LONGITUDINAL FEEDBACK SYSTEM FOR THE PHOTON FACTORY

T. Obina#, W. X. Cheng, T. Honda and M. Tobiyama
High Energy Accelerator Research Organization (KEK), Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

In the KEK Photon Factory, longitudinal coupled-bunch instabilities are suppressed using the RF phase-modulation technique during the users operation. This technique is very effective not only to suppress the instabilities but also to enlarge the beam lifetime. Together with the study for top-up operation, longitudinal bunch-by-bunch feedback system has been developed. A two-port longitudinal kicker based on DAΦNE-type cavity were designed and installed in the storage ring in the summer of 2006. FPGA-based signal processing part is under development based on the KEKB design. A mode feedback system which suppresses a specific coupled-bunch mode was tested successfully as a preliminary test of the kicker. By using a commercial FPGA evaluation board, a simple bunch-by-bunch feedback system was implemented and succeeded to suppress the coupled-bunch instability up to 52 bunches in the ring.

INTRODUCTION

The 2.5 GeV Photon Factory (PF) electron storage ring is a dedicated synchrotron light source. When multi-bunched beam above 50 mA is stored in the ring, the longitudinal coupled-bunch instabilities are observed. The source of the instabilities was thought to be the broad-band impedance caused by narrow gaps or step structure in the vacuum wall. In 2005, reconstruction of the straight sections of the PF was carried out, and the old vacuum components such as unshielded bellows were replaced by the new one. After the replacement, some longitudinal instabilities became weak, however several instabilities still remained.

The phase modulation on the RF accelerating frequency at twice of synchrotron frequency can suppress the longitudinal instabilities considerably[1]. This technique has a disadvantage that it will enhance the energy spread of the beam. On the other hand, the phase modulation enlarges the beam lifetime about the factor of 1.5, which is desirable for many users.

The study of the top-up operation is under way. Since we do not need to worry about short beam lifetime with the top-up operation, longitudinal feedback system has been developed to stabilize the instability for the suppression of longitudinal instabilities.

Table 1: Main Parameters of PF-Ring

Energy	2.5	GeV
RF frequency [f_{RF}]	500.1	MHz
Circumference	187	m
harmonic number	312	
natural emittance	36	nm rad
revolution frequency [f_{rev}]	1.6029	MHz
synchrotron tune [ν_s]	0.014	
longitudinal damping time	3.9	ms
beam current (multi-bunch)	450	mA
beam current (single-bunch)	75	mA

LONGITUDINAL KICKER

A longitudinal kicker based on DAΦNE-type cavity was designed and fabricated. Compared to the original design, the number of input and output port was reduced from 4 to 2. The shunt impedance is about 700 Ohm. The wakefield and beam impedance of the cavity was simulated with MAFIA code. The fastest growth time of the instability was slower than radiation damping time. The detail of the cavity design and the estimated impedance were reported in previous paper[2].

After the fabrication of the cavity, S21 parameter was measured to check the characteristics of the cavity. The 3dB bandwidth of the cavity was 150 MHz, which is narrower than the original design of 250 MHz. We found a mistake in the fabrication process: size of ridge part was different from the design which is used for HFSS or MAFIA calculation.

The cavity was installed in the PF-Ring in the summer of 2006. Figure 1 shows a schematic drawing of the internal structure of the longitudinal kicker. A photo of the cavity installed at downstream of the accelerating cavity is also shown in the figure. The diameter of the beam pipe is 100 mm.

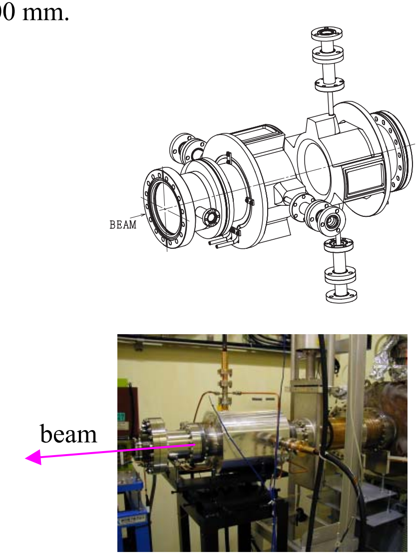


Figure 1: Drawing and a photo of the longitudinal kicker installed at downstream of the RF accelerating cavity. Blue cables in the photo are temperature sensors.

#takashi.obina@kek.jp

1-4244-0917-9/07/$25.00

From the observation of the beam spectrum, it is confirmed that the feedback cavity does not induce any kind of instabilities in transverse and longitudinal plane. Since in the single bunch operation, the PF-Ring store more than 75 mA, the peak voltage is much higher than the normal multi-bunch operation, and it can damage many RF components or cables. In order to avoid these damages, all ports of the cavity are connected to dummy load during the single bunch operation. Temperature of the cavity body, feedthroughs of input/output port and cables were watched in all the time. The increase of the temperature in the single bunch operation was less than ten degrees, and which is small enough to avoid breakdown.

