BUNCH-BY-BUNCH FEEDBACK FOR THE PHOTON FACTORY STORAGE RING

Weixing Cheng, Takashi Obina, Tohru Honda, Masaaki Izawa, Mikito Tadano, Makoto Tobiyama,
KEK, Oho 1-1 Tsukuba, Ibaraki ken, Japan
Takeshi Nakamura, Kazuo Kobayashi, JASRI/SPring-8, Hyogo-ken, Japan

Abstract

The Photon Factory (PF) ring will start the top-up operation or the continuous injection in 2006. Previously the octupole magnets were used to suppress the transverse coupled bunch instability and RF modulation method to enhance the bunch length has been effectively used to suppress the longitudinal instabilities. However, such kind of methods are not suitable for the top-up operation, we are preparing active bunch-by-bunch feedback systems for both transverse and longitudinal planes. The transverse feedback system has been installed along with the straight-sections upgrade, this system uses a FPGA based feedback processor board developed at the SPring-8, both horizontal and vertical signals are processed in a single control loop. For the longitudinal feedback, a two-port DAFNE type wide-band cavity has been designed and is now manufacturing, a digital signal processing part is under design. The system will start commissioning in autumn 2006.

INTRODUCTION

The 2.5GeV Photon Factory (PF) ring has upgraded the straight-sections, which increases the number of insertion devices [1]. After this upgrade, there has a plan to run the PF ring in top-up injection mode. Table 1 gives the specification of PF ring after the straight section upgrade.

Table 1: Main parameters of PF ring

Energy	2.5 GeV
Circumference	187 m
RF frequency	500.1 MHz
Harmonic Number	312
f_{rev}	1.6029 MHz
Natural emittance ε_x	36 nm·rad
Tune ν_x / ν_y / ν_s	9.60 /5.28/0.014
Damping time τ_x / τ_y / τ_s	7.8/7.8/3.9 ms

Normally, PF ring operates in multi-bunch mode, 280 bunches are stored with the initial beam current of 450mA. Transverse betatron oscillation, which is assumed to be ion instability, is observed while the beam current exceeds 100mA. Octupole magnets were used to increase the tune spread to cure the instabilities, however, they also limit the dynamic aperture of the ring, so that they can not be used at top-up injection.

And for longitudinal plane, the sideband will appear at about 60mA, it is assumed to be coupled bunch instability which is caused by cavity-like structures in the ring. RF phase modulation at twice of the synchrotron oscillation frequency[2] can considerably suppress the longitudinal instability, but it will increase the beam energy spread. It is necessary to suppress the longitudinal oscillation during the top-up operation.

TRANSVERSE FEEDBACK SYSTEM

Overview

Diagonal BPM button signals from a 6-button BPM detector are used to get the horizontal and vertical bunch oscillation. Variable attenuator (0.1 dB/step) is used for each button signal to adjust the level. Timing of two-channel signal is well adjusted by line stretchers while single bunch is stored. The difference signal from hybrid is amplified and split into 6 channels, these signals are sampled by six 12-bit ADCs, 20-tap FIR filter and one turn delay function are implemented inside a FPGA chip to get the correction signal, 500MHz DAC output feed to amplifier and stripline kicker. Two amplifiers AR75A400 (Amplifier Research, 75W, 10kHz-400MHz bandwidth) and 45cm stripline kicker are available. ADC+FPGA+DAC box was originally developed at SPring-8, both horizontal and vertical plane FIR filters can be realized in the single control loop[3,4]. Agilent 81130A pulse/pattern generator is used to generate the LO signal and clock signal for ADC-FPGA-DAC digital box, the frequency is $f_{RF}/6$ and duty cycle is exactly 50%, which can be provided by the programmed pulse pattern in 81130A. With this LO signal, each bunch oscillation can be detected at the edge of LO signal. Block diagram of transverse bunch by bunch feedback system is shown in Fig 1.

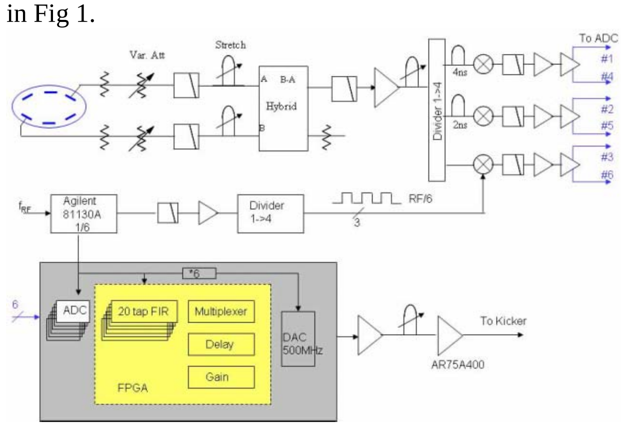

Figure 1: Transverse bunch-by-bunch feedback system block diagram at PF ring.

Performance

Figure 2 shows the spectrum with and without feedback. Horizontal sideband completely damped when the feedback turn on, and beam profile contracts obviously from the SR monitor.

