MULTI-BUNCH FEEDBACK ACTIVITIES AT PHOTON FACTORY ADVANCED RING

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Abstract

The photon factory advanced ring (PF-AR) is a dedicated single bunch light source operating at KEK, normally it's operated at 6.5 GeV with 60mA injection beam current. However, there has some users' experiment require multi-bunch operation for high intensity x-ray beams. The old transverse damping system can suppress only one (or two) bunches, new multi-bunch feedback system has been successfully tested to a maximum of 64 bunches.

Both analog and digital transverse feedback loop has been tested at AR to store multi-bunches. For analog feedback control loop, long cables are used to delay the bunch position error signal from BPM buttons. Betatron phase advance between stripline kicker and BPM are well selected to be around 90 deg. A digital feedback loop based on FPGA evaluation board has been successfully operation, which include two ADCs, one Virtex4 FPGA chip and two 14 bit DACs. Bunch position error signal sampled by ADC, filtered by 10-tap FIR filter implemented in FPGA and send to DAC output for correction. Phase shifter in the FIR filter can be adjusted depend on the kicker and BPM betatron phase advance, FIR filter will also cut the DC components and pass through the betatron oscillation signal which increase the system dynamic range a lot. Digital delay can also be implemented inside FPGA instead of long cable delays.

Maximum beam current of 97mA has been achieved for several bunches' storage, betatron oscillation of the stored beam can be suppressed well.

INTRODUCTION

The PF-AR is a dedicated single bunch ring, injection beam current of 60mA with a typical lifetime of 15 hours has been achieved. Some user's experiment need more high intensity x-ray radiation, one example is clinical application at 5.0 GeV mode[1], for this reason, multi-bunch injection and storage has been tested at PF-AR.

There has injection threshold around 20mA even for single bunch injection at PF-AR, feedback damper system is needed to suppress the injection oscillation, as well as stored beam betatron oscillation. The old transverse damping system has been operated in PF-AR for more than 20 years, key component of the damper system is such a called BOD (Bunch Oscillation Detector[2]), which can detect and damp one bunch oscillation. There has two such kind of BOD detection circuits available, that means it's possible to store 2 bunches. For more bunches injection and storage, new feedback systems is required, benefits of highly developed digital technology makes it possible to implement the required feedback control loop relatively simple in these days. Compared to digital feedback control, analog control suppress the beam oscillation in a more direct way, there has many good review paper for feedback control.[3,4] Both analog and digital feedback loop has been successfully tested for multi-bunch injection and storage. Table 1 list the main parameters of PF-AR feedback system.

Table 1: Parameters of PF-AR Feedback System.

Beam Energy	6.5 GeV/ 5 GeV
Injection Energy	3.0 GeV
RF frequency	508.57 MHz
Harmonic Number	640
Circumference	377.26 m
Revolution frequency	795 kHz
Qx/Qy/Qs	10.15/10.21/0.03
Emittance	294 nm.rad
BPM SW20 $\beta x/\beta y$	13.6527/2.43916 m
Kicker $\beta x/\beta y$	3.81227/12.1319 m
BPM->Kicker $\Delta\Phi x/\Delta\Phi y$	9.73924/9.73916
Kicker length	1300 mm
Kicker shunt impedance	>100 kOhm @20MHz

FEEDBACK IMPLEMENTATION

For analog feedback system, it's convenient to use two BPMs to detect bunch position signal. Two BPMs vector sum can produce arbitrary phase advance between BPM and kicker. Figure 1 shows the betatron phase relations of BPMs and kicker. During the machine study at PF-AR, to make the RF electronics simple, only one BPM signal is used to detect the betatron position oscillation, phase advance from the BPM to kicker is well selected to be around 90/270 deg, which means the fractional part of BPM-> kicker phase advance should be near 0.25 or 0.75, BPM SW20 can fulfill it in both vertical and horizontal plane as shown in Table 1.

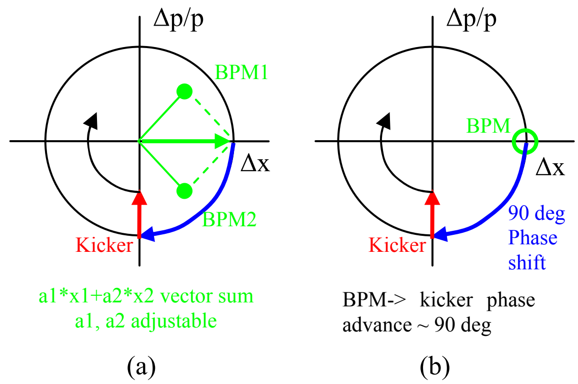


Figure 1: Phase relations between BPMs and kicker in analog feedback.

