ACCELERATOR PHYSICS ISSUES AT THE POHANG LIGHT SOURCE

Eun-San Kim*
Pohang Accelerator Lab., POSTECH, Pohang, KyungBuk, 790-784 Korea

Abstract

Since PLS started operation with 2 GeV beam in the range of 100 mA in 1994, the operation of PLS has aimed to realize stable beam operation with higher beam currents and higher beam energy. Through improvements in operational beam modes and cure of the beam instabilities, beam availability in the ring was raised to about 95% and beam quality could be also improved. We present several issues of accelerator physics that have performed to achieve these improvements: such as operation beam modes, cure of beam instabilities, beam lifetimes, tune survey of dynamic aperture, estimation of the ring impedance, coupling constant and design of a low emittance lattice at the ring.

OPERATIONAL BEAM MODE

We have applied two methods to store the beams of 2.5 GeV: first method was to ramp the beam of 2 GeV in the ring to 2.5 GeV and second method was to perform full energy injection from the linac. We present these methods that have investigated for the 2.5 GeV beam operation.

Energy Ramping and De-ramping

During Jan. 2000 to April 2001, 2 GeV beam was injected from the linac to the ring and then the beam was ramped to 2.5 GeV. In order to re-fill the beam current at 2.0 GeV, the 2.5 GeV beam was dumped and degaussing was performed. In the ramping process current increment rates in bends and Q2 quadrupole power supplies were not constant. This was because the relationships of the magnet field strengths and MPS currents were not linear due to insufficient synchronization. It also showed large variations in betatron tunes during the ramping process and so both vertical and horizontal betatron tunes were merged at approximately 0.25 at the starting of ramping not to make cause beam losses due to third-order resonance. Energy ramping on resonance also caused significant changes in beam lifetime due to enlarged vertical beam sizes.

As the energy increment rates during the energy ramping could be constant due to the synchronization, 0.32% for bends and 0.30% for other magnets per step were utilized. During the ramping, the betatron tunes could be kept with the values at the starting of the ramping. The ramping system could also decrease the beam energy from 2.5 GeV to 2.0 GeV (de-ramping), at the same rate but in the reverse direction with the energy ramping. The variation of closed orbit distortion(COD) during the energy ramping could be reduced by a factor of 1.5. No beam loss was noted during the ramping which took 1.3 min, which was about four times faster.

2.5 GeV Full energy injection

The 2.5 GeV full energy injection from the linac to the ring was performed since Oct. 2002. The injection system in the ring consists of a Lambertson-type septum magnet and four injection kicker magnets. When we performed the full energy injection, leakage field of the septum magnet was increased and rms value of the vertical COD was increased about five times. Orbit correction to reduce the orbit deviations due to the leakage field was performed. The current in the kicker magnets was 22500 A for 2.5 GeV, while it was 19500A for 2 GeV. On the other hand, when we utilized a DC bump that was consisted of two bends and two correctors, 2.5 GeV beams could be injected by current of the kicker magnet of 19500A. The full energy injection has showed improvements in machine stability, shorter injection time and orbit stability.

BEAM INSTABILITIES AT 2 GEV

Stored beam currents in 2.0 GeV have been limited by coupled-bunch instabilities. It was found that the beam currents was mainly limited by 830.45 MHz transverse higher-order mode in RF cavities. It was shown that longitudinal coupled-bunch instabilities were caused by 758.66 MHz and 1300 MHz modes. Fig. 1 shows stored beam current of 450 mA at 2.0 GeV by suppressing of these coupled-bunch instabilities. Designed beam current of 400 mA at 2.0 GeV was at first stored in Nov. 2000.

Transverse coupled-bunch instability

When we analyzed beam signal of 830.45 MHz, we got the relation of $f_{\mu,n}$ = nB$f_r - (\mu f_r + f_{osci})$= 830.45 MHz with $n = 1$, $B = 400$ and $f_{osci} = 200.8kHz$. Here, B is the number of bunches, μ is the mode number of oscillation, n is integer and f_r is the revolution frequency. The relation indicates that the instability is associated with bunch oscillation of the frequency of 200.8 kHz, which agrees with frequency of vertical beam oscillation. It was observed that the vertical-coupled instability due to 830.45 MHz dropped the stored beam around 250 mA. Then, vacuum pressures inside rf cavities were also increased to above 100 nTorr. The betatron tune dependence of the instability was studied for a wider range. To shift the vertical mode, we selected the betatron tune of ν_x=14.27 and ν_y=8.23 through betatron tune survey, and

---

[*] eskim1@postech.ac.kr

the tune resulted in suppression of the beam instability due to the vertical mode.

