CURE OF COUPLED BUNCH INSTABILITIES IN PLS STORAGE RING

H.S. Kang, W.H. Hwang, H.J. Park, J.S. Yang, M.H. Chun, Y.J. Kim, M.K. Park, J.Y. Huang, S.H. Nam, Y. M. Koo, Pohang Accelerator Laboratory, Pohang, Kyungbuk, Korea
M. Kwon, Korea Basic Science Institute, Daejon, Korea
J. Fox, D. Teytelman, SLAC, Stanford, CA, USA

Abstract

The Pohang Light Source (PLS) storage ring whose design emittance is 12-nm uses four 500 MHz nose-cone-structure rf cavities to store beam current up to 400-mA at 2-GeV. The stored beam current was limited to 180-mA at 2-GeV because of the coupled bunch instabilities (CBI) excited by higher order modes (HOMs) of rf cavity. In order to cure the CBIs three measures are incorporated: HOM frequency tuning by cavity temperature adjustment; a longitudinal feedback system (LFS); a transverse feedback system (TFS). Growth rate of longitudinal and transverse HOMs of all rf cavities as a function of cavity temperature was estimated with the low-power measurement data of frequency shift, and confirmed with the BPM amplitude of CBMs. The LFS which uses programmable digital signal processors supplied by SLAC was successfully commissioned at the end of 1999, and a very stable and low emittance electron beam could be stored up to 230-mA over which transverse CBIs grow severely and drive to beam loss. After completion of TFS at the beginning of 2000 we will be able to cure all CBIs by LFS and TFS, and store beam current higher than 300-mA.

1 INTRODUCTION

Beam instability is a big issue in a 3-rd generation light source. The quality of light from synchrotron radiation depends on the longitudinal and transverse stability of the stored electron beam. Beam instability in a multi-bunch mode operation of storage ring behaves like coupled bunch mode, which is mainly driven by higher order modes of rf cavities. When longitudinal instability grows, it causes a broadening of the horizontal beam size and synchrotron radiation fluctuation and reduces a brilliance of the photon beam. The transverse instability increases the transverse oscillation amplitude and drives beam to loss.

Table 1 shows the parameters of the PLS storage ring. Beam energy of user service operation mode is 2.5 GeV at which beam quality becomes better than 2 GeV due to the advantage of damping time. Beam energy is ramped to 2.5 GeV from the injection energy of 2.0 GeV. In case of 2 GeV operation, there exist strong CBIs from rf cavity HOMs to limit the stored current. There also exist beam instability at 2.5 GeV with the beam current of 170 mA.

HOM frequency tuning by cavity temperature adjustment and a longitudinal feedback system (LFS) and a transverse feedback system (TFS) incorporate to cure the CBIs.

Table 1. Parameters of RF system of the PLS storage ring.

Beam energy, E (GeV)	2.0	2.5
Accelerating Freq., f_0 (MHz)	500.066	
Revolution Freq., f_r (MHz)	1.068517	
Synchrotron Freq., f_s (kHz)	11.4	10.05
Harmonic number, h	468	
Momentum compaction factor, α	0.001809	
Horizontal tune, ν_x	14.28	
Vertical tune, ν_y	8.18	
Horizontal emittance, ε_x (nm-rad)	12.1	
Damping time (transverse), ms	16.62	8.5
Damping time (longitudinal), ms	8.34	4.2
Number of RF cavities	4	4
Cavity gap voltage, kV	400	400
Shunt impedance of cavity, MΩ	8	8
Synchronous phase,	171.3°	159.3°
Over-voltage factor	6.6	2.83
Insertion Device	U7	

2 INSTABILITY GROWTH RATE

2.1 RF cavity HOMs

Table 2 shows the dangerous longitudinal and transverse HOMs of the PLS RF cavity[1]. Important cavity parameters are frequency and R/Q. High R/Q means the high coupling impedance between cavity and electron beam. The HOM characteristics like frequency shift vs. tuner position were measured with network analyser[2]. The measured resonant frequencies of the same HOM are different for each cavity because of machining errors.

2.2 Growth Rate

The growth rate of longitudinal coupled bunch instability for a beam current I_b stored in M uniform filled and spaced bunches is

$$\frac{1}{\tau_{\parallel}} = \frac{\eta I_b}{4\pi \nu_s (E/e)} \omega_{pn} \Re(Z_{\parallel}(\omega_{pn})) e^{-(\omega_{pn}\sigma_t)^2},$$

where η is the momentum compaction factor (=0.001809), ν_s the synchrotron tune (=0.011), E the beam energy, $\omega_{pn} = (pM + n + m\nu_s)\omega_0$ the frequency of CBM number n, ω_o the revolution frequency, and $Z_{\parallel}$ the impedance of the resonance cavity[3].

