SUPPRESSION OF THE LONGITUDINAL COUPLED-BUNCH INSTABILITIES BY THE RF PHASE MODULATION IN THE POHANG LIGHT SOURCE

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Abstract

In the 2.5 GeV Pohang Light Source, we have investigated the suppression of the longitudinal coupled instabilities (CBI) caused by higher order modes (HOMs) of RF cavities. At higher beam current than 170 mA the 758 MHz or 1300 MHz HOMs occurred and the beam could be unstable. The longitudinal CBI could be suppressed by modulating the phase of an RF accelerating voltage at a frequency of 2 times the synchrotron oscillation frequency and by adjusting the water temperatures of the RF cavities. The longitudinal beam oscillations measured by streak camera in synchro-scan mode were shown. The experiment results were compared with the macro particle tracking simulation.

INTRODUCTION

The storage ring is operated with the bunched beams to supply the energy by the RF cavity. The bunches interact with each other by the wake fields in the surrounding structures, e.g. higher order modes (HOMs) of RF cavity, resistive walls, steps, bellows, beam position monitors. The coupled bunch instabilities (CBI) reduce the beam qualities such as the maximum stored current, the beam stability, the emittance [1,2]. The most direct cure of the CBI is to change the stuctures which cause the strongest wake fields. But it is generally difficult and expansive. The RF phase or amplitude modulation can be a powerful and cheap solution [3-5]. We investiaged the CBI suppression by the RF phase modulation in the Pohang Light Source. The experiment results were compared with the macro particle tracking simulation.

HIGHER ORDER MODE OF THE RF CAVITY

Although the RF cavity is designed primarily for one resonant frequency, many HOMs can be excited at higher frequencies These modes can be described by the parallel LRC resonator circuit. The impedance of the circuit is given by

$$\frac{1}{Z_m^{||}} = \frac{1}{R_s} + \frac{i}{\omega L} - i\omega C, \tag{1}$$

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Table 1: PLS parameter

Parameter	Value
Energy	2.5 GeV
Circumference	280.56 m
Revolution Frequency	1.068 MHz
Momentum Compaction	0.00181
Tune (z/x/y)	0.01/14.28/8.18
Natural Bunch Length	9 mm
Energy Spread	8.5 x 10^{-4}
Damping Time (z/x/y)	4.3/8/8 ms
Harmonic Number	468
Stored Beam Current	∼170 mA
Higher Order Mode 758 MHz	Q_0 =37000, Z=1.34 MΩ
(KEK data) 1300 MHz	Q_0 =112000, Z=2.9 MΩ

which gives

$$Z_m^{||} = \frac{R_s}{1 + iQ(\omega_R/\omega - \omega/\omega_R)}, \tag{2}$$

where $Q = R_s\sqrt{C/L}$ is the quality factor and $\omega_R = 1/\sqrt{CL}$ is the resonant frequency. The wake function can be obtained by performing a Fourier transformation on the impedance:

$$W'_m(\tau) = \begin{cases} (\tau > 0) & 0, \\ (\tau = 0) & \alpha R_s, \\ (\tau < 0) & 2\alpha R_s e^{\alpha\tau}(\cos\bar{\omega}\tau + \frac{\alpha}{\bar{\omega}}\sin\omega\tau), \end{cases} \tag{3}$$

where τ the longitudinal time advance, $\alpha = \omega_R/2Q$ and $\bar{\omega} = \sqrt{\omega_R^2 - \alpha^2}$.

RF PHASE MODULATION

In the simple model, the longitudinal motion of a electron under phase modulation can be described by the turn by turn equations :

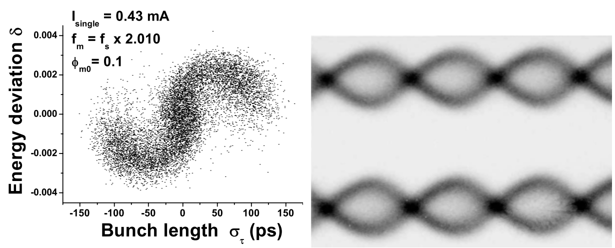
$$\Delta\tau = -\alpha T_0 \delta, \tag{4}$$