Chromaticity was controlled to prevent transverse instabilities and it was shown that the amplitude of the transverse spectrum could be varied by magnitudes of currents in the sextupoles. Fig. 2(a) shows side-band near horizontal tune when currents of SD and SF are 138 A and 90 A, respectively. Fig. 2(b) shows side-band near vertical tune when currents of SD and SF are set to 133 A and 94 A, respectively. The side-bands could be clearly suppressed when the currents of SF and SD are 138 A and 94 A, respectively. In result, by selecting an optimal betatron tune and chromaticity, we could suppress the transverse instabilities at 2.0 GeV.

Longitudinal-coupled bunch instability

When we analyzed the beam signal of 758.66 MHz, we got the relation of $f_{\mu,n}$ = 400 $f_r - (310 f_r + 11.7kHz)$= 758.66 MHz. The relation indicates that the instability is associated with the frequency of 11.7 kHz, which is synchrotron frequency. On the other hand, the instability due to the 1300 MHz mode did not lead to beam loss since the shunt impedance of the mode is small.

We observed longitudinal coupled-bunch instabilities around 360 mA due to the 758.66 MHz and 1300 MHz modes. The 1300 MHz mode disappeared as the stored beam current increased more. However, the longitudinal beam oscillation due to the 758.6 MHz mode enlarged beam size horizontally, and moreover, accompanied with beam size fluctuation and bunch-lengthening. When the fluctuation amplitude due to the 758.66 MHz mode was large, it was observed that the beam lifetime decreased. The instability due to the 758.66 MHz mode was suppressed by controlling the water temperatures of 4 rf cavities and it did not lead to beam loss up to 450 mA.

BEAM INSTABILITIES AT 2.5 GEV

During operation between Jan. 2000 and July 2000, the number of bunches was 468 that was equal to the harmonic number. Operated tune was 14.26 and 8.15 in horizontal and vertical, respectively. Then, we have observed resonant frequency of 831.8 MHz in beam spectrum due to the HOM in rf cavities.

Since Sep. 2000, we have changed the number of bunches and the betatron tune for the operation. The number of bunches was changed to 400 and operating tune was 14.28 and 8.18 in horizontal and vertical, respectively. At present we don't have observed any beam instabilities. At 2.5 GeV we can store the beam stably up to 200 mA. Beam current higher than 200 mA is limited by total rf power.

BEAM LIFETIME

Touschek lifetime dominates beam lifetime in the storage ring. Figure 3 shows the beam lifetimes as a function of the beam current for 2.5-GeV normal operation, which includes 400 bunches. Line shows the beam lifetimes versus the beam current during 12 hours for an initial beam current of 180 mA. Circles show the simulated beam lifetimes that are obtained from the tracking of beam-residual gas bremsstrahlung, beam-residual gas scattering and intra-beam scattering. By a simulation method, we obtained a beam lifetime of around 18.9 hours for a beam current of 180 mA under of a vacuum pressure of 0.6 $\times 10^{-9}$ Torr.

TUNE SURVEY OF DYNAMIC APERTURE

The dynamic apertures have been investigated by a simulation method using the code Strategic Accelerator Design. The dynamic apertures in the lattice without and with machine errors were obtained by a tune survey in the simulation. Errors of magnetic field of 0.05% rms, alignment of 80μm rms, rotation of 0.15% rms, length of 100μm rms, kick of steering magnet of 0.01% rms and resolution of beam position monitor of 5μm rms were considered to be machine errors in the simulation. The operating tune for 2.5 GeV can be obtained on the view point of dynamic apertures obtained from a tune survey. Fig. 4(a) shows the dynamic apertures obtained from the tune survey when the machine errors are not included in the lattice. Fig. 4(b) shows the dynamic apertures obtained from the tune survey when the machine errors are included in the lattice.

ESTIMATION OF IMPEDANCE FROM BUNCH-LENGTHENING

Characteristics of the bunch-lengthening were investigated to estimate impedances of the ring. The impedances of the ring were estimated by fitting the solutions of the Haïssinski equation and the measured bunch-lengthening. The ring impedances estimated by a series R+L impedance model indicated an inductance of L=13.7nH $\pm$ 3.5nH and a resistance of R=743 $\Omega \pm 84\Omega$. The bunch lengthening for a series R+L impedance model showed a good agreement within 7% with the results of the bunch lengthening measurements. The threshold beam current was estimated to be 7.4 mA. The scaling law for the bunch-lengthening above microwave instability threshold is obtained as $\sigma_z = 0.437 I^{1/3.35}$ where I is beam current and the total longitudinal impedance was estimated to be 0.24Ω.

DESIGN OF A LOW EMITTANCE LATTICE AT 2.5 GEV

A low-emittance lattice of 10.3 nm was designed to achieve smaller beam emittance that might provide more brilliant synchrotron radiation. Fig. 5 shows an optics of the low-emittance of 10.3 nm. It is necessary to estimate how sufficient dynamic aperture for beam injection and storage into the ring can be obtained in the low-emittance lattice. Through scanning of the betatron tunes within a specified tune space, we got a betatron tune of ν_x=17.64 and ν_y=11.6 that showed a sufficient dynamic aperture.

