these two different measurements were consistent within a few tenths of a percent.

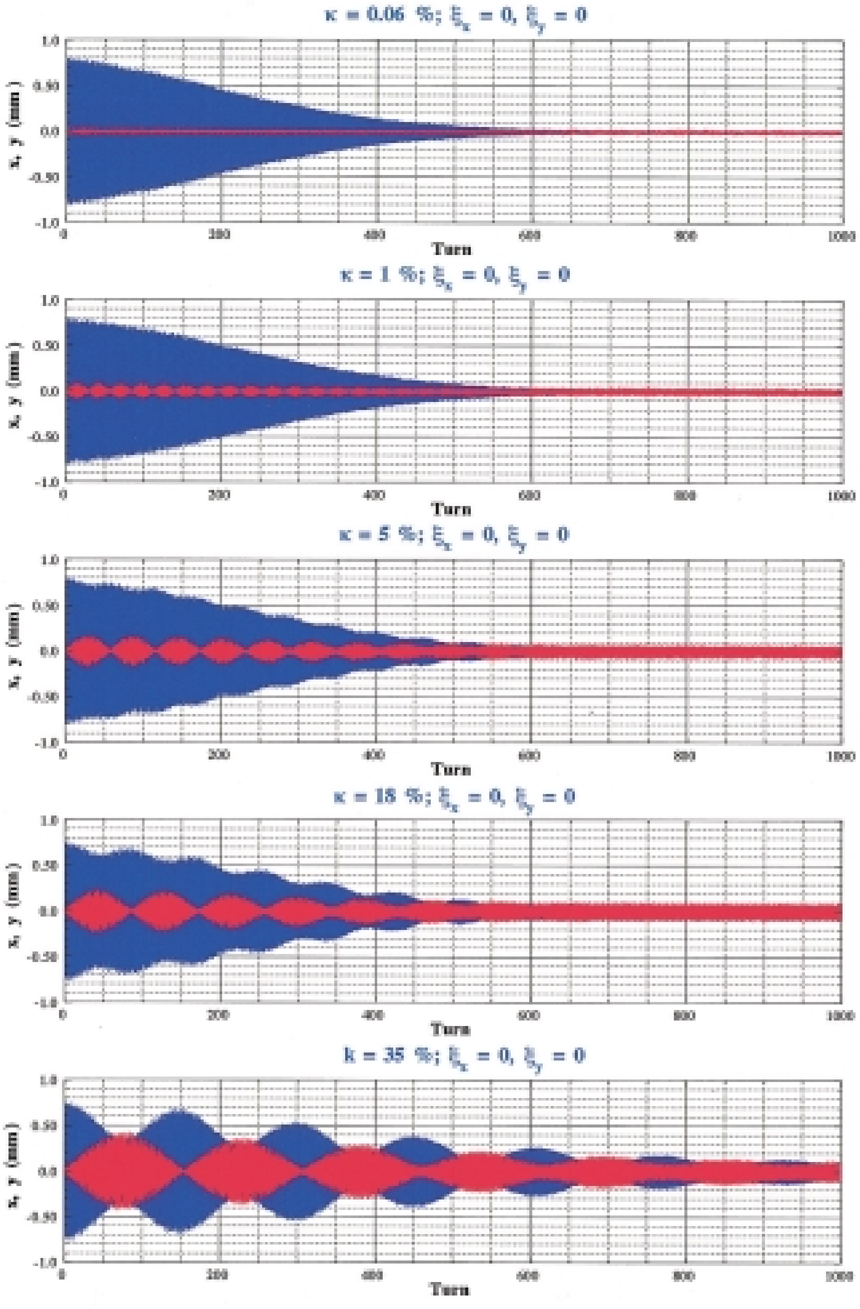

Figure 3: Horizontal (blue) and vertical (red) coherent oscillations measured after a horizontal kick.

3. Coupling Dependence of Touscheck Lifetime

The Touscheck lifetime has a high sensitivity to the coupling ratio in the single-bunch mode of the SPring-8 storage ring. The measured lifetime as a function of the coupling ratio estimated from the measurement of the mode frequencies at the single-bunch mode of 1 mA/bunch is shown in Figure 4. The 0th order dependence of Touscheck lifetime (τ_T) on coupling ratio (κ) is given by the following equation.

$$\tau_T = c \times \sigma_x \times \sigma_y \times \sigma_\ell = A \times \sigma_\ell \times \sqrt{\kappa/(1+\kappa)} ,$$

where σ_x is the bunch width, σ_y the bunch height and σ_ℓ the bunch length. Only the constant of A was calibrated by using the relation between lifetime and coupling ratio obtained by the four measurements of the coherent oscillation. The theoretical lifetime obtained as a function of coupling ratio is a solid line in this figure. The agreement between the theoretical line and the measured data is very good. From the lifetime of about 3 hours measured at the operation point of (51.11, 16.32), the minimum coupling ratio is estimated to be around 0.04%.