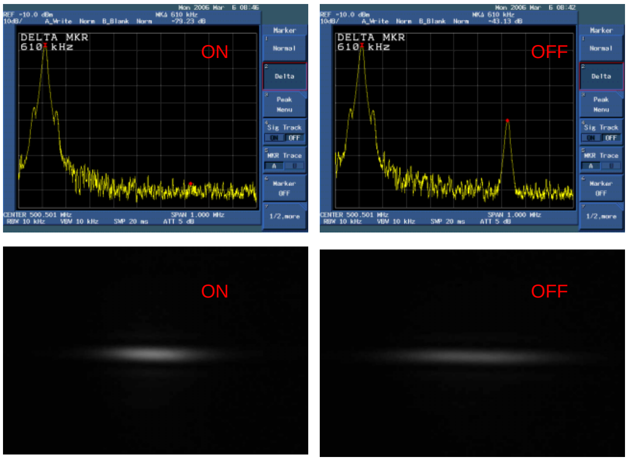

Figure 2: Spectrum and SR beam profile while feedback ON/OFF. (SPAN=1MHz, f_{peak}=500.1MHz).

After the straight-sections upgrade, the dominant transverse instability of PF ring is caused by ion instability, the mode number of such kind of instability is small (less than 10 in PF ring's case). Using the transverse feedback system, all these modes can be suppressed well.

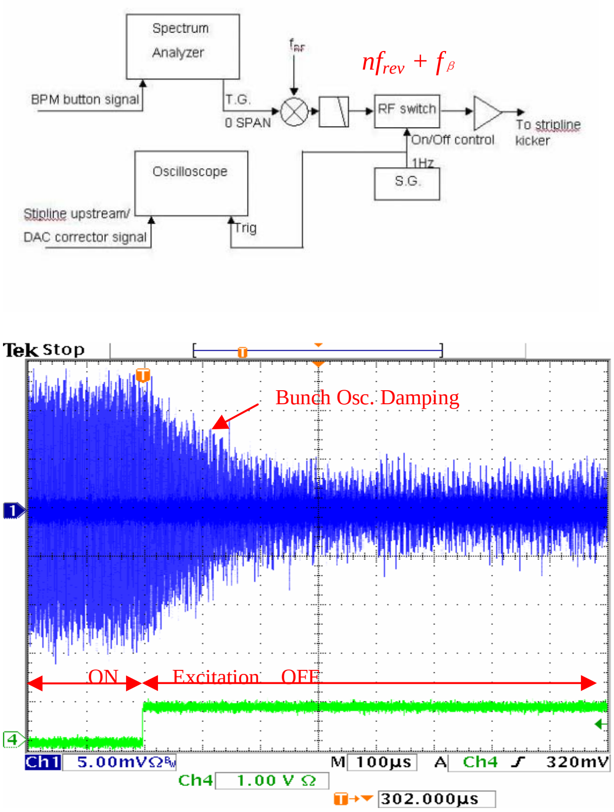

Figure 3: Damping time measurement for different modes.

Tracking generator signal from spectrum analyzer is used to excite the beam (f_{RF} + nf_{rev} + f_β, n is the mode number). Using an RF switch, we can control the excitation ON/OFF, then bunch oscillation changes with the switch and we can measure the damping time from the oscilloscope. Measurement setup and a typical oscillation damping waveform while turn off the excitation are shown in Fig 3. With feedback on, the damping time of all modes is less than 1 ms, that's much faster than radiation damping time and it can suppress the instability growth very well. Since injection bump is not closed and that will excite the stored beam during injection, damping of the excited beam is also compared with feedback ON and OFF, while turn on the feedback, the damping time due to injection excitation can be decreased to 0.8ms, without feedback, it is determined by radiation damping time ~ 8ms, and the oscillation will blow up sometimes.

LONGITUDIANLFEEDBACK SYSTEM

System Consideration

Longitudinal instability at PF ring is suppressed by RF phase modulation during user operation, however, some instability mode can not be suppressed well and it's changing depend on the beam current. Longitudinal bunch-by-bunch feedback system is under consideration now. For the control loop, RF part will get the phase information (synchrotron oscillation), ADC + FPGA + DAC implementation will be adopted, we plan to use GBoard[5] which is under development by SLAC and KEKB. Down-sampling and digital filter will detect the synchrotron oscillation and set the correct signal through DAC.

To get the high shunt impedance, a 2-port DAFNE-type cavity[6] has been designed, the peak shunt impedance can be as high as 700 Ohm. Specifications of longitudinal kicker are listed in table 2. To cure all the instability modes, the kicker bandwidth should be larger than $f_{RF}/2$, which is 250MHz in PF ring, the center frequency is selected to 2.25×f_{RF}, that is mainly determined by commercial high power amplifier. Shunt impedance should be large enough to kick the beam effectively for the working frequency (1GHz – 1.25GHz).

Base-band correct signal from DAC is modulated to the cavity working frequency, SSB modulator can be used. Wide-band circulator is necessary to protect the high power amplifier damaged by the pickup signal from cavity. Preliminary design of the system is shown in Fig 4. Comb filter can increase the phase detection sensibility.