RF PHASE MODULATION

Rf phase modulation near twice the synchrotron frequency has been experimentally investigated to increase the bunch length and the beam lifetime. This made the average bunch length long and resulted in the long Touschek lifetime. We observed that the beam lifetime could be increased from 28 h to 45 h in the beam current of 140 mA at 2.5 GeV by modulating the phase to 18.6 kHz. At the same time, we also observed that the longitudinal coupled-bunch instabilities due to rf HOMs could be suppressed.

COUPLING CORRECTION

Coupling constant was estimated by measuring tunes close to the coupling resonance. The minimum separation of the tunes was obtained by measuring of the horizontal and vertical tune variations as a function of quadrupole power supply current. The coupling constant was shown to be 0.8 % on normal operation. When four skew quadrupoles were excited, minimum achievable coupling constant in the ring was 0.15 % at 2.5 GeV.

CONCLUSIONS

The main accelerator physics issues in the PLS during the last several years are described. We have solved some challengable issues at PLS and as a result, the accelerator and beam performance were improved and more reliable than years before. To obtain low emittance beam and small v ow on.

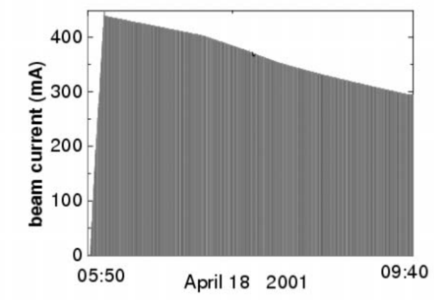
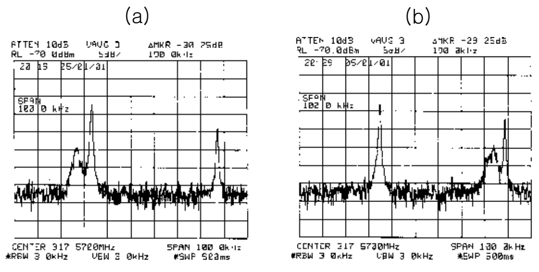


Figure 1: Stored beam current of 450 mA at 2.0 GeV.


(a)

(b)

Figure 2: Beam spectra that show batatron tunes and sidebands in 273 mA of 2.0 GeV. (SD,SF)=(138 A,90 A) in (a). (SD,SF)=(133 A,94 A) in (b).

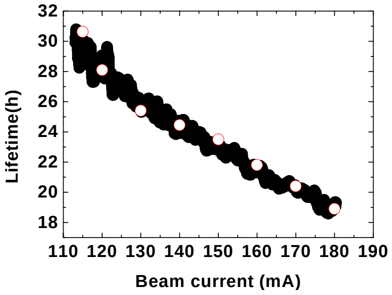


Figure 3: Black line and circles show the beam lifetimes on operation and simulation at 2.5 GeV, respectively.

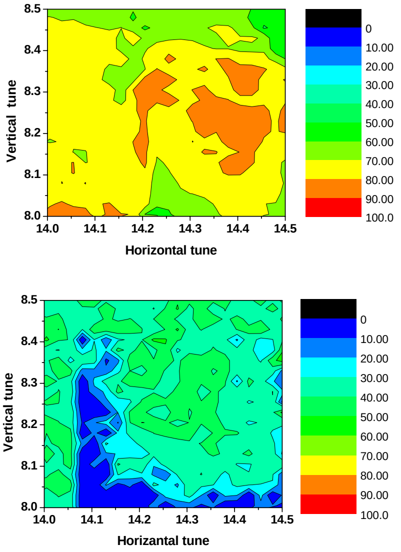


Figure 4: Dynamic apertures for a tune survey. Without machine errors (top) and with machine errors (bottom).

REFERENCES

[1] Design Report of Pohang Light Source, January (1992).

[2] E.-S. Kim at el, PAC 2003, Portland, May (2003) p. 3114.

[3] E.-S. Kim, PAC 2001, Chicago, June (2001) p. 1945.

[4] E.-S. Kim at el, PAC 2001, Chicago, June (2001) p. 1948.

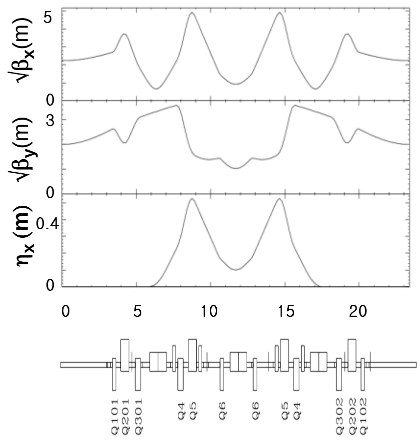


Figure 5: A low emittance lattice of 10.3 nm at 2.5 GeV.