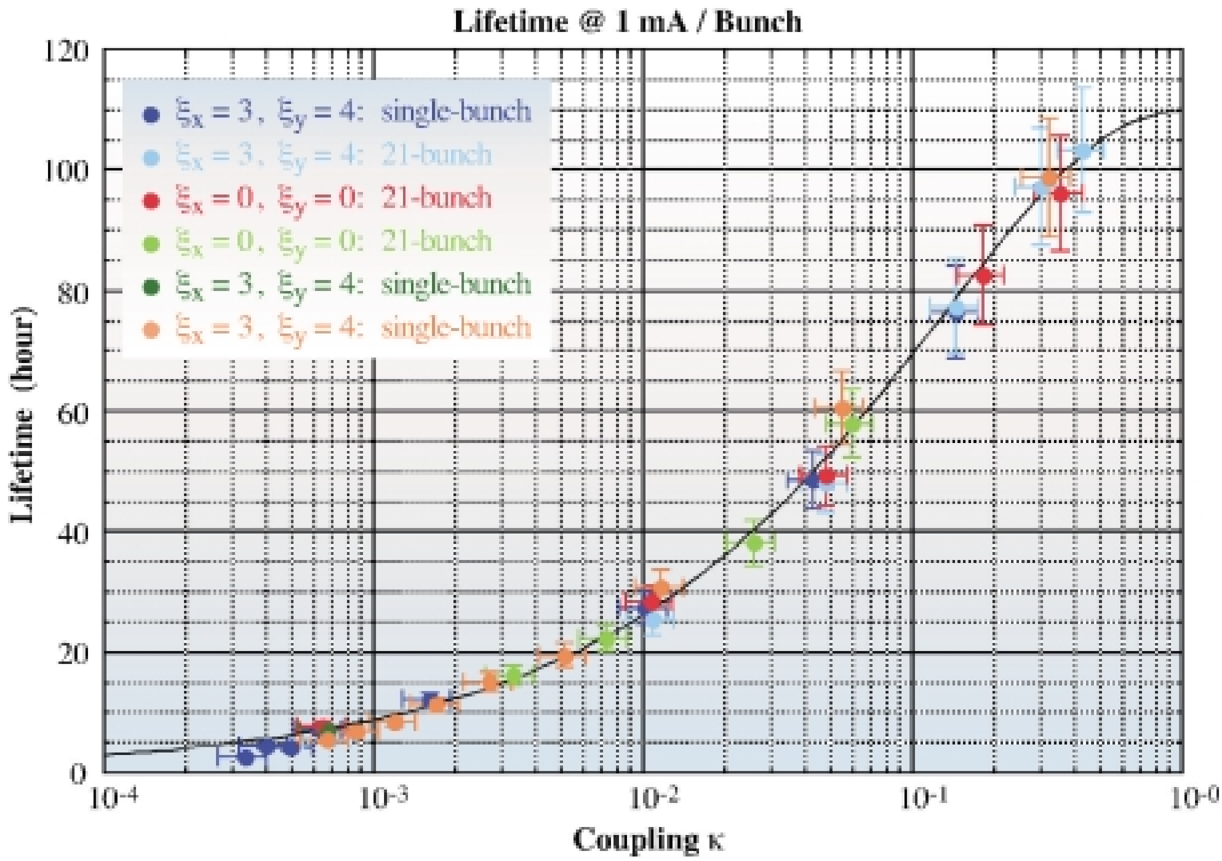

Figure 4: Beam lifetime as a function of betatron coupling (κ); solid line shows the theoretical Touschek lifetime.

4. Measurement of Visibility by Interferometer

The visibilities of visible light from a bending magnet and an X-ray from an ID taken by an interferometer directly give the vertical electron beam size. These visibility measurements are now underway. As a preliminary result for visible light, a beam size corresponding to the coupling ratio of 0.2% as an upper limit has been obtained under normal operation (51.16, 16.32).

Orbit Stability

In the third generation synchrotron radiation source, stability of the electron beam orbit is one of the most important performance requirements for achieving a highly brilliant photon beam. In the construction design of the SPring-8 storage ring, the effect of perturbation sources inducing orbit movement was minimized. Consequently, an orbit stability of less than 70 μm was achieved in the horizontal and vertical planes without any feedback control. The digital feedback system was developed to further stabilize the electron orbit. The system corrects only the COD components corresponding to the betatron tune harmonics and those of its satellite in the horizontal and vertical directions and a beam energy at intervals of 1 min. The results are shown in Figure 5. The obtained beam stability is 0.8 μm (in rms) for the 51st betatron tune harmonic in the horizontal COD and 0.5 μm (in rms) for the 16th harmonic in the vertical COD. Also, the circumference change corresponding to the 0th harmonic in the horizontal COD was corrected within 0.3 μm (in rms) by adjusting the RF frequency. The system is now routinely employed in the user service mode operation.

