STATUS OF LONGITUDINAL FEEDBACK SYSTEM FOR THE PLS STORAGE RING*

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Abstract

The Pohang Light Source (PLS) storage ring was originally designed to store the beam current up to 400 mA at 2.0 GeV. But owing to the interactions between the HOMs of RF cavities and bunched beams which make the coupled bunch mode instabilities (CBMIs) such as dipole, quadrupole, and sextupole modes, the beam current can be stored up to 200 mA. Thus, a longitudinal feedback system (LFS) using parallel digital signal processors has been installed to cure those CBMIs at the PLS storage ring. This programmable LFS is useful for various beam diagnostics as well as for the cure of the CBMIs. At present, via this LFS, we have obtained the various useful bunch-by-bunch diagnostic information such as growth rates of the instabilities, beam pseudo spectra, HOM frequencies of RF cavities which generate the CBMIs, the threshold beam currents, and the dependence on RF cavities temperatures.

1 INTRODUCTION

The Pohang Light Source (PLS) is a 3rd generation synchrotron light source, designed to store the beam current up to 400 mA at 2.0 GeV and 250 mA at 2.5 GeV. We have upgraded the PLS RF system by adding one more RF cavity in 1996 and by installing the cooling water temperature control system in 1997 to store the designed beam current [1]. But owing to the most dangerous HOMs of RF cavities, TM_{011} (758 MHz) and TM_{013} (1707 MHz) which make the CBMIs, the stored beam current is possible up to 200 mA at 2.0 GeV with substantially reduced amplitudes of the CBMIs via the precision temperature control of four RF cavities. But all dangerous HOMs of the RF cavities can not be simultaneously damped or avoided by the cooling system. Therefore, an active feedback system for curing the CBMIs is necessary for the PLS storage ring. There are various types of the LFS running at several accelerators such as PEP-II (SLAC), ALS (LBL), DAΦNE (LNF), KEKB (KEK), etc. In terms of the origin of impedance that generates the CBMIs, the feedback system can be classified into two kinds; the time domain system and the frequency domain one. The harmful transverse or longitudinal HOMs of accelerating RF cavities can be cured by the time domain, bunch-by-bunch feedback system. The dangerous longitudinal fundamental mode of accelerating RF cavities and the transverse resistive wall impedance due to the beam pipe can be cured by the frequency domain feedback system. In case of the time domain feedback system, no pre-knowledge of the dangerous coupled modes is required while the pre-knowledge is required for the frequency domain feedback system. The LFS which have been developed by the collaboration of SLAC, LBL, LNF laboratories is a time domain, bunch-by-bunch feedback system which uses the programmable digital signal processing processors (DSPs). In the PLS case, after having considered the developing cost and period, we have purchased the digital signal processing unit from SLAC, and one pickup and one LFS kicker have been fabricated by the PLS and domestic manufacturer [2]. We have installed the LFS for the PLS storage ring during 1999 Summer maintenance period. During PLS LFS commissioning, we have obtained the various useful diagnostic informations such as the growth rates of the CBMIs, threshold beam currents, beam pseudo spectra, CBMIs dependences on RF cavities temperatures, and bunch-by-bunch currents by saving longitudinal bunch-by-bunch phase motions at the dual port memories (DPMs) on DSP boards.

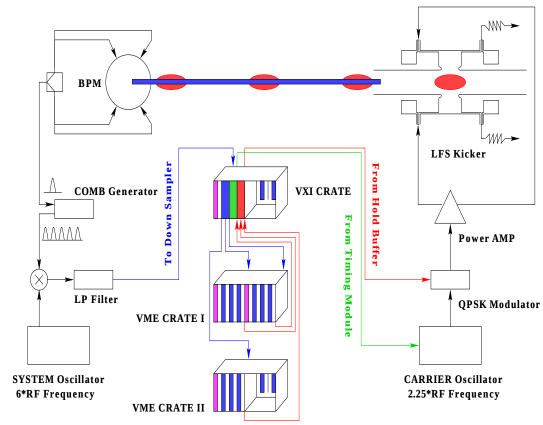

Figure 1: Block diagram of the PLS LFS.

2 LFS FOR THE PLS

2.1 Basic Working Principles

The PLS LFS consists of a phase error pickup, digital signal processing units, and a kicker as shown in Fig. 1. The digital signal processing unit consists of a system oscillator and a DSP farm with a VXI and two VME crates. A VXI controller, a timing module, a front end module, a down sampler module, a hold buffer module, and a back end module are housed in a VXI crate, and a VME controller, five DSP board modules, an interface module are housed in a VME crates. The signals from the BPM are combined and then fed into the stripline comb generator where a coherent tone burst from the BPM signals is generated by a periodic

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Table 1: Parameters for the PLS LFS

