BEAM-PERFORMANCE IMPROVEMENT OF THE SPring-8 STORAGE RING

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Abstract

The SPring-8 storage ring has improved its reliability and beam performance. At the beginning of year 2001, a project of beam orbit stabilization started aiming for the stability of sub-micron. By two years' activities, we have taken a remarkable progress on improvement of the orbit stability of the SPring-8 storage ring. Recently, optics of the ring was changed from the Double Bend Achromat type to new one with finite dispersion at the straight section for insertion devices. The horizontal emittance of 3 nm.rad was obtained which is close to the theoretical value. To increase time-averaged brilliance in several bunch operation, we have prepared a top-up operation in user time from September 2003. In this paper, the operational status and recent beam performance of the SPring-8 storage ring are presented.

OPERATION IN 2002

Operation Statistics

In 2002, the SPring-8 storage ring was operated on four- or five-week period for one operation-cycle. The total operation time of accelerator complex was 5542.9 hours. 70.3% (3896.7 hours) of the operation time was available to the users and 1.1% (60.8 hours) was injection time. 3.4% (190.5 hours) of the operation time was the down time due to failure. There was a major failure at June 2002 leading to a great deal of lost user time. Cooling water leak to vacuum vessel of in-vacuum undulator occurred, and the in-vacuum undulator was removed from the storage ring. And then, a dummy vacuum chamber was re-installed. As a result, user time of 134.5 hours was cancelled. The remaining 25.2% was dedicated for: (i) the machine and beamline study, (ii) the machine and beamline tuning, (iii) the commissioning of new photon beamlines.

Filling Modes

Three different filling modes were delivered to the user time; 35.0% in the multi-bunch mode operation, 47.2 in the several bunch mode such as 203-bunch mode (203 equally spaced bunches), 84 equally spaced 4-bunch trains, and the remaining 17.8% in the hybrid filling mode such as a 2/11-partially filled multi-bunch with 18-isolated bunches. For the hybrid filling mode, 1 or 1.5 mA is stored in each isolated bunch. A purity of isolated bunch better than 10^{-9} is routinely being obtained.

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NEW OPTICS

We tried to reduce the emittance by breaking the achromatic condition imposed to Chasman Green cells[1][2][3]. This method is effective for the case where undulators with a moderate field are used as main insertion devices (IDs). The SPring-8 storage ring just meets this condition [4] and the calculation shows that about 20 % extra reduction is also obtained by closing gaps of all IDs to the minimum even after breaking the achromatic condition. In the summer shutdown, to realize the new optics we modified cabling of the quadrupoles in the dispersive arc to change the strengths of the quadrupoles keeping the phase matching condition over each long straight section. Since September 2002 we started the machine tuning of this new optics with the distributed dispersion. Figure 1 shows the new optical function. As a result, from the last operation-cycle of November 2002 this new optics was released to user operation. The achieved emittance is about 2.8nm·rad with all ID gaps closed. This agrees well with the predicted value. The major beam parameters of the SPring-8 storage ring before and after introducing the new optics are listed in Table 1.

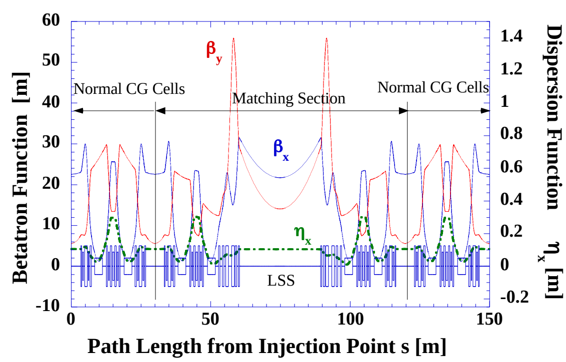

Figure 1: Optical function for new optics.

ORBIT STABILITY

A project of beam orbit stabilization has been started from February 2001. The first year was just for the survey of fluctuation sources and in the second year 2002 the suppression of the vibration sources was carried out as follows. (1) By observing the correlation between the vacuum chamber vibration and the beam fluctuation, the broad peak around 30Hz in the vertical beam spectrum is caused by the vibration of upstream chamber in a unit cell. When the vacuum chamber vibrates in quadrupole magnetic field, eddy currents are induced on the vacuum chamber wall, which generate electro-magnetic fields and result in shaking the electron beam[5]. On the basis of measured data, we have done some improvements to reduce the chamber vibration. By this counter measures, the vertical beam fluctuations around 30Hz were reduced by one order in amplitude as shown in Fig.2. This improvement is also effective to suppress the horizontal beam fluctuations from 50 to 100 Hz and the amplitude in this frequency range was reduced by factor 3.

