# LONGITUDINAL FEEDBACK CONTROL SYSTEM FOR THE PLS

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*Abstract*

In the Pohang Light Source(PLS) storage ring, beam current has been limited at less than 180mA by the coupled bunch mode instabilities(CBMIs) caused by RF cavity higher order modes(HOMs). To suppress such CBMIs and to store the high current beam at more than 300mA, a bunch-by-bunch longitudinal feedback system(LFS) has been installed and commissioned. So far we have stored 237mA in the storage ring using LFS. The LFS that has developed by SLAC, is a modular programmable system almost identical to the ALS/PEP-II/DAΦNE system. It is composed of state-of-the-art technology and analog & digital processors fully controlled by computer. All the rf processors and DSP boards are implemented in the VXI modules and VME modules respectively. The EPICS control system is used for the operation of the system as well as the diagnostic tools for machine physics. The analyses of the beam parameters and instabilities are performed with MATLAB program. In this paper, the details of the architecture, functionality, implementation and the commissioning experiences of the LFS in the PLS will be presented.

## 1 INTRODUCTION

The PLS is the third-generation synchrotron light source which designed to store beam current up to 400mA at 2GeV, 200mA at 2.5GeV. We had completed commissioning the machine in 1994, and have begun the user service since 1995. In next stage, our attention was to achieve 400mA stored current at 2GeV, which was limited below 180mA due to some beam instabilities in transverse and longitudinal planes. First, we have developed the analog-type bunch-by-bunch transverse feedback control system(TFS) and finished the system commissioning. The TFS can suppress all transverse instabilities over entire 250MHz frequency band in x, and y direction separately. Recently we are going on upgrading TFS with double pickups and kickers. As the one way to remove the longitudinal instabilities arisen by mainly RF cavity's HOM's, we developed the precision temperature control system for RF cavities, which can regulate the temperature of cooling water of cavities within 0.2°C, and make it avoid the dangerous HOM frequencies to grow CBMI's. The other way is to adapt an active feedback control system. The bunch-by-bunch longitudinal feedback control system(LFS) was

originally developed for the use of ALS, PEP-II and DAΦNE machines. SLAC also had developed all system hardware, software and analysis program for PLS feedback system. We installed it during last summer maintenance period and have completed commissioning successfully. We achieved to store the beam current up to 237mA at 2.04GeV with damping of all CBMI's. Also, the emittance in horizontal plane was improved about 38%[1]. The additional advantage of the system is that the LFS with powerful analysis program is useful beam diagnostic tool to obtain various information such as a mode spectrum of all HOM's, a signal spectrum of any other noises in a beam, and stored beam current of each bunch, etc. The major parameters of the LFS are described in Table 1.

Table 1 : Parameters of the system

| Parameters | Value |
|---|---|
| RF frequency $f_{RF}$ | 500.066 MHz |
| Revolution frequency $f_o$ | 1.0685 MHz |
| Synchrotron Frequency $f_s$ | 11.72 KHz |
| Harmonic No. | 468 |
| Sampling Frequency | 500 MHz |
| Down-sampling factor | 15 |
| No. Of DSPs | 60 |
| Kicker Type (No.) | Cavity (1) |
| Kick Frequency | $9/4* f_{RF}$ |
| Output Power | 200 W |

## 2 DESCRIPTION OF THE SYSTEM

The LFS is composed of three parts; a phase error pickup, a signal processing part, and kicker as shown in Figure 1.
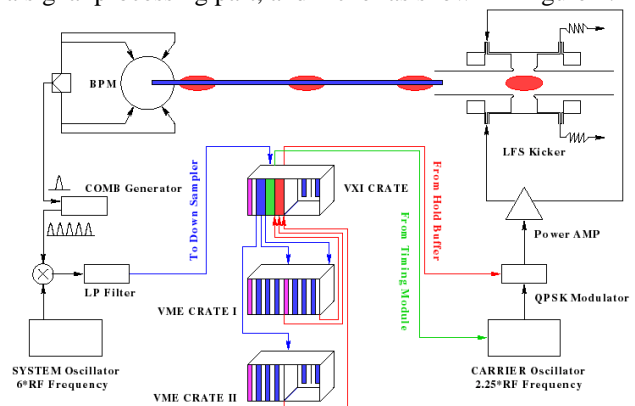


Figure 1: Block Diagram of the LFS

All the modules of a signal processing part are implemented in VXI/VME standard modules housed in a VXI and 2 VME crates. The necessary clocks and reference signals for the operation of the LFS are produced in Timer VXI module and a system oscillator which synchronized to SR RF frequency.