To realize one-turn delay from BPM to kicker, additional 160m low-loss cable is needed besides the cables between ring tunnel and local control station. Such a long cable and analog loop has some disadvantages, for example close orbit change will decrease the system dynamic range a lot. One solution is adopting analog 2-tap filter to cut the DC orbit offset and revolution harmonics, however another one-turn delay cable is needed and cable length varies depends on the environment temperature, that will generate one-turn delay errors and decrease the 2-tap filter performance; another solution is adopt feedback loop to cancel the closed orbit change, for example, gain of each button-channels can be adjusted depends on the COD offset. In this way, it's possible to compensate the COD influence, however, the system becomes complicated. Long cable attenuation is another problem, which will decrease the signal-to-noise ratio too.

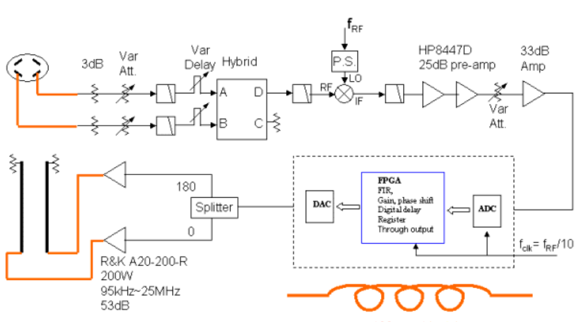


Figure 2: Multi-bunch transverse feedback for PF-AR.

Reliable solution for these analog feedback disadvantages is using digital filter. As the FPGA (Field Programmable Gate Array) technology developing, more and more accelerator diagnostic and control systems have used FPGA chips [5]. A digital feedback loop based on FPGA evaluation board has been successfully operation at PF-AR, the evaluation board includes 2 channels 105MSPS 14 bit ADC, Xilinx Virtex4 XC4VSX35 FPGA chip and 2 channels 14 bit DAC. As shown in Figure 2, bunch position error signal sampled by ADC, filtered by 10-tap FIR filter implemented in FPGA and send to DAC output for correction. Phase shift in the FIR filter can be adjusted depending on betatron phase advance from BPM to kicker, FIR filter will also cut the DC components and pass through the betatron oscillation signal, which increase the system dynamic range. Digital delay can be easily implemented inside FPGA instead of long cable delays. In Fig. 2, ADC+FPGA+DAC inside the dashed box is implemented in the evaluation board, which can be replaced by 160m long cable (8-D low loss) shown as brown line in the drawing.

System Generator[6] from Xilinx is a powerful toolbox for DSP design and implementation into FPGA chips. Combined with MATLAB/Simulink, System Generator can generate the model including FIR filters and digital delay, ISE[6] project can be produced from it. For non-experts of HDL (Hardware Description Language) programmer, System Generator is an easy to use toolbox which makes you possible to realise the design within one hour. Generated bit file can be downloaded through JTAG cable.

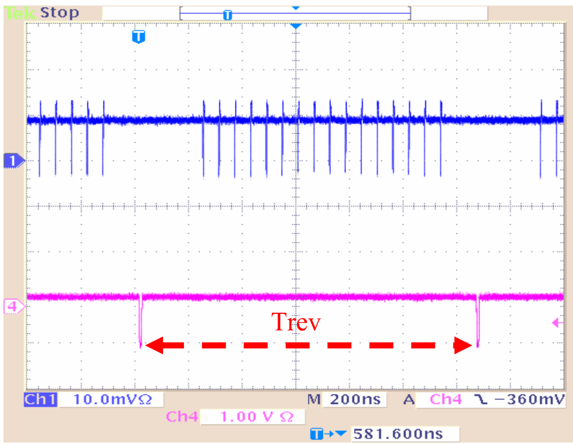
For ADC, FPGA and DAC processing clock, it's possible to handle maximum sampling rate of 105 MSPS, however, the main component who limit the system bandwidth is high power amplifier. There has 25MHz 200W amplifier available which can feedback about 64 bunches even fill in PF-AR ring. In this case, ADC and FPGA processing clock is divided by 10 from RF frequency. Latency from ADC to DAC output is about 534ns, which makes it possible to feedback within one turn even considering the cables between tunnel and local station. 10-tap FIR filter implemented with simple MAC (Multiplier-Accumulator) operation passes horizontal betatron oscillation component, DC and revolution harmonic are well suppressed, a typical measured FIR filter response is shown in Fig. 3.