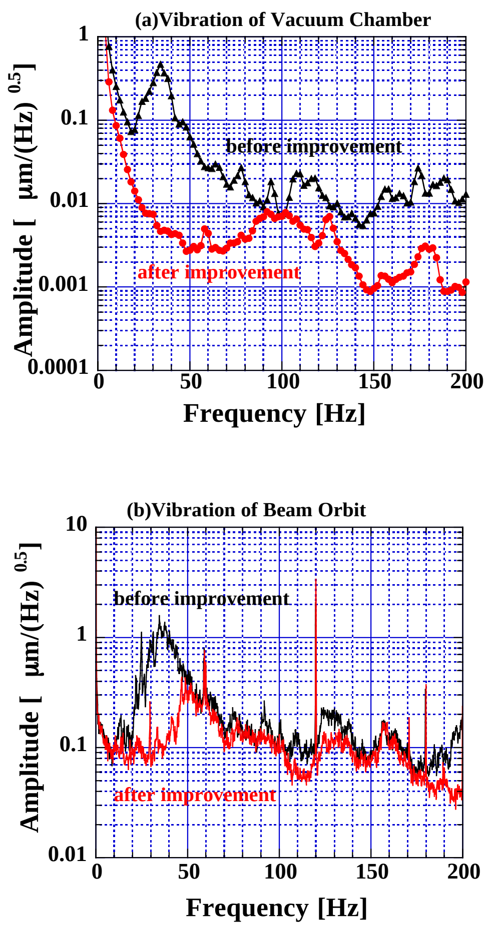

Figure 2: Vertical vibration of vacuum chamber and stored electron beam before and after improvements[6].

(2) To suppress the slow orbit drift, we increased the number of air-core type steering magnets with high resolution and low hysteresis from twelve to twenty-four in the summer shutdown of 2002. This increases the degree of freedom for the correction phase. In principle, this is effective to reduce the slow drift. To avoid the mixing between the circumference change and orbit distortion due to the increment in the steering number, we adopted the algorithm to subtract the contribution of the energy shift from the measured orbit. By using the new periodic correction system, horizontal and vertical orbit deviations were reduced by a factor two, down to about 5 mm in rms for one-day operation.

Table 1: Parameters of SPring-8 storage ring.

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		Old Optics	New Optics
Tunes (ν_x / ν_y)		40.15/18.35	40.15/18.35
Current[mA]:	single bunch	13	10
	multi bunch	100(120[$1])	100
Bunch length (FWHM)[psec]		32	34
Horizontal emittance[nm·rad]		6.3[$2]/6.6[$3]	3.1[$2]
Vertical emittance[pm·rad]		16.9[$3]	3.9[$4]/8.7[$3]
Coupling[%]		0.26[$3]	0.13[$4]/0.28[$3]
Operation chromaticities	(ξ_x / ξ_y)	+7/+6	+8/+8
Momentum acceptance[%]		2.6	2.1
Energy spread ($\Delta E/E$)		0.0011	0.0011
Lifetime[hr]:			
100mA (multi bunch)		~150[$5]	~97[$5]
1mA (single bunch)		~24	~9
Dispersion distortion[mm]:			
horizontal (rms)		4	9.3
vertical (rms)		1.1[$6]	1.1[$6]

Note: Lifetime before and after introducing the new optics can not be compared because of differences in operation chromaticityes.

[$1] maximum stored beam current at machine study

[$2] estimated with the beam size measured by a pulse bump and scraper[7]

[$3] estimated with the beam size measured by two dimensional interferometer[8]

[$4] estimated with the beam size measured by two photon correlation[9]

[$5] (12-1)*160 pulse train [normal beam-filling pattern for multi-bunch operation], Vrf=16MV, typical value at user time operation

[$6] with correction by 24 skew Q's

TOP-UP OPERATION

Since 1999 we have been investigating the realization of "top-up operation" in the SPring-8 storage ring. In the year 2002, we set a target to introduce top-up operation to user time from September 2003. To meet this time schedule, we are rushing to upgrade a machine control, beam monitors, and an interlock system for radiation safety, and to design and manufacture the new injection bump magnets and their power supplies.