## 2.1 Phase Error Detection

For the detection a phase error of the beam, the BPM signals from 4 button-type pickups are summed at a 4-way power combiner, and then fed to a stripline comb generator in a system oscillator where a 4-cycle tone burst signal from BPM signal is generated at six harmonic of RF frequency (3GHz). The phase error detection is performed in the front-end VXI module by comparing the signal from the comb generator with 3GHz reference signal which phase-locked to the RF master oscillator. The phase error can be detected in the range of $\pm15°$ with a resolution better than $0.5°$ by using the $6 \times f_{RF}$ as an operating frequency. We can see some measurement signals in Figure 2 when multi bunches having 2ns spacing are filled with some ion gap.
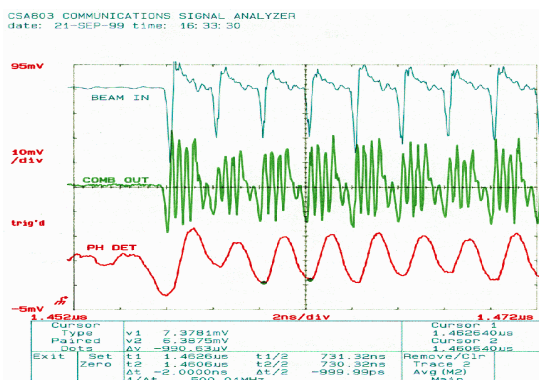


Figure 2: Phase error detection in the Front-end
(The first is a BPM signal, the second a tone burst signal at $6 * f_{RF}$ from comb generator, and the third a phase error detection signal at the front-end module)

## 2.2 Down Sampling

The detected phase error signals from the front-end are digitized at 500MHz sampling rate in the down-sampling VXI module and then transferred to the DSP farms via 3 serial links to calculate the correction outputs for each beam. According to the Nyquist theorem, it is possible to recover a signal from its samples if the signal is band-limited and the samples are taken at least at twice of the highest frequency in the signal. For the PLS storage ring, the revolution frequency is 90 times greater than the synchrotron frequency. And so, we sample only 6 times over one complete synchrotron period, which is enough to recover the phase error oscillation (syncrotron oscillation), to reduce the burden to the DSP. This process is called as the down sampling technique and down sampling factor for the PLS is 90/6=15.

## 2.3 DSP Farms/ Hold Buffer

Using the information of the phase error from down sampler, 60 DSPs which implemented in 15 DSP boards in three VME backplnes, perform the calculation the correction output for each bunch in parallel. Each DSP is responsible for 8 bunches. For calculation, the DSPs use N-tap finite impulse response (FIR) filter algorithm which uses the past N information with proper coefficients and filter gain to calculate the present correction output. The calculated phase error outputs from DSPs are transferred to the memory in the hold buffer VXI module via three gigabit serial links, and then D-to-A converted at a 500MHz bunch crossing rate to generate the analog baseband correction signal.

## 2.4 AM/QPSK Modulator

To choose the center frequency of the kicker, the cost of the power amplifier and obtainable shunt impedance of the kicker must be considered. We selected the center frequency of 1125 MHz, $(2+1/4) * f_{RF}$. Also, minimum desirable bandwidth of the kicker to suppress the all CBMI's is $f_{RF}/2$, 250 MHz. Therefore, the baseband signal must be up-converted to the center frequency of the kicker in VXI back-end module. Because 1125MHz has phase difference of $90°$ with circulating beam, 1125MHz carrier signal should be QPSK-modulated. The baseband correction signal from the hold-buffer module is AM-modulated with QPSK-modulated carrier signal [3]. And, careful consideration is needed to adjust back-end timing to align kick signal with a circulating beam for maximum correction power to be delivered to the beam.