$$\begin{aligned} \Delta\delta = -\frac{U_0}{E_0} + \frac{V_{rf}}{E_0}\cos(\omega_{rf}\tau - \phi_0 + \phi_m) \\ -2\frac{T_0}{\tau_\epsilon} + 2\sigma_{\delta 0}\sqrt{\frac{T_0}{\tau_\epsilon}} < r > -\frac{V_b}{E_0} \end{aligned}, \tag{5}$$

where τ the longitudinal time advance, δ the energy deviation, α the momentum compaction factor, T_0 the revolution time, τ_ϵ the longitudinal damping, U_0 the energy loss per turn, E_0 the particle energy, V_{rf} the RF accelerating voltage, $\sigma_{\delta 0}$ the initial energy spread, ϕ_0 the synchronous phase, V_b the induced Voltage due to wake fields, and $< r >$ the gaussian random number with mean 0 and rms 1. The RF phase modulation is expressed as

$$\phi_m = \phi_{m0} \cos(\omega_m t), \tag{6}$$

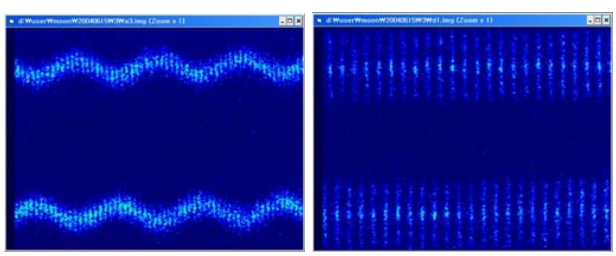
where ϕ_{m0} the RF phase modulation amplitude and ω_m the RF phase modulation frequency. As shown in Fig. 1, the phase space of the bunch is expanded by the RF phase modulation at a frequency of twice the synchrotron frequency and the bunch is lengthened on the average.



(a) (b) Horizontal scale 100 μs

Figure 1: (a) An simulation of the RF phase modulation. The phase space is expanded by modulating the phase of an RF accelerating voltage. (b) An Streak camera image of the RF phase modulation with the horizontal range of 10 μs. The modulation frequency is 18.95 kHz, and the modulation amplitude ϕ_{m0} is 2×10^{-4} rad.

MEASUREMENT

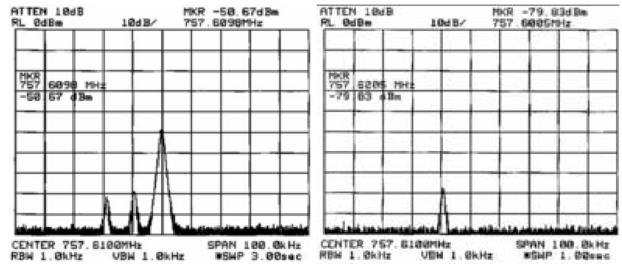


(a) Horizontal scale 0.5 μm (b) Horizontal scale 0.2 μm

Figure 2: (a) The coupled bunch instability due to 758 MHz HOM. (b) The CBI is compressed by the RF phase modulation at the frequency of about 2 times the synchrotron oscillation frequency (18.95 kHz).

A dual-axis streak camera, Hamamatsu model C5680, has been used to measure the longitudinal profile of the electron bunch. We can see the bunch profile in the synchro-scan mode as shown in Fig. 1 (b). With the horizontal sweeping time range of 100 μs, the revolution under the RF phase modulation of the 18.95 kHz is clearly observed.

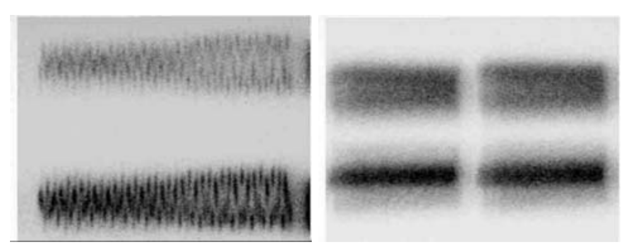
In the storage ring of the 2.5 GeV PLS, the 758 MHz or 1300 MHz HOMs occurred and the beam could be unstable at higher beam current than 170 mA. The HOMs of



(a) (b)

Figure 3: (a) A RF cavity spectrum of the 758 MHz HOM. (b) The 758 MHz HOM is compressed by the RF phase modulation.

