BEAM DIAGNOSTICS WITH A STREAK CAMERA IN PLS STORAGE RING

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Abstract

Various modulated longitudinal oscillations due to RF noises have been observed with a streak camera at the end of the diagnostic beam line in the Pohang Light Source (PLS) storage ring. The same modulated oscillations can be also detected by a spectrum analyzer and the longitudinal feedback system. Strong quadrupole and sextupole mode oscillations as well as the dipole mode can be found with the streak camera. Moreover, the bunch length beating and the transverse beam size increase are observed. We report the various observations done by the streak camera in the PLS storage ring and explain where these abnormal behaviors come from.

1 INTRODUCTION

In the Pohang Light Source (PLS) storage ring, the transverse and the longitudinal beam motions are monitored at the diagnostic beam line. There are a spectrum analyzer, which receives a signal from the beam position monitor, and a streak camera (Hamamatsu C5680) in the diagnostic beam line for the longitudinal beam dynamics study [1]. During the normal operation at 400 filled bunch and 2.5 GeV, we occasionally observed various beam oscillations and a bunch length beating from the streak camera. From the spectrum analyzer, the same frequencies which are observed in the streak camera image are found as a sideband of synchrotron frequency. After the investigation, it is reported that the RF noises are generated from the No. 1 and the No. 3 low level RF system of the PLS storage ring. In Fig. 1, the frequency spectrum of RF noise from the No. 3 low level RF system is shown. The No. 3 low level RF system noises came from a large phase offset at the front of the phase detector in the phase loop of the RF station. The No. 1 low level RF system generated the noise in the same way but made lower frequency noises than the synchrotron frequency of 9.8 kHz at 2.5 GeV. Moreover, the RF noise pattern is similar to that of the RF phase modulation and RF noise contribute to the beam as a RF modulation [2]. The RF modulation effects on various beam properties via the longitudinal nonlinear beam dynamics and makes the beam oscillation and the bunch length beating [3]. In this paper, we show various beam oscillations and a bunch length beating which are due to RF noises in the PLS storage ring. We have found the quadrupole and

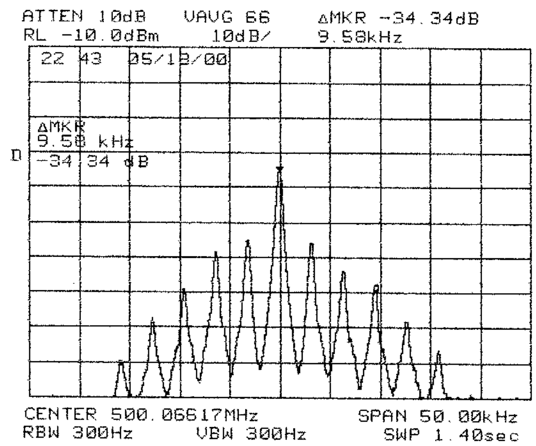

Figure 1: Frequency spectrum of RF noise. RF noises are shown as sidebands of synchrotron frequency. These RF noises work as a RF phase modulation and make beam oscillations and bunch length beating.

the sextupole mode oscillation from the streak camera image and describe the bunch length beating, which makes the transverse beam size blowup, as a dipole mode parametric resonance.

2 BEAM OSCILLATION AND RF NOISE

2.1 Oscillations with Various Frequencies

In the streak camera image, either the horizontal axis and the vertical one are time scale axes. The horizontal axis is a longer time axis which is from the nanosecond to the millisecond order and the vertical axis is a shorter time axis which is from 500 ps to 2 ns. We can calculate a longitudinal bunch oscillation frequency from the horizontal axis. For example, if the horizontal axis is 1 msec and there are 8 oscillations, the oscillation frequency is 8 kHz. From the vertical axis, the bunch length can be obtained. When a bunch occupies an one tenth of the 500 ps vertical axis, the whole bunch length is 50 ps.

From a beam oscillation image of the streak camera, not only a plain smooth oscillation, but also a complex oscillation can be observed. The beam oscillation will have a smooth waves when there is a single frequency in the RF noise. On the other hand, if there are more than one fre-

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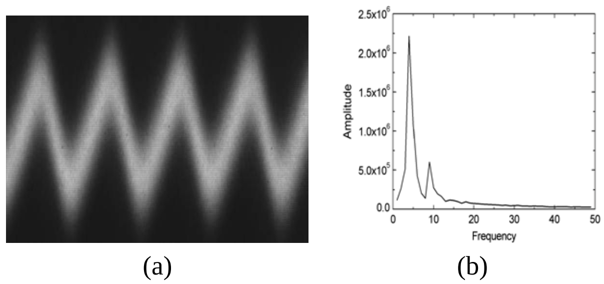


Figure 2: Sawtooth-like oscillation and FFT analysis result. In the streak camera image, the time scale of the horizontal axis is 1 ms and the vertical time scale means the bunch length. In the FFT analysis result, the horizontal axis is the frequency and the vertical axis is the amplitude. Frequencies of 4 kHz and 9 kHz are shown in the FFT analysis result.