Figure 3: 10-tap FIR filter frequency response used in PF-AR multi-bunch feedback. (Blue line – amplitude response; red line – phase response).

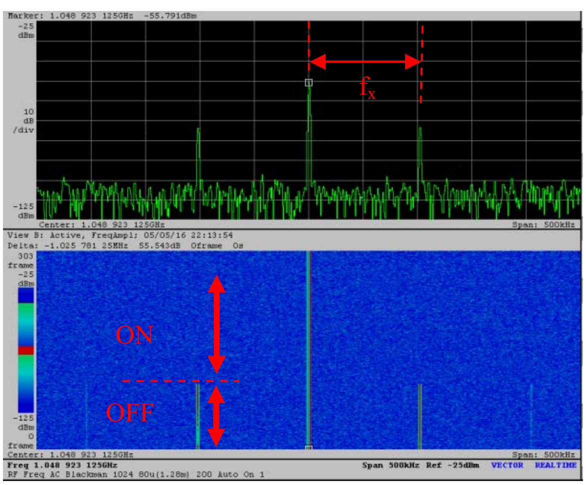
PERFORMANCE

With the analog and digital control loop, several machine studies have been going on at PF-AR, maximum beam current of 97mA has been achieved for multi-bunch injection and storage.

Figure 4 shows the filling pattern of 16 bunches in AR ring using analog feedback, BPM spectrum getting from real-time spectrum analyzer gives the betatron oscillation information with feedback ON and OFF.



(a)



(b)

Figure 4: (a). Sixteen bunches filled in AR ring, CH1 is BPM button signal, CH4 is revolution frequency of the ring; (b). BPM spectrum with feedback ON/OFF, while feedback turns off, the horizontal sideband appears clearly. (Centre frequency: 1.048923125 GHz, SPAN: 500 kHz).

Digital feedback control loop based on the FPGA evaluation board has been tested in PF-AR. A typical filling pattern getting in AR's machine study is shown in Fig. 5. In the oscilloscope screen capture, 3 bunches were stored, labelled bunch #1, #2, #3, CH1 is the BPM diagonal buttons delta signal, oscillation can be observed while the feedback is OFF, CH2 is stripline kicker upstream signal, CH3 is the revolution frequency. Since bunch #3 is under injection, the oscillation is larger compared with other two bunches.

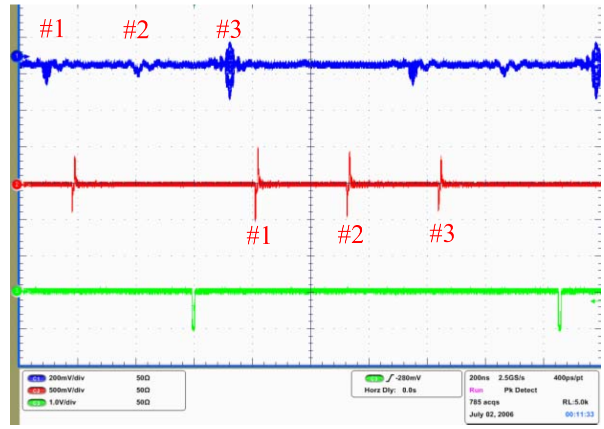


Figure 5: Filling of 3 bunches in AR ring using digital feedback loop. (I ~ 60mA).

Injection damping can be achieved to be less than 1ms using the feedback system, however blow up phenomena has been observed after several ms to several tens ms. This phenomena had been analyzed before by Dr. Minagawa[7] as a saw-tooth instability. From BOD output, same blow up phenomena has been observed. While blow up happens, it's very hard to injection any more, the reason for this blow up phenomena seems related to longitudinal instabilities, which is not clarified yet.

SUMMARY

Using multi-bunch feedback, 16 bunches (64 bunches maximum) has been successful stored with a maximum beam current large than 90mA. Blow up phenomena was observed for several bunches' injection, while this blow up happens, it's very hard to injection the beam. Future work will try to solve this problem and increase the beam lifetime for multi-bunch operation.

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