## 2.6 Kicker/Power Amplifier

After intensive study and investigation, we decided the LFS kicker to the type of a single-ridged waveguide-overloaded cavity in Figure 3, the same type of the DAΦNE, which has four input/output ports to get the wide bandwidth and a nose cone to increase the shunt impedance. The fabricated kicker has a bandwidth of 285MHz, and maximum shunt impedance of 470 $\Omega$ [1]. We use a class-A, GaAs-type, commercial amplifier, model AS0820-250R from Milmega, which has a frequency bandwidth from 800MHz to 2000MHz and a maximum rating power of 250W, as the power amplifier for LFS kicker. The output of the amplifier are fed to the 4 inputs of the kicker through a 4-way power divider and 4 circulators with the appropriate termination are installed in front of the inputs of the kicker to protect the power amplifier from the damage due to reflected signal from the kicker. Also, 4 line stretchers are used after the power divider to get a phase match in 10ps between 4 feeding lines.
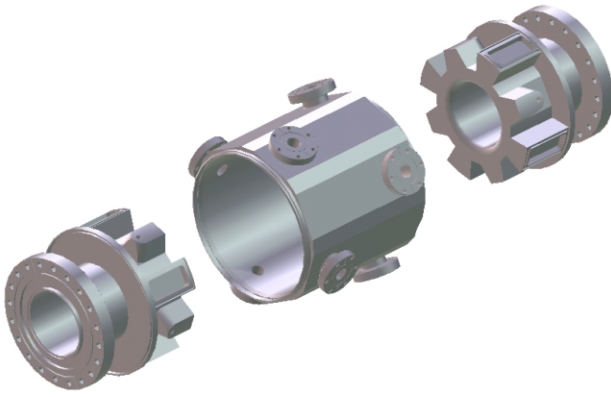
And also, the analysis of the Cavity HOM's and tuning the temperature of the cooling water were performed during the commissioning. As a result, the LFS suppresses all the longitudinal instabilities at the stored current up to 237mA at 2.04GeV. The envelope oscillations of the beam are shown in Figure 4, 5 when the LFS is turned off and on, respectively.

## 4 SUMMARY

We have achieved the stored beam current up to 237mA at 2.04GeV and the emitance has been improved 10% in vertical plane, 30% in horizontal plane, respectively. In further test, we must figure out the reason why the LFS looses the control of instability over that current. And, We are trying to investigate the source of the some noise signal whose harmonics reside near the synchrotron frequency. Also, to confirm the stable operation, we are implementing the fiducial signal board in the LFS in near future.



Figure 3: Geometry of LFS Kicker

## 3 COMMISSIONING RESULTS

We made some effort to find optimum signal level between the modules and adjust parameters for the system using some drive program and utility program.
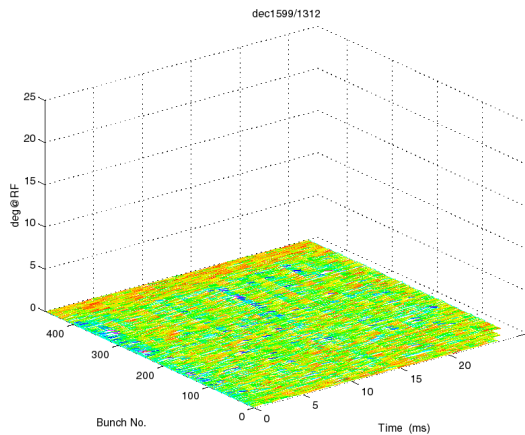


Figure 4: Multi-bunch envelope oscillation in time domain when LFS turned off (181mA, 2.04GeV)
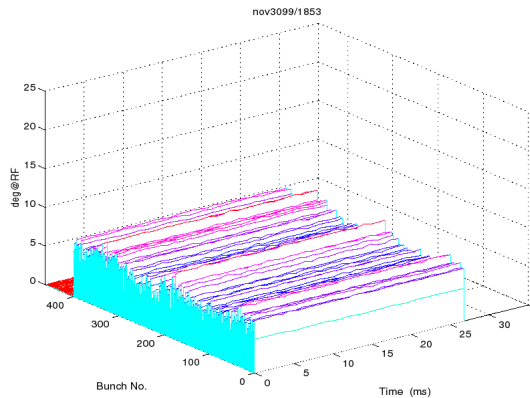


Figure 5: Multi-bunch envelope oscillation in time domain when LFS turned on (237mA, 2.04GeV)

## 5 ACKNOWLEDGMENTS

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