LIMITATION OF BEAM CURRENT IN THE PLS STORAGE RING

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Abstract

We present investigations on beam instabilities that have been observed at 2.0 GeV and 2.5 GeV in the PLS storage ring. Stored beam currents of 2.0 GeV in the ring has been mainly limited by coupled-bunch instabilities. We have investigated dependences of the coupled-bunch instabilities on betatron tune, chromaticity and rf cavity temperatures at 2.0 GeV. 450 mA beam could be stored at 2.0 GeV. Bunch filling patterns and betatron tune are investigated to suppress the beam instabilities at 2.5 GeV. At 2.5 GeV, we do not observe any beam instabilities up to 200 mA. Higher beam currents than 200 mA are limited by total rf power.

1 INTRODUCTION

The PLS storage ring is a third generation synchrotron radiation source. It consists of a 2 GeV linac and a storage ring which can be accelerated by 2.0 GeV to 2.5 GeV. The storage ring has been operated at 2.0 GeV from 1995 to 1999 and at 2.5 GeV since 2000. The parameters of the storage ring are listed in Table 1.

It is a general requirement on the storage ring for a synchrotron radiation source that it provides a stable beam having a small emittance in order to obtain a high brilliance photon beam. It is apparent that the beam quality is strongly determined by beam instabilties in such a machine having a low emittance. Therefore, a study to cure beam instabilities is important to obtain a stable and small beam [1]. The designed value of the beam current in the PLS storage ring is 400 mA at 2.0 GeV. However, PLS storage ring has operated in less beam currents than 190 mA at an energy of 2.0 GeV which has been limited by the coupled-bunch instabilities. The machine study at the PLS has been focused to cure the beam instabilities and to store high beam current. In this paper, we present the activities to suppress the beam instabilities at 2.0 GeV and 2.5 GeV in the PLS storage ring during the last one year.

2 BEAM INSTABILITIES AND CURRENT LIMITATION AT 2.5 GEV

The storage ring has been operated at 170 mA of 2.5 GeV since January 2000. During the user operation between January 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 horizontally and vertically, respectively. We observed resonant frequency of 831.8 MHz in beam spectrum due to higher order mode (HOM) in rf cavities. Figure 1(a) shows the beam oscillation that is observed in streak camera. We see that the beam motions are unstable.

Since September 2000, we have changed the number of bunches and betatron tune for the user operation. The number of bunches is 400 and operating tune is 14.28 and 8.18 in horizontally and vertically, respectively. Figure 1(b) shows the beam oscillation that is observed in streak camera. We see that the beam motions become more stably. We don't observe resonant frequency in beam spectrum due to rf HOMs. Deformed beam shape were not observed in beam profile monitor. Vacuum value in the ring is 0.6 nTorr in the beam current of 170 mA in 400 bunches. At 2.5 GeV we can store the beam stably up to 200 mA. Higher beam current than 200 mA in present operation is limited by total rf power. The beam lifetime is about 26 hours in 170 mA.

3 BEAM INSTABILITIES AND CURRENT LIMITATION AT 2.0 GEV

3.1 Machine study in April 2000

We have experienced coupled-bunch instability over the beam current of 200 mA. We observed that beam was an elliptic under around 200 mA and the shape suddenly expanded to the horizontal direction over 200 mA. Transverse 834 MHz rf HOM was observed in the beam spectrum. We increased currents of SD (vertical focusing) and SF (horizontal focusing) sextupoles by 10 %. Then it was observed that the HOM was suppressed. Beam was injected again and the beam with elliptic shape was obtained up to 200 mA. But, long injection time of 30 minutes for 200 mA was taken due to changed betatron tune.

Above 200 mA, longitudinal 758 MHz rf HOM was observed in # 1 cavity. Then elliptic beam was changed to longitudinally deformed beam. To suppress the instability, we changed water temperture of rf cavity # 1 at the rate of 0.5 degree. When the beam gradually expands, we reversed the direction of variation in temperature. It means that we need to measure HOM's frequencies about all cavities beforehand. Then the 758 MHz rf HOM could be suppressed and the beam shape was kept up to about 250 mA.

About 250 mA, the information obtained by spectrum analyzer showed that no HOM's frequencies were observed, but the beam was shaken. Then we changed the currents of SD and SF sextupoles to lower or higher values in order to obtain stable beam as we observe the beam shape in beam profile monitor. After this procedure, the deformation of beam was cured and the beam became an elliptic shape. More 30 mA beam could be stored maintaining stable beam.