Parameters	Value
RF frequency f_{RF}	500.082 MHz
Revolution frequency f_o	1.06855 MHz
Synchrotron frequency f_s	11.72 kHz
Ratio of f_o/f_s	90
Tap No of FIR algorithm N	6
Down sampling factor d	15
Bunch spacing for full filling	2 ns

microwave coupler circuit at six harmonic of RF frequency (3000 MHz). The phase error detection is performed by the double balanced mixer (DBM) where the signal from the comb generator is compared with 3000 MHz ($6 \times f_{RF}$) signal from the master oscillator phased locked to the ring. It is possible to obtain a phase processing range of $\pm 15°$ at the f_{RF} with a resolution better than $0.5°$ by choosing the $6 \times f_{RF}$ as an operating frequency. The detected phase error signals are digitized by an eight-bit ADC converter at the bunch crossing rate (2 ns for fully filled buckets). From the fact that the revolution frequency f_o of the PLS storage ring is ninety times greater than the synchrotron frequency f_s as summarized in Table 1, the calculating process can apply the Nyquist sampling. But, since the phase error oscillation (synchrotron oscillation) is not a perfect sinusoidal signal, six is selected as the number of taking samples per one synchrotron period. This process is called the down sampling. One VME crate has two VME backplanes where one Motorola MVME166 control processor and five DSP boards are housed. Each DSP board contains four 80 MHz AT&T 1610 DSPs. Each DSP chip has a 16 kB dual port memory (DPM) that can be accessible by the DSP and MVME166 control processor. After the longitudinal phase errors are detected and down sampled, the feedback correction output can be calculated by sixty DSPs in parallel which are housed at the fifteen DSP boards ($4 \times 15 = 60$) in three VME backplanes. To calculate the correction output, the DSPs use the N-taps finite impulse response (FIR) algorithm which is given by

$$y(t_n) = \sum_{k=1}^{N} h(k) \cdot \phi(t_{n-k}) \,, \tag{1}$$

$$g(k) = 2^{G_s} \cdot G \cdot \sin(2\pi[k/N + \varphi/360]) \,, \tag{2}$$

$$h(k) = g(k) - \frac{1}{N} \sum_{k=1}^{N} g(k) \,, \tag{3}$$

where $y(t_n)$ is the present correction output of the FIR filter, $h(k)$ is the programmable coefficient of the filter, $\phi(t_{n-k})$ is the phase error of previous turn as an input of the filter, G_s is the post multiply-accumulate shift gain of the filter, and G and φ [$°$] are the gain and the phase of filter which can be used to choose the coefficient of FIR filter on EPICS operator interface. G = 0 means that the feedback is off. In case of the tap number $N = 6$, six sampled phase errors ($\phi(t_{n-1}) \sim \phi(t_{n-6})$) in one synchrotron period will be used to calculate a correction output $y(t_n)$. The calculated correction outputs are sent to the hold buffer with gigabit serial links. The hold buffer is a memory where the most recent kicking values are stored. Because of the down sampling, the most recent kicking values must be used to kick each bunch until a new kicking output is calculated by the DSPs. The output signal of the hold buffer is $-\pi/2$ phase shifted and amplitude modulated, then will be sent to the power amplifier. Finally, the correction output of amplifier will be sent to the beam through the LFS kicker.

2.2 *Data Acquisitions with the LFS*

The Experimental Physics and Industrial Control System (EPICS) is used for the LFS control operator interface (OPI). The setting of FIR algorithm, the diagnostic of LFS hardwares and data acquisitions can be performed with the OPI. After the frontend calibration which has been done by injecting a triangle wave (peak-to-peak 1.26 V, 700 Hz) into the *external phase in*, we can record the phase oscillations of all or selected bunches in the DSP DPM with help of a triggerable recording OPI program, "lfbGrwDmp.dl". Then, by running a Tcl/Tk code (gd_post.tcl), we can generate and transfer a MATLAB compatible data file (gd.mat) from the DPM on DSP boards to the LFS console workstation. It is possible to obtain many useful diagnostic information such as the growth and damping rates of the instabilities, the HOM frequencies of RF cavities which generate the CBMIs, bunch-by-bunch currents, and beam pseudo spectra by analyzing the data with the MATLAB codes.

3 TEMPERATURE TUNING VIA LFS

Without any available working LFS, we can increase threshold of beam current against existing the CBMIs with several methods. One is the RF cavity temperature tuning which shifts the dangerous HOM frequencies not to generate resonance with circulating beams. A precise tuning will reduce the amplitudes of dangerous HOMs. It also reduce the needed LFS power to damp the CBMIs. For a precise tuning, we have used the triggerable recording OPI program of PLS LFS.