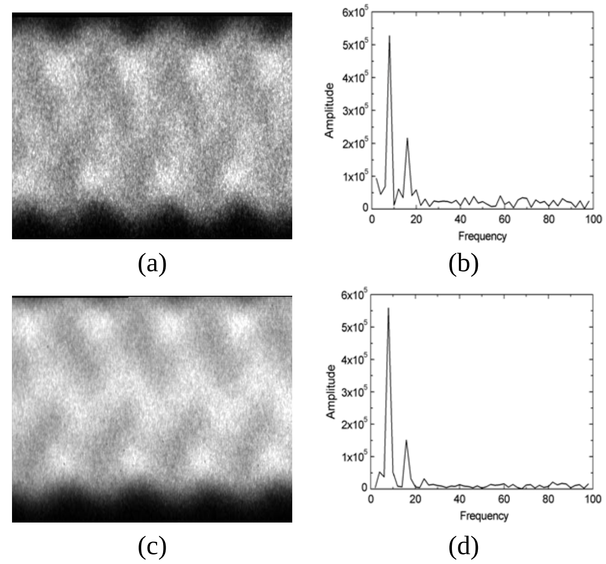


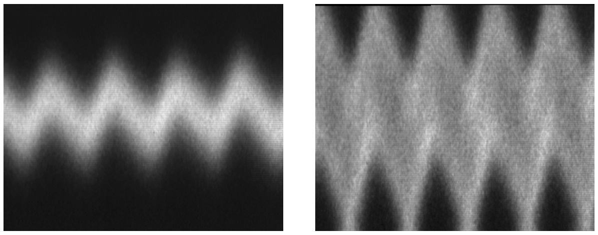
Figure 3: Quadrupole, sextupole mode oscillation images, and their FFT analysis results. In the quadrupole image of (a) and the sextupole image of (b), the time scale of the horizontal axis is 500 μs and the vertical time scale which means the bunch length is same for two cases. From the FFT analysis result, 8 kHz and 16 kHz frequencies are shown in (b) and 8 kHz, 16 kHz, and 24 kHz frequencies are shown in (d).

quency in the RF noise, we can see more complex waves as shown in Fig. 2. To find what frequencies are in a beam oscillation, a spectrum analyzer can be used along with a streak camera. The beam oscillation is detected by a beam position monitor (BPM) and the BPM sends the beam oscillation signal to the spectrum analyzer. Thus, the spectrum analyzer can show a frequency spectrum of the beam oscillation. However, it is hard to take a picture of the streak image with a spectrum analyzer simultaneously. Thus, we get a frequency spectrum from a fast fourier transform (FFT) analysis of the streak camera image because there are frequency information of oscillation in the streak camera image. After a FFT analysis, a complex oscillation separated into several frequency peaks. In Fig. 2, which is a sawtooth-like oscillation case, there are a primary frequency 4 kHz with a big amplitude and 9 kHz frequency with a small amplitude on the side of the primary frequency. These frequencies make the sawtooth-like oscillation.

2.2 Quadrupole and Sextupole Mode Oscillation

From streak camera images, we can observe a dipole mode oscillation and higher order mode oscillations as well. In Fig. 3, there are a dipole mode oscillation which makes a beam envelope oscillation and additional oscillations inside the beam envelope oscillation. This means that there are more than one frequency in the RF noise similar with the sawtooth-like oscillation case. However, this oscillation is different from the sawtooth-like oscillation because additional frequencies do not modulate the envelope oscillation to a different shape, but make another oscillations inside the envelope oscillation. One way to make this kind of oscillation is that the envelope oscillation frequency is closed to the synchrotron frequency and additional frequencies are harmonics of the envelope oscillation frequency. The first harmonic frequency makes a quadrupole mode oscillation and second harmonic frequency makes a sextupole mode oscillation, and so on. After the FFT analysis, 8 kHz and 16 kHz frequencies are observed in Fig. 3 (a). Frequencies of 8 kHz, 16 kHz, and 24 kHz are found in Fig. 3 (c). Here, Frequencies of 16 kHz and 24 kHz are the first and the second harmonics of the 8 kHz frequency. Thus, Fig. 3 (a) represents a quadrupole mode oscillation and Fig. 3 (c) is a sextupole mode oscillation. Note that the quadrupole and the sextupole oscillation amplitudes are relatively small and the vertical axis scale is a linear one in the FFT analysis results. When we transform the liner scale to the dB scale which is used in the spectrum analyzer, these amplitudes are considerably high.