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In 280 mA, we detuned rf cavity # 1 and # 4 by 1.5 kHz more. More 20 mA could be stored by detuning the fundamental frequency. At last we could store 300 mA beam for just 20 minutes. On the other hand, vacuum value inside rf cavities was increased to 10^{-7} Torr in higher beam current than 280 mA.

In resut, to store 300 mA at 2GeV in the storage ring, we performed activities such as the detuning of cavity frequency to remove Robinson instability, temperature control of the rf cavity to suppress HOMs and the suppression of transverse instability by control of chromaticity.

3.2 Machine study in May 2000

In 5 May, we could store the beam stably up to 250 mA with SD=135 A and SF=90 A. Above 250 mA, we changed the currents of sextupoles to lower or higher values as we observe the beam shape in beam profile monitor in order to obtain stable beam. Then we could store 300 mA beam stably for 10 hours. Figure 2 shows the stored beam current of 300 mA. Betatron tune was ν_x=14.28 and ν_y=8.18.

3.3 Machine study in June 2000

Betatron tune survey was performed to understand the characteristics of the transverse rf HOMs. We also investigated effects of bunch filling patterns on the beam instability. Figure 3 shows the beam spectra in 175 mA of 2.0 GeV. Fig.3(a) shows the beam spectrum for the case of 468 bunches, ν_x=14.26 and ν_y=18.16. Fig.3(b) shows the beam spectrum for the case of 468 bunches, ν_x=14.20 and ν_y=18.19. Fig.3(c)shows the beam spectrum for the case of 400 bunches, ν_x=14.26 and ν_y=18.19. Here, we note that positions and magnitudes of rf HOMs are affected by the number of bunches and betatron tunes. Figure 4 shows the increased magnitude of vertical tune frequency for the case of 468 bunches. It seemed to be related to ion effect. The increased magnitude of vertical tune frequency could be greatly decreased for the case of 400 bunches.

3.4 Machine study in November 2000

We attempted to store the beam current as high as possible at a fixed tune. Horizontal coupled-bunch instability was observed during beam injection and storage. As the stored beam current was increased, horizontal beam blow-up was seen on the beam profile monitor. It was observed that the horizontal-coupled instability due to 830.45 MHz HOM drops the stored beam around 250 mA. Then, vacuum value inside rf cavities was also increased to above 100 nTorr. At last, the beam was suddenly dropped around 250 mA. To shift the transverse HOM, we selected the betatron tune of ν_x=14.27 and ν_y=8.23 that suppresses the transverse rf HOM. In this process the frequency spectrum of the beam was monitored to confirm that the instability was always related with the horizontal coupled-bunch oscillation. It was observed with spectrum analyzer that the resonant frequency was 830.45 MHz. The tune dependence of the instability was studied for a wider range. To suppress the transverse instability such as head-tail instability, we also adjusted the chromaticity. Contrary to the May and March cases, we fixed the betatron tune and chromaticity during the beam injection. We could suppress the transverse instabilities and could store 430 mA beam, without showing increased vacuum value inside rf cavities. Above 400 mA we observed the longitudinal 758.6 MHz rf HOM. But, the longitudinal coupled-bunch instabilities modes did not lead to beam loss up to 430 mA.

3.5 Machine study in April 2001

In April 2001, we choosed a different optimal betatron tune with November 2000 by tune survey. The selected tune was ν_x=14.19 and ν_y=8.25. We did not change betatron tune and chromaticity during the beam injection. We did not observe the transverse rf HOM and horizontal beam blow-up, and the beam could be stored up to 450 mA, without showing increased vacuum value inside rf cavities. Above 400 mA we observed the longitudinal 758.6 MHz rf HOM. The longitudinal coupled-bunch instability mode does not lead to beam loss up to 450 mA. We did not store higher beam current than 450 mA for the safety of vacuum components. The injection rate was typically 2-3 mA per pulse and showed better injection rate than case of November 2000. Figure 5 shows the stored beam current of 450 mA. The beam lifetime at the 450 mA was 6 hours.

4 BEAM INSTABILITIES TO BE CURED MORE

4.1 Longitudinal-coupled bunch instability

At this moment, we still observe longitudinal coupled-bunch instabilities around 360 mA due to 758.66 MHz and 1300 MHz modes at 2.0 GeV. The instability due to the 1300 MHz mode does not lead to beam loss since the shunt impedance of the mode is small. The 1300 MHz mode disappeare as the stored beam current increases. The instability due to the 758.66 MHz mode does not lead to beam loss up to 450 mA. However, the longitudinal beam oscillation due to the 758.6 MHz mode enlarges beam size horizontally, and moreover, accompanies with beam size fluctuation and bunch-lengthening. When the fluctuation amplitude due to the 758.66 MHz mode is large, it is observed that the beam lifetime decreases.

