DESIGN AND COMMISSIONING OF A BUNCH BY BUNCH FEEDBACK SYSTEM FOR THE AUSTRALIAN SYNCHROTRON

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Abstract

A transverse bunch feedback system has been designed in order to fight the effects of coupled bunch instabilities. This system is currently in the commissioning phase. A digital system was chosen because of its flexibility and diagnostic potential. While the major components were sourced from a private company, time has also been spent on in house development of an analogue front-end and the diagnostic components of the software.

INTRODUCTION

Measurements and calculations have shown that in-vacuum insertion devices installed in the Australian Synchrotron's storage ring lattice [1] are increasing the effects of coupled bunch instabilities. The growth rates associated with these instabilities will eventually exceed the amount that it is possible to damp with adjustments to the chromaticity. At this time it will be necessary to have an operational bunch by bunch feedback system.

System Overview

A bunch by bunch feedback system (figure 1) monitors the transverse position of each bunch on a turn by turn basis and then determines an appropriate 'kick' to damp any detected motion. The calculated kick is applied to each bunch every turn. Such a system is in operation on many storage rings [2-5]. Systems similar to the design described in this paper are in operation at Diamond [6], and ESRF [7].

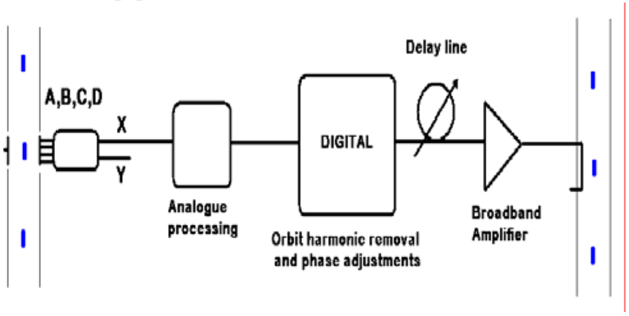


Figure 1. An overview of the bunch feedback system. Only the x-plane feedback system is shown. An identical system is implemented for the vertical feedback.

DESIGN CONSIDERATIONS

The parameters of the Australian Synchrotron's storage ring that are relevant to bunch by bunch feedback are shown in table 1. The growth rates are the theoretical values with a chromaticity of [1 1], and all 3 existing IVUs (In Vacuum Undulators) set at minimum gap. The kicker shunt impedance is calculated from the known geometry of the kickers.

Table 1. Key parameters of the Australian Synchrotron's lattice.

Bunch spacing	0.6 m, 2 ns, 500 MHz
Storage ring circumference	217 m, 720 ns, 1.39 MHz
Harmonic number	217/0.6 = 360
Nominal tunes (x and y)	13.29, 5.216
Estimated growth rates (x and y)	5.2 ms, 1.1 ms
Kicker shunt impedances (X and Y)	$R_x = 1.3$ kΩ (at 700 kHz)
	$R_y = 7.8$ kΩ (at 700 kHz)
Beta functions at the button and kicker.	$\beta_{x,BPM} \approx 9$ m
	$\beta_{y,BPM} \approx 3.2$ m
	$\beta_{x,kicker} \approx 9.2$ m
	$\beta_{y,kicker} \approx 3.5$ m

The ADC (Analogue to Digital Converter) digitisation rate is determined by the bunch spacing to be 500 MSamples/s. This rate gives one sample per bunch per turn.

Each bunch follows a sinusoidal motion at the tune frequency., therefore the calculation to determine the damping kick is simply a phase delay at the tune frequency. This calculation can be performed digitally as an FIR filter.

The motion of the 360 bunches can be thought of as the sum of 360 modes of oscillation, the lowest mode is at half the orbit frequency, and the highest mode is at half the bunch frequency (700 kHz to 250 MHz). All of the information on bunch motion is in this frequency range and so this frequency range was important to determine component specifications.

The equation used to determine the power necessary to damp the motion of the bunches is [8]:

$$P_{kicker} = \frac{2}{R_k \beta_k \beta_{BPM}} (E)^2 (T_0)^2 \left(\frac{A_{BPM\max}}{\tau} \right)^2 ,$$

where the values for R and β are defined in table 1, E is the energy of the beam in *eV*, T_0 is the period of oscillation of the ring (720 ns), τ is the desired damping time (and must be less than the growth time of the instabilities) and A is the oscillation amplitude of the beam at the BPM. Once damped, the oscillation amplitude associated with the instability will be very small (~ 10 μm) and so the power required to maintain a stable beam is in the order of 10 mW. However, the initial instability amplitude is in the order of 1 mm and in that case, the required power to damp the instability is in the order of 10 W - 100 W. This drives the decision to use 100 W amplifiers.