Table 2. HOMs of the PLS RF cavity

Freq. (MHz)	Mode	Q_L	R/Q or $R_{\perp}$	Instability (Problems)
758	TM011	21000	83.2	Long. (blow-up)
1300	TM020		11.4	Long.
1326	TM021		9.9	Long.
1658	TM022		7.7	Long.
1707	TM013	45000	9.2	Long. (blow-up)
826	TM110V	1700		Vert.
833	TM110H	40000	12±2	Hori. (Loss)
1071	TM111H	14000	27±1	Hori. (Loss)
1073	TM111V	13000		Vert. (blow-up)
1350	TM112			Vert.

Fig. 1 depicts the calculated growth rate of coupled bunch instability driven by HOMs as a function of cavity cooling water temperature for cavity #1 and cavity #3. The beam current is assumed to be 300 mA and the beam energy 2 GeV. Longitudinal instability modes like TM011 and TM013 are dominant for cavity #1. Quite different HOM behaviours are shown in cavity #3. Very wide cavity temperature window is available for cavity #3.

The growth rate of transverse coupled bunch instability depends on beta function at the location of rf cavity, and the coupled bunch mode frequency changes a bit as the horizontal and vertical tune. Thus the choice of tune value is important in this respect. The calculation uses the design tune.

3 CURE OF COUPLED BUNCH INSTABILITY

3.1 Cavity Temperature Tuning

From the estimated growth rate data of four cavities we can choose the operating temperature of cavity cooling water. The operating temperatures of cavity cooling water are as follows; cavity #1: 37.3°C, cavity #2: 46.4°C, cavity #3: 45.0°C, cavity #4: 36.6°C. For cavity #1 it is impossible to increase the temperature higher than 55.0°C because of the limitation of cooling system capacity. Dominate HOM mode of cavity #1 is TM020-HOM that is not shown in Fig. 1.

Fig. 2 shows the measured instability modes as a function of cavity cooling water temperature at cavity #1. The result is very similar to Fig. 1(a). No-data area is the forbidden temperature range where it is impossible to store electron beam due to HOM TM011. Mode OO and X in Fig. 2(b) reflect other coupled bunch modes excited by different HOMs of cavity #1.

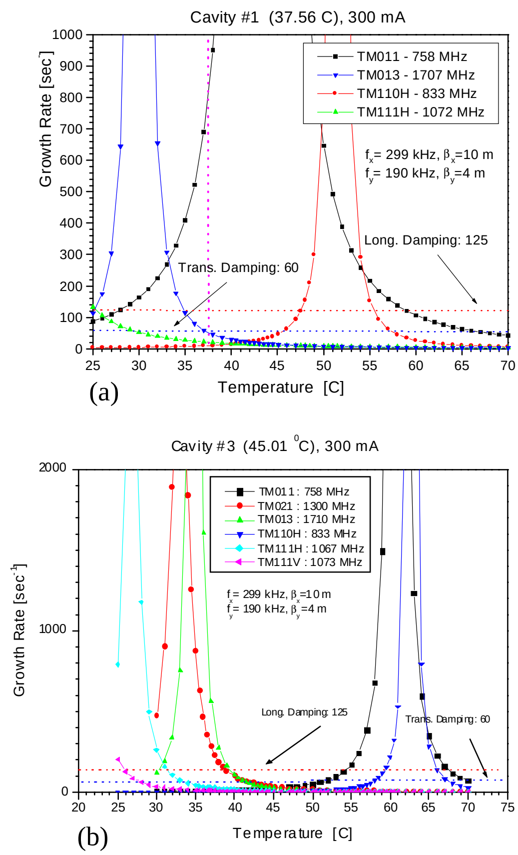


Figure 1: Calculated growth rate of coupled bunch instability excited by the HOMs of cavity #1 (a), and #3 (b).

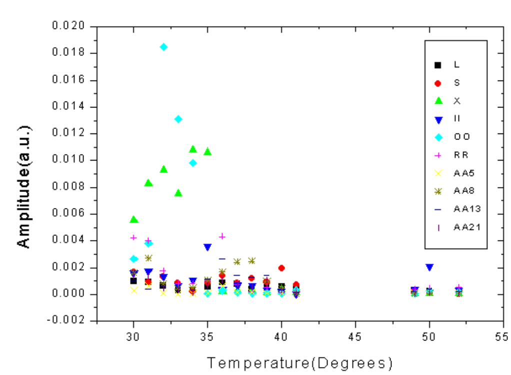


Figure 2: Measured instability modes as a function of cavity cooling water temperature for cavity #1.