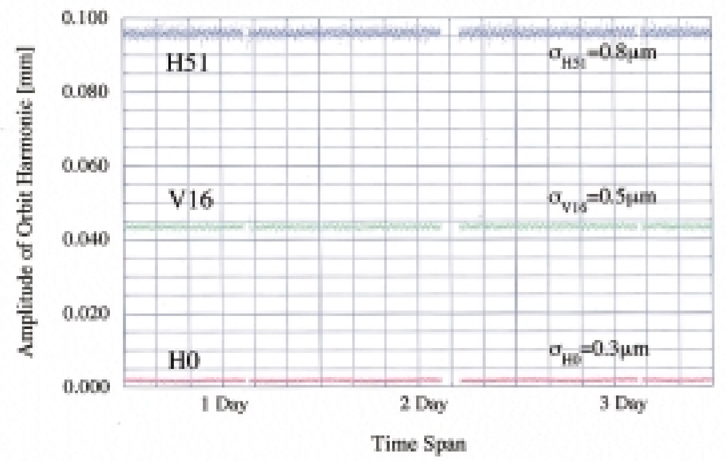

Figure 5: Amplitude changes of tune harmonics (51st for horizontal (blue) and 16th for vertical (green)) and 0th harmonic (circumference change (red)) in COD for three days with periodic correction of global orbit.

Brilliance

In the SPring-8 storage ring, the brilliance of the photon beam is achieved to nearly the diffraction limit in the vertical plane due to an extremely low coupling ratio. In Figure 6, the relative brilliance, normalized by the value of the vertical limit, is plotted for three different vertical betafunctions at the ID section as a function of the wavelength. The relative brilliance at the wavelength of 1 Å is about 0.3 at the present operation of β_y=8 m. This value is almost the diffraction limit for the user because the photon beam size at a user position of more than 30 m away from the source point is not determined by the vertical emittance of the electron beam and the vertical beta function at the ID position but mainly by the angular divergence of the photon beam. Therefore, we now have no plans for the optimization of β_y in the ID section to improve brilliance.

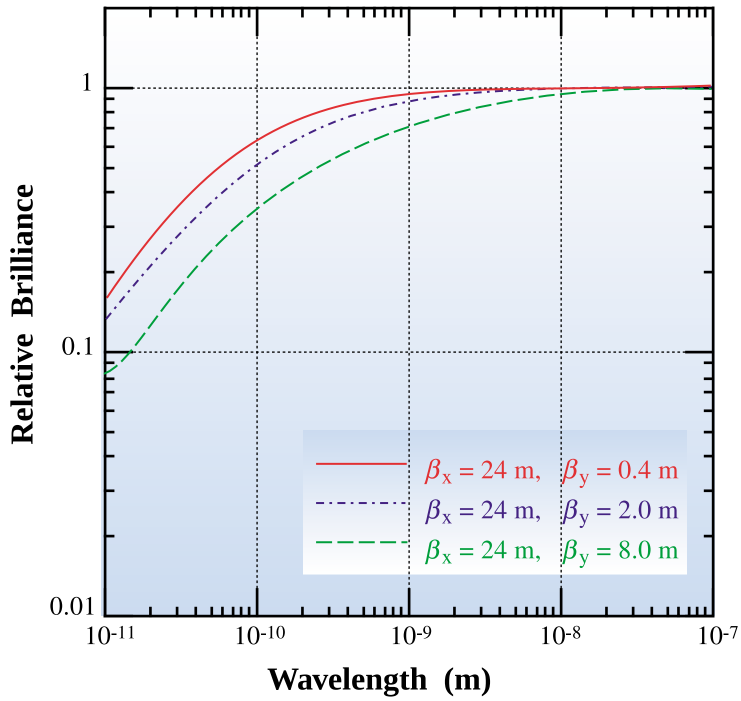

Figure 6: Relative brilliance as a function of wavelength for three different β_y at ID section: β_y = 8.0 m in normal operation and β_y = 0.4 m with optimization of brilliance to maximum value.

Plans for Next Year

We are scheduling:

- the installation of a top-up operation mode to effectively improve lifetime,
- the development of new-type injection magnets to achieve an injection orbit error of less than 0.1mm in top-up operation,
- the correction of fast orbit movement with a frequency of more than 0.1 Hz,
- the correction of the coupling ratio and residual vertical dispersion by skew quadrupole magnets, and
- the construction of a long straight section of 30 m, with beam commissioning scheduled for the autumn of 2000.

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