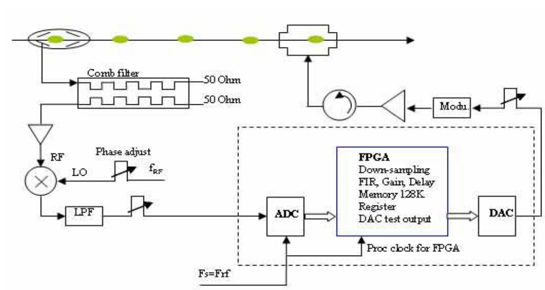

Figure 4: Longitudinal feedback architecture.

Table 2: Specification of longitudinal kicker

TM010 center freq.	1.13 GHz
Bandwidth	>250 MHz
Port Number	2
Beam pipe radius	50 mm
Shunt impedance	> 500 Ohm (1-1.25 GHz)

Longitudinal Kicker Design

HFSS and MAFIA T3 module are used to design the cavity kicker, HOM of the cavity is analyzed. HFSS model of 2-port cavity design and mechanical drawing are shown in Fig 5.

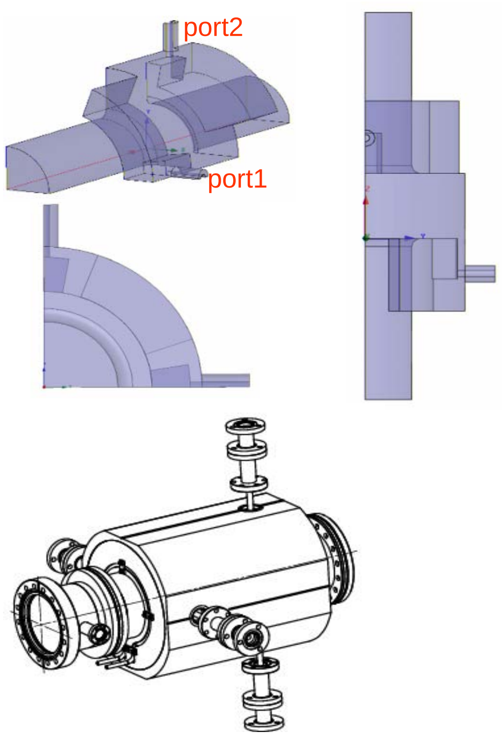

Figure 5: HFSS model (1/4) for 2-port longitudinal cavity and mechanical drawing.

To estimate the wakefield and beam impedance of this longitudinal cavity, MAFIA calculation has been done. The longitudinal peak impedance is less than 300 Ohm, that means the fastest growth rate is about 1.2 sec^{-1}, transverse impedance is about 18kOhm/m, which means the transverse growth rate is about 0.0013 sec^{-1}. Both transverse and longitudinal instability growth rates are much smaller compare to radiation damping rate. Therefore the cavity kicker has almost no contribution to the instabilities. Calculated impedance and corresponding instability growth time for each mode are shown in Fig 6.

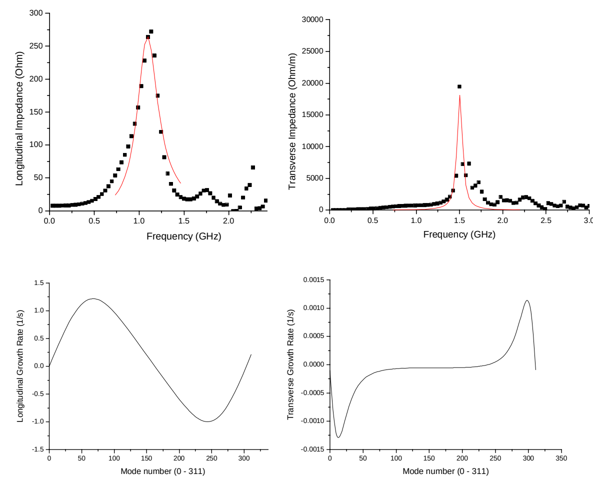

Figure 6: 2-port cavity kicker impedance and instability growth rate for longitudinal and transverse plane.

SUMMARY

Transverse bunch-by-bunch feedback system has been implemented and working without any trouble since Oct. 2005. It can suppress the horizontal and vertical instabilities simultaneously in one control loop. Damping time for each instability mode has been measured. Future analysis will try to figure out the main source of instabilities using this system.

For longitudinal plane, 2-port cavity kicker has been designed, which is under fabrication now. Digital control loop and other RF components are under development.

The authors thank to staff of the PF light source division for support of the machine studies, thank to S. Sakanaka for helpful information on cavity impedance and instability growth time calculation.

REFERENCES

[1] T. Honda et. al, in proc of PAC05, 2678
[2] S. Sakanaka Physical Review ST. Vol.3 (2000)
[3] T. Nakamura, K. Kobayashi, ICALEPCS'05, Geneva, Oct. 2005，PO2.022-2
[4] T. Nakamura et. al, this conference.
[5] http://www.slac.stanford.edu/~dim/Gboard/index.html
[6] R. Boni, et. al, Particle Accelerators, 1996. Vol. 52. pp.95-113.