RF cavity were adjusted by changing the temperature of RF cavity. In case of the 758 MHz HOM, the longitudinal CBI of 6 $\sim$ 7 MHz is measured as Fig. 2 (a), and the oscillaion amplitude is estimated to be 3.5 times the natural bunch length. The frequency of the HOM is estimated to be 757.609 MHz which varied with the RF cavity temperature. When the RF phase is modulated at the frequency of about twice the synchrotron oscillation frequency (18.95 kHz), the effect of the CBI is remarkably reduced as shown in Fig. 2,3. In case of the 1300 MHz HOM, the CBI is more complicated as shown in Fig. 4 (a). The longitudinal oscillation amplitude is estimated to be 1.1 times the natural bunch length at the front of the bunch train and 3.5 times at the end. The bunch length is measured to be 1$\sim$3 times the natural length. The CBI due to 1300 MHz HOM is also compressed by the RF modulation at the frequency of about twice the synchrotron frequency (19.00 kHz) as shown in Fig. 4(b),5.



(a) Horizontal scale 1 μm (b) Horizontal scale 2 μm

Figure 4: (a) A train picture with the CBI due to 1300 MHz HOM. (b) The CBI is suppressed by the RF phase modulation at the frequency of about 2 times the synchrotron oscillation frequency (19.00 kHz).

SIMULATION

We studied the effect of RF phase modulation on the CBI by a macro particle tracking code. As the source of the wake field, the resonator model is considered with the parameters in Table 1. As a qualitative analysis, R/Q is taken as large as 1000. The longitudinal mode due to 758 MHz HOM can be explained by the resonator model of the RF cavity as shown in Fig. 6. With the RF phase modulation

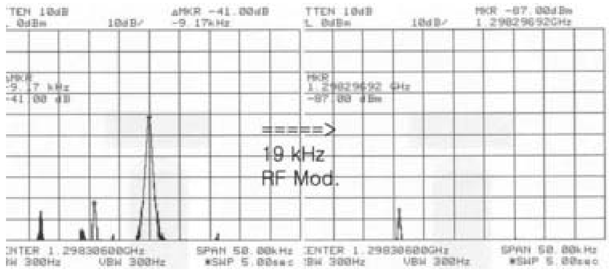
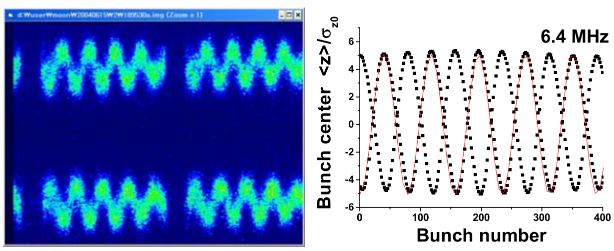


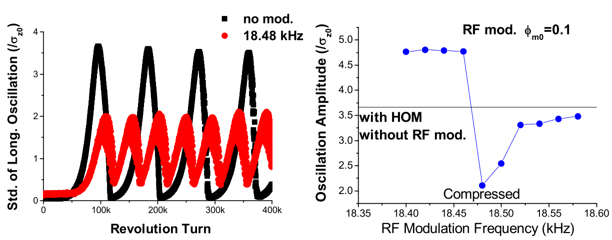
Figure 5: In the RF cavity spectrum, the 1300 MHz HOM is suppressed by the RF phase modulation.

of the about twice synchrotron frequency, the longitudinal CBI can be suppressed as shown in Fig. 7. The sawtooth effect is expected but not observed in the experiment.



(a) Horizontal scale 2 μm (b)

Figure 6: (a) The CBI due to 758 MHz HOM. (b) The resonator model showes the coupled motion of 6.4 MHz.



(a) (b)

Figure 7: (a) The longitudinal oscillation of the HOM resonator model with/without the RF phase modulation (b) The frequency scan of the RF phase modulation.

CONCLUSION

In PLS the longitudinal coupled bunch instabilities were measured at 170 mA by the streak camera. The longitudinal coupled motion of 6$\sim$7 MHz is generated by 758 MHz HOM. The CBI due to 1300 MHz HOM is more sophisticated. The CBI of 758 MHz and 1300MHz HOMs can be suppressed by the RF phase modulation. The resonator model shows a CBI caused by 758 MHz HOM and its suppression by the RF phase modulation. The further experiment and more realistic simulation research is required to enhance the CBI suppression effect of the RF modulation and to reduce the side effects such as the transverse oscillation, large effective emittance, and etc.

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