Multi-bunch motions in the time domain as shown in Fig. 2 where growing 350 bunches and 118 empty buckets are displayed, can be plotted by a MATLAB code (Modes.m). These growing oscillations are induced by a HOM of RF cavities. After arranging the data of Fig. 2 in 2D array (bunch number $\times$ sampling number), by performing FFT and exponential fitting, we can find that the growth is induced by TM_{011} (758 MHz) mode and its growth rate is about 30 [sec^{-1}] [3]. Cavity temperatures for four cavities of this status are 37.9, 45.6, 45.9, 37.2 °C in respectively. Beam pseudo spectra which are the beam spectra without revolution harmonics have been obtained for various RF cavity temperatures, beam currents, and beam energies as shown in Fig. 3. In case of 2.5 GeV-151.68 mA operation, though it is high current status, all amplitudes

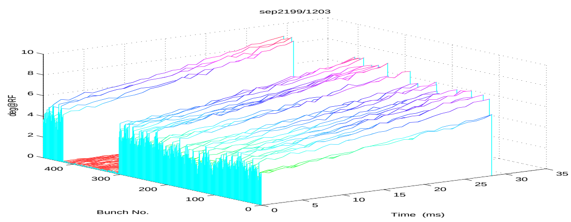

Figure 2: TM_{011} mode induced bunch oscillations.

of HOMs are damped. This damping is caused by Landau damping and the optimum temperature tuning (37.4, 45.0, 44.9, 37.2 °C). In case of 2.0 GeV-89.7 mA operation, though its current is low, tuning temperatures (37.8, 45.5, 45.5, 39.4 °C) are in the resonance region with the circulating beams. Therefore, many dangerous HOMs are arising. In case of 2.0 GeV-152.50 mA operation, Fig. 3 (b) is obtained by changing the cavity temperatures to 37.8, 45.6, 45.6, 37.6°C. In this case, we can find TM_{013} mode near 200 MHz and the threshold beam current of this mode has been increased to 152.50 mA which is higher than the case of 2.0 GeV-89.7 mA operation. Growth rates of TM_{013} mode with the same temperature status for various beam currents have been investigated as shown in Fig. 4. We can find the threshold beam current of the mode is about 152.50 mA. In case of 2.0 GeV-151.31 mA operation, we can find the TM_{011} mode near 250 MHz by changing cavity temperatures again. The large difference between the case of 2.0 GeV-152.50 mA operation and the case of 2.0 GeV-89.7 mA operation is the fourth cavity temperature. Therefore, to avoid many dangerous HOMs, we must keep the cavity temperatures near 37.x, 45.x, 45.x, 37.x °C, respectively. To optimize cavity temperatures at 2.0 GeV beam energy, more tuning will be needed.

4 CURRENT STATUS

Everything except a power amplifier has been installed and tuned. Because there is a problem in the amplifier, we had to sent our LFS power amplifier to its manufacturer to fix the problem and to attach the GPIB controller. When the power amplifier is returned, we will restart the tuning of backend delay. Then, we will be able to operate the LFS to damp the existing CBMIs in the PLS storage ring. It will be also possible for PLS to find the best operating conditions of the temperatures of RF cavities and various filling patterns by recording bunch motions with the help of the programmable LFS. Also, the much narrower and higher intensity spectrum of U7 undulator will be obtained.

5 ACKNOWLEDGMENTS

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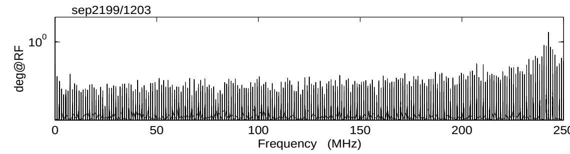
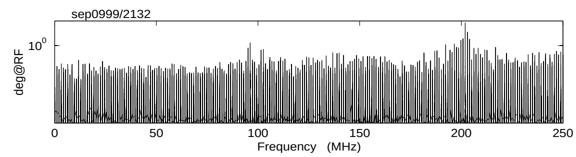
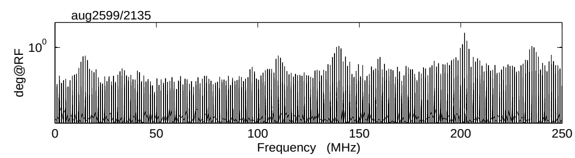


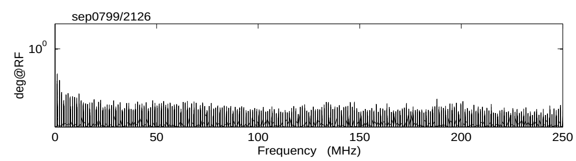
(a) 2.0 GeV - 151.31 mA Operation



(b) 2.0 GeV - 152.50 mA Operation



(c) 2.0 GeV - 89.7 mA Operation



(d) 2.5 GeV - 151.68 mA Operation

Figure 3: Beam pseudo spectra.

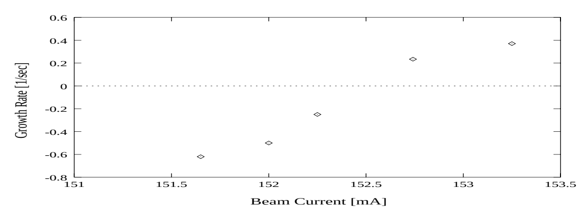


Figure 4: Growth rates of TM_{013} mode.

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