5 CONCLUSION

In this paper, we present the activities to suppress the beam instabilities at 2.0 GeV and 2.5 GeV in the PLS storage ring during the last one year. We have investigated dependences of the beam instabilities on betatron tune, chromaticity, bunch filling patterns and rf cavity temperatures. The designed beam current at 2.0 GeV in the ring could be stored. Longitudinal coupled-bunch instability due to 758.6 MHz mode at 2.5 GeV remains in only instability

Table 1: Designed parameters in the PLS storage ring

Parameters	2.0 GeV	2.5 GeV
Lattics type	TBA	TBA
Circumference	280.56 m	280.56 m
Natural emittance	12.1 nm	18.9 nm
Harmonic number	468	468
Energy spread	0.00068	0.00085
Synchrotron frequency	11.7 kHz	10 kHz
RF voltage	1.6 MV	1.6 MV
Damping time(T/L)	16.6/8.3 ms	8.5/4.2 ms
Bunch length	5 mm	8 mm

mode to be cured in the ring. We do not observe beam instabilities at 2.5 GeV up to 200 mA. Higher beam currents than 200 mA at 2.5 GeV are limited by the total rf power.

6 REFERENCES

[1] A.W. Chao, Physics of Collective Beam Instabilities in High Energy Accelerators (Wiley, New York, 1993).

Figure 1: Beam oscillations at 2.5 GeV that are observed in streak camera. (a) the number of bunches is 468, ν_x=14.26 and ν_y=8.15. (b) the number of bunches is 400, ν_x=14.28 and ν_y=8.18. Beam currents in (a) and (b) are 115 mA and 110 mA, respectively.

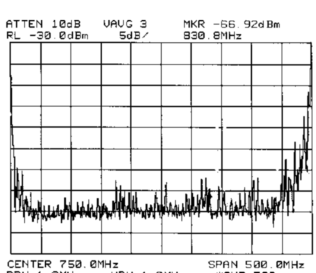

Figure 2: Beam spectrum on spectrum analyzer in the beam current of 193 mA at 2.5 GeV. The spectrum shows frequency band between 500 MHz and 1 GHz.

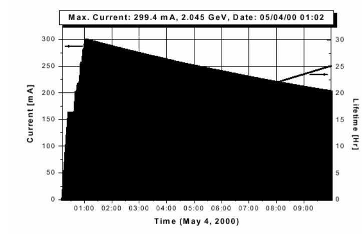

Figure 3: Stored beam current of 300 mA at 2.0 GeV.

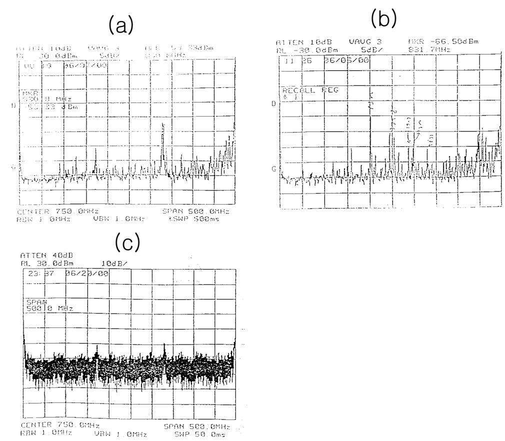

Figure 4: Beam spectra at 2.0 GeV that show frequency bands between 500 MHz and 1 GHz. (a) 468 bunches, ν_x=14.26 and ν_y=18.16. (b) 468 bunches, ν_x=14.20 and ν_y=18.19. (c) 400 bunches, ν_x=14.26 and ν_y=18.19.

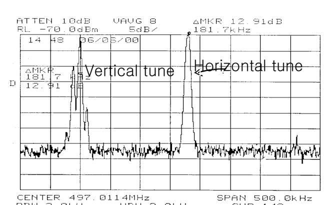

Figure 5: Beam spectrum shows increased magnitude and side-bands in vertical tune when number of bunches is 468.

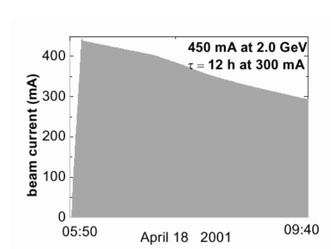

Figure 6: Stored beam current of 450 mA at 2.0 GeV.