There are two major problems as follows; (1)Demagnetization of undulator magnets due to frequent beam injections: This phenomenon is occurred by the loss of injected beams at a narrow vertical aperture of an in-vacuum undulator. In consideration with both the experimental and simulation results, we have designed the collimator system to cut the horizontal beam tail. This system will be installed in the beam transport-line from the booster synchrotron to storage ring. (2)Excitation of betatron oscillation of stored beam by beam injections: An off-axis beam injection was adopted to store the high current by repeating beam injections. The bump orbit for the injection is generated by 4 pulse bump magnets. The magnetic field pattern is a half-sine of which width is about 8 μs. As this bump orbit is not closed completely, the stored beam suffers error kicks in passing through 4 bump magnets and then the betatron oscillation is excited. We found that the oscillation was mainly excited by following two effects; (a) One is the effect of nonlinearlity due to sextupoles within the bump orbit. We think that error kicks due to this effect can be compensated by one or two correction pulse magnets. (b) The other is cause by the existence of two types of bump magnet. These two have the different patterns of eddy current, which change the shape of the field overshoot. We think this comes from the eddy currents at the end plates of each magnet. To solve the problem, we have designed new magnets having end plates made by insulating material to reduce an eddy current effect.

LOW ENERGY OPERATION

In general, the emittance of stored beam is proportional to the square of its energy and can be reduced by lowering the beam energy. The bunch length is also reduced when we lower the energy. This reduction of emittance and bunch length will open up a new opportunity of using brighter synchrotron radiation with shorter pulse lengths in SPring-8. For this aim, we performed the ramping down of beam energy from a design value of 8GeV and the beam injection at 4GeV. In the ramping down experiments, we first stored a low-current beam of 5mA in a multi-bunch mode and then lowered the energy, step by step, down to 4GeV. At each step of beam energy we measured beam parameters, such as a horizontal beam size, bunch length, synchrotron frequency, etc., and compared with expected values obtained from a single-particle picture as shown in Fig.3. We found no significant difference between measured and expected values. Beam instabilities were not observed in the above-mentioned current and a filling mode. We also performed a beam injection at 4GeV. To improve the efficiency of beam injection and hence increase the stored current, further studies are planned such as optimization of the strength of harmonic sextupole magnets and correction of optics distortion.

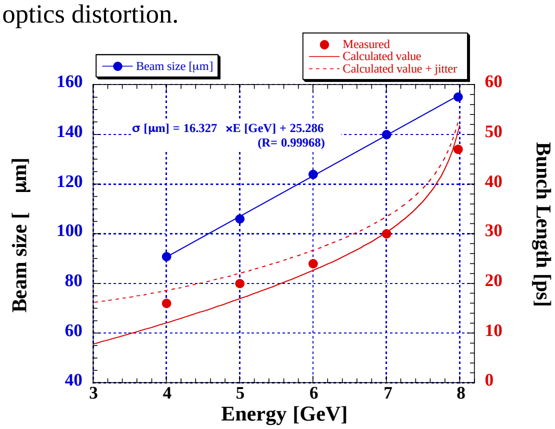

Figure 3: Horizontal beam size and bunch length as a function of beam energy.

ACCELERATOR DIAGNOSTICS BEAMLINES

The accelerator diagnostics beamline #1, which has a bending magnet light source, is in operation. The visible synchrotron light is used for longitudinal diagnostics of the stored electron beam, such as bunch length and single bunch impurity. Single bunch impurity is measured by a gated photon counting method that utilizes fast pockels cells for switching light pulses[10]. To improve the extinction ratio or isolation of the light shutter, the optical system was improved that two pockels cells are arranged in tandem. The sensitivity to satellite bunches of the order of 10^{-10} of the main bunch has been achieved.

A beam profile monitor based on a phase zone plate has been installed (Fig. 4)[11]. The synchrotron radiation from a dipole magnet source is imaged by a single-phase zone plate. Monochromatic X-ray is selected by a double crystal monochromator, which covers the energy range of 4 to 14 keV by Si (111) reflection. An X-ray zooming tube observes the X-ray image of the electron beam. Results from preliminary experiments show that the observed profile of the beam is affected by small bend in the monochromator Si crystals, which was predicted from extensive measurements of the rocking curves of the monochromator. The experiments will resume after improvement of the crystal holders of the monochromator.

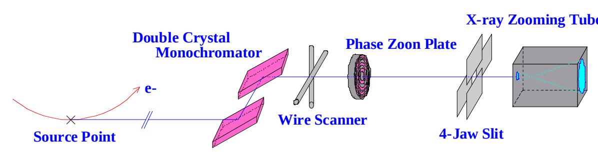

Figure 4: Optical system of X-ray imaging of the electron beam.

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