If there is a dipole mode oscillation in a beam motion, the beam oscillates back and forth to the longitudinal direction. The bunch length does not changed and the length of the beam envelope remains constant. On the contrary, when there is a quadrupole mode oscillation, the bunch length are increased and decreased as time goes on. The total length of beam envelope will repeat a blowup and a shrink on the quadrupole mode oscillation frequency. In Fig. 3 (a), the total length of the envelope does not change and the quadrupole mode frequency of 16 kHz are appeared inside the dipole mode envelope oscillation. This is because there exists not only the quadrupole mode oscillation frequency but also the dipole mode oscillation frequency simultaneously in the frequency spectrum. Moreover, the amplitude of the dipole mode oscillation frequency is much big-



(a) (b)

Figure 4: Streak camera images of the bunch length beating. (a) is a image of before the bunch lengthening and (b) is a image of after the bunch lengthening by the RF noise phase modulation. The horizontal time scale is 1 ms and the vertical time scale which means the bunch length is same for two cases.

ger than the quadrupole mode oscillation one. This means that the dipole mode oscillation is the dominant oscillation and the quadrupole mode oscillation is the subordinate one. This is the reason why the dipole mode oscillation is shown as a dominant envelope oscillation and the total length of the envelope remains constant even though the quadrupole mode oscillation frequency is appeared in the FFT analysis result.

2.3 Bunch Length Beating due to RF Noise

Besides the beam oscillation, irregular bunch length beatings are noticed from streak camera images. As shown in Fig. 4, abnormal bunch length increases and decreases are observed during the normal operation period. When the bunch length beating is happened, a 5.2 kHz RF noise is detected as well and the amplitude of the RF noise changes continuously. The bunch length is increased to about a hundred ps from the normal operation bunch length of 20 ps. From the resent study in the PLS, this abnormal phenomena can be explained by a dipole mode parametric resonance [3]. After solving the time averaged Hamiltonian equations of motion which is affected by the sinusoidal phase modulation, one can obtain an inner fixed point and two outer fixed points in the phase diagram [4]. In the phase diagram, the phase space area means the energy spread or the bunch length. This area can be enlarged or narrowed down by the modulation amplitude change. When the amplitude of the RF noise is small, electrons stay around the inner stable fixed point and the bunch length is short as Fig. 4 (a). As the amplitude of the RF noise increases, electrons are diffused from the inner stable fixed point to the outer stable fixed point and the bunch length is increased enormously as shown in Fig. 4 (b). If the amplitude of the RF noise shrink down, most of electrons return to the inner stable fixed point and the bunch length is reduced again.

Figure 5 is a CCD image of a transverse beam profile when a bunch length increase is happened. The normal transverse beam shape is a Gaussian ellipsoid and the RMS horizontal beam size is 200 μm. After the bunch length

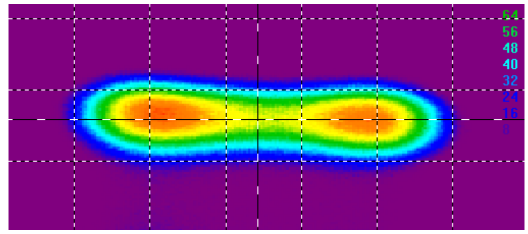


Figure 5: Transverse beam size image when the bunch lengthening is happened. The beam shape is changed from a Guassian ellipsoid to a dumbbell-like wide beam. The longitudinal dispersion makes the transverse beam size spread via the synchrotron oscillation.

is increased, the beam shape is changed to a dumbbell-like wide beam and the horizontal beam size blow up to 300 μm. Transverse beam size is wide due to the dispersion when the bunch lengthening is generated. Since almost all electrons stay the outer stable fixed point when the bunch lengthening is generated, outer part of the transverse beam image have higher density than inner part as shown in Fig. 5. Therefore, the beam becomes wide like a dumbbell.

3 SUMMARY

Beam oscillations and bunch length beating are observed at the diagnostic beam line in the PLS storage ring. After the investigation, it is known that noises come from the RF low level and these noises make the beam oscillation. By the streak camera, we can get various oscillation patterns not only a plane smooth waves but also sawtooth-like waves. From the streak camera image, we can pick up frequencies which make various oscillations and find the dipole, the quadrupole, and the sextupole mode oscillations. These azimuthal quadrupole and sextupole oscillations are appeared when noise frequencies are harmonics of the envelope oscillation frequency. Besides beam oscillations, the bunch length beating and the transverse beam size change are also observed. It is reported that these phenomena can be explained by the diffusion between two stable fixed points in the phase space due to the RF noise driven phase modulation. The beam size blow up comes from the increase of the longitudinal dispersion. RF noises are removed by attaching a mechanical phase shifter in the phase loop of the RF station.

4 REFERENCES

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