ANALOG MODE FEEDBACK

System Setup

Only one longitudinal coupled-bunch mode is observed in the beam spectrum at the low beam current. The frequency of the instability was determined to be 942.5 MHz (mode number = 275). A mode feedback system to suppress this mode was constructed in order to confirm the cavity performance.

A block diagram of the mode feedback system is shown in Fig. 2. Two diagonal BPMs are summed to eliminate the transverse motion of the beam. A local oscillator, which is locked to main RF signal via 10 MHz external clock, is used to detect the instability mode. The detected synchrotron oscillation around 24 kHz is amplified and shifted in 90 degrees by an analog phase shifter. The single side band (SSB) modulator must be required for the feedback purpose. The IQ modulator, which consists of a local oscillator locked to $2\times f_{RF} + n\times f_{rev}$ frequency, are used to generate SSB signal as shown in Fig.2. The extenal 10 MHz signal is also used to lock to the main RF accelerating frequency. The output of the modulator was amplified by 500 W amplifiers (R&K, A0812-6057) and fed to the feedback cavity. The high power circulator is necessary to protect the amplifier from the reflection from the cavity, and to match the impedance between the

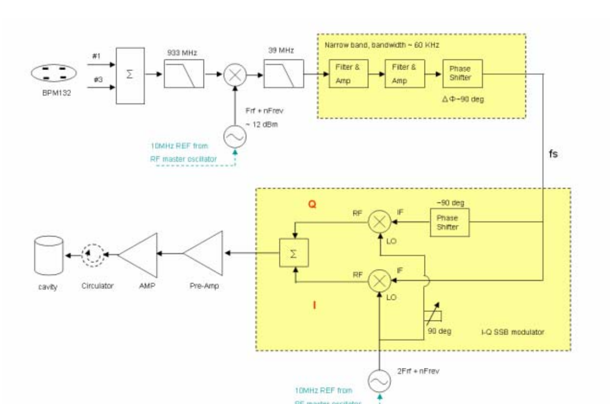


Figure 2: Block diagram of anlog mode feedback system. A high power circulator was not installed during this experiment.

cavity and the amplifier. Hence the circulator was not yet delivered during this experiment period, the power amplifier was directly connected to the cavity through 8-D coaxial cable. The highly-formed polyethylene cables were used to reduce the power loss in the cable. The distance from the amplifier to the cavity is about 8 m.

Results of Analog Mode Feedback

The beam spectrum without feedback measured by the button electrode is shown in Fig. 3(a). The center frequency of the spectrum analyzer was set to $2\times f_{RF}$ (= 1 GHz), and span was set to 1 GHz. The filling pattern of the storage ring was same as uses experiment condition, namely, 280 buckets are filled against the harmonic number of 312. The tail around the RF harmonics arises from the filling pattern. The several peaks around the tail are caused by the longitudinal coupled bunch instability, which are observed 58 MHz apart from RF harmonics. The beam current was about 70mA. When the mode feedback loop is closed, instability line was disappeared as shown in Fig.3 (b).

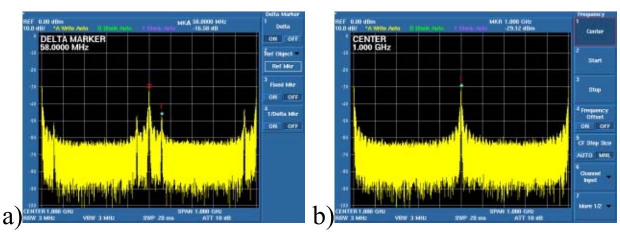
a)  b)

Figure 3: Beam spectrum measured by button electrode when feedback system are turned off (a) and on (b).

A gate signal with the period of 1 second was applied to the output of the IQ modulator to measure the growth time and damping time of the longitudinal instability. A result is shown in Fig. 4. The growth time was 80 ms and damping time was

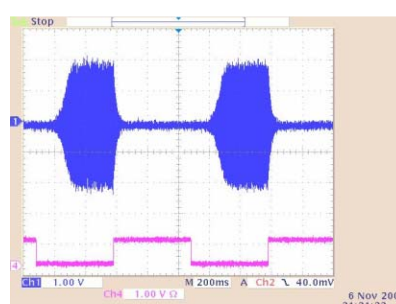


Figure 4: The grow/damp measurement of the instability. The blue line (CH1) shows the longitudinal oscillation and red line (CH4) represents the gate signal.

SEVERAL BUNCH FEEDBACK

Setup

By using the analog mode feedback configuration in the previous section, only one mode can be suppressed and we cannot increase the number of feedback loop up to the harmonic number, 312. Actually, the digital bunch-by-bunch feedback system is more suitable to damp every mode of the instabilities.