3.2 Robinson Damping

Growth rate for the dipole mode from the rf harmonics is defined as [4]

$$\frac{1}{\tau} = \frac{\eta e I_b \omega_r}{2E_o T_o \omega_s}[\mathrm{Re}\, Z_o^{\|}(q\omega_o + \omega_s) - \mathrm{Re}\, Z_o^{\|}(q\omega_o - \omega_s)],$$

where η is momentum compaction factor, ω_r the cavity resonant frequency, ω_s the synchrotron frequency, E_o the electron energy, T_o the revolution time, and

$$\mathrm{Re}\, Z_o^{\|}(\omega) = \frac{(R/Q) \cdot Q_L}{1 + Q_L^2 \cdot (\omega/\omega_r - \omega_r/\omega)^2}.$$

If the cavity detuning is $\delta\omega$, $\omega_r = q\omega_o + \delta\omega$. The four cavities are detuned to a value listed in Table 3.

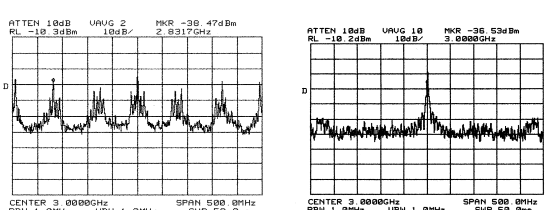
Table 3. Cavity detuning and Robinson damping.

	Cavity #1	Cavity #2	Cavity #3	Cavity #4
Detuning [kHz]	-4.97	-2.42	-1.56	-0.91
Growth rate [sec^{-1}]	-5035	-2542	-1650	-966

With the Robinson damping and by the cavity temperature tuning we achieved a 300 mA stored beam at 2 GeV. There still exists coupled bunch instability.

3.3 Longitudinal Feedback System

The PLS use a LFS, originally developed for the PEP-II, DAΦNE and ALS machines uses programmable digital signal processors and control system supplied by SLAC[5]. It was successfully commissioned at the end of 1999 with the aid of SLAC, and a very stable and low emittance electron beam could be stored up to 230-mA. Fig. 3 shows the spectrum data before and after LFS Turn ON.



(a) (b)

Figure3: BPM spectrum at 2 GeV/ 200 mA / 400 bunches. (a) LFS is OFF and, (b) LFS is ON.

The LFS failed to control when the stored beam current becomes higher than 230 mA at 2 GeV. Fig. 4 shows a strong forced oscillation of all bunches driven by strong rf noise of about 2.7 kHz. Control failure of LFS is due to these strong RF noises. The RF noise of 10.38 kHz is slightly different to the synchrotron oscillation frequency of 10.05 kHz at 2.5 GeV and there is no coupled bunch instability due to this external forced oscillation. The source of rf noise was confirmed to low level rf phase loop, and the amplitude of noises was greatly reduced recently.

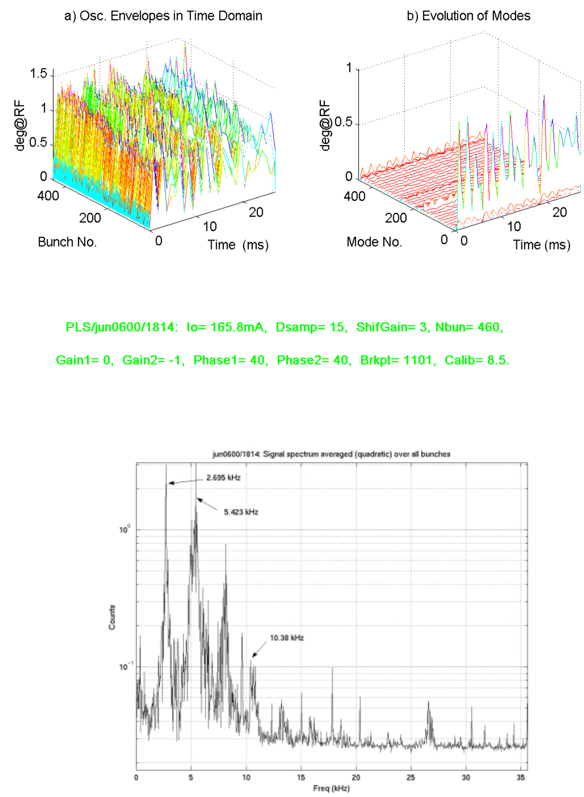


Figure 4: Oscillation envelopes and evolution of modes in time domain and signal spectrum obtained from LFS grow and damp module when strong RF noise modulates beam oscillation at 2.5 GeV/165.8 mA/ full bunch.

4 SUMMARY

Curing of coupled bunch instabilities was studied using the cavity temperature tuning and Robinson damping, and bunch-by-bunch feedback system like LFS and TFS. Effects of HOM tuning and Robinson damping were ascertained at the high current store experiment. We can cure the instability perfectly after optimising the performances of LFS and TFS.

REFERENCES

[1] Y. Yamazaki, KEK Preprint 95-6 (1995).
[2] M. Kwon, et al., Proc. IEEE Particle Accelerator Conference, 1999.
[3] M. Svandrlik, et al., Proc. IEEE Particle Accelerator Conference, 1995.
[4] K.Y. Ng, FERMILAB-TM-2090 (1999).
[5] J. Fox, et al., SLAC-PUB-8128 (1998).