We plan to use GBoard [3] developed by SLAC, KEKB and DAΦNE, etc for the signal processing part. It equips 1 GSPS 8-bit analog-to-digital converter (ADC), Virtex-II FPGA and 12-bit digital-to-analog converter (DAC). For longitudinal feedback purpose, synchrotron frequency is much slower than the bunch frequency. In GBoard, a downsampling feature can save the FPGA logic size.

In prior to use the GBoard, digital signal processing part that consists of ADC+FPGA+DAC was tested using a commercial FPGA evaluation platform from Xilinx[4]. The evaluation board includes 2 channels 105 MSPS 14 bit ADC, Virtex4 XC4VSX35 FPGA and 2 channels DAC. Advantage of using the evaluation board is 1) easy and rapid application development is possible, 2) cheap price. On the other hand, the major disadvantage is that the ADC and DAC are not fast enough compared to the bunch spacing for PF. It is possible to handle the bunch motion up to 52 bunches. The evaluation board is not suitable for the real applications; however, it is worth testing the back-end modulator with the bunch-by-bunch system.

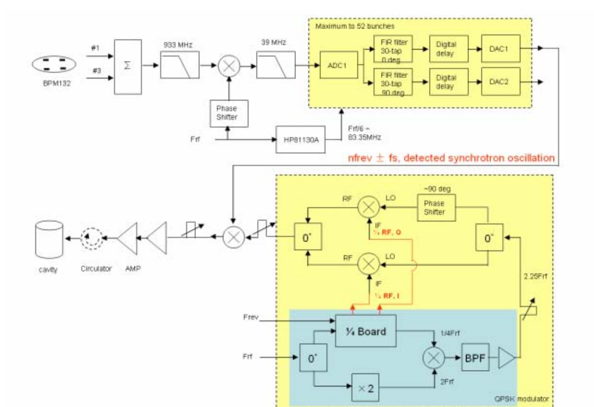


Figure 5: Bunch-by-bunch feedback system using Xilinx FPGA evaluation board and QPSK modulator.

To design feedback login on FPGA, System Generator [4] from Xilinx combined with MATLAB/Simulink from Math Works [5] is a very powerful tool. It is possible to design FIR filters and digital delay using graphical user interface of Simulink, and can generate a bit file that can be downloaded to FPGA without any deep knowledge of hardware description language (HDL). The 30-tap FIR filter, DC and revolution harmonics suppression were designed for the longitudinal feedback in PF.

A QPSK modulator was developed for KEKB bunch feedback system. Because the RF frequency of the KEKB and PF is slightly different, the delay lines are adjusted to match the PF parameters.

Results

Fifty two bunches are stored in equal spacing with the bunch current of 1mA. In this case, spectral line in each harmonics of $52\times f_{rev}$ will be expected. In Fig. 6, the span is set to observe the component of $2\times f_{RF}$ and $2\times f_{RF} + 52\times f_{rev}$. The spectral lines those are correspond to the coupled-bunch instabilities are observed in Fig. 6 (a). The bunch-by-bunch feedback system using the FPGA evaluation board suppressed the instabilities completely as shown in Fig. 6 (b).

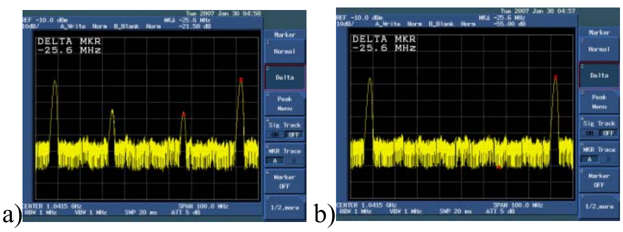


Figure 6: Beam spectrum when 52 bunches are stored in the ring. The digital bunch-by-bunch feedback is turned off (a) and on (b).

CONCLUSION AND FUTURE PLAN

The longitudinal bunch-by-bunch feedback system has been developed for the top-up injection of the Photon Factory. The feedback cavity was designed and installed in the storage ring. In order to investigate the performance of the cavity and other components such as a detector or modulator, mode feedback system was constructed. By using a commercial FPGA evaluation board, simple bunch-by-bunch feedback system were tested. In both case, the coupled-bunch instabilities were successfully suppressed up to 70mA. The maximum achieved current was limited by the reflection interlock of the power amplifier because the high power circulator was not used during this experiment.

We plan to close the bunch-by-bunch feedback loop in the end of Jun/2007. The latest version of GBoard, i.e. iGp [6], with a new firmware for the PF parameter is ready now. Also, two high power circulators are ready to install.

REFERENCES

[1] S. Sakanaka, *et al*, Phys. Rev. ST Accel. Beams 3, 050701 (2000)
[2] W.X.Cheng, T.Obina, T.Honda *et al*., "Bunch-by-bunch Feedback for the Photon Factory Storage Ring", EPAC2006 (2006) 3009
[3] D. Teytelman *et al*. "Design and testing of Gproto bunch-by-bunch signal processor", EPAC2006 (2006) 3038
[4] http://www.xilinx.com/
[5] http://www.mathworks.com/products/matlab
[6] http://www.dimtel.com/