DETAILED DESCRIPTION

Button Signal Analysis

The 4 signals from a BPM are fed to hybrids which add and subtract the signals to create pulses which are proportional to the x and y positions of the bunches. (figure 2)

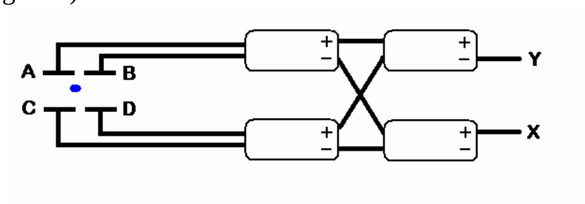


Figure 2. The configuration of the analogue hybrids which calculate the x and y position of the bunches.

The cables between the buttons and the hybrids were all made to be the same lengths so that the analogue sum and difference calculations are accurate. For this reason, the hybrids were placed close to the BPM and semi-rigid cables used.

The hybrids were chosen to have a bandwidth of 1.5 GHz ± 250 MHz. This range covers the third harmonic of the bunch frequency. Surrounding the third harmonic is all of the required information of bunch oscillation. The third RF harmonic was chosen because the BPM response peaks at this point and the best signal is obtained. It is also important to consider the fact that RF components covering the range 700 kHz – 250 MHz are more difficult to produce than components covering the range 1.25 GHz – 1.75 GHz and are therefore lower quality and more expensive.

Analogue Processing Front End

The analogue front end (figure 3 and 4) demodulates the 1.5 GHz ± 250 MHz bunch signal to base-band (0 – 250 MHz). This conversion is achieved by mixing the bunch signal with the 3rd harmonic of the 500 MHz master oscillator signal. The mixed signal is then fed through a low pass filter to remove all irrelevant signal noise.

One analogue front end was bought from the company I-tech while a second was designed and produced at our laboratory. The 'in-house' development consists of individual RF components connected with semi-rigid cable while the unit purchased from I-tech is a PCB (Printed Circuit Board) device.

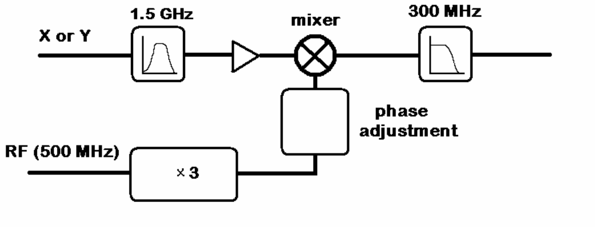


Figure 3: The analogue front end configuration.

Figure 4: The physical layout of the analogue front-end produced by the Australian Synchrotron. Both x and y channels visible.

Currently we are using a loan front end fom I-tech until either of the two permanent front ends are prepared.

Digital Processing

The Digital processing:

- Adjusts the phase of the signal from each bunch so that the applied kick will damp the motion of that bunch.
- Removes any DC component of the signal
- Removes unwanted noise from the signal

The signal from the front end is digitised by 4 separate 125 MSample/s ADCs each offset by 2ns. This provides an effective digitisation of 500 MSamples/s so that each bunch's position is recorded every turn. The clock for the ADC and DAC (Digital to Analogue Converter) is provided from an external source to maintain coincidence with the bunches in the storage ring.

The bunch position data of each bunch is treated independently by a separate FIR (Finite Impulse Response) filter (figure 5). Each filter has up to 16 taps.

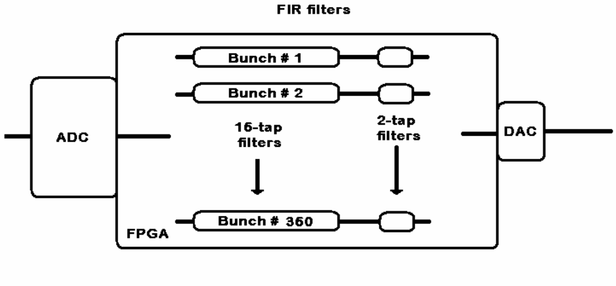


Figure 5: The digital processing configuration.

A second 2-tap filter associated with each bunch acts as a 'knob' to adjust the phase delay of the bunch signal through the system. This is useful during commissioning when it is necessary to tune the system to give the optimum kick to each bunch.

There is a digital delay associated with the DAC which adjusts the signal delay in 2 ns steps. This is to ensure that the correction signal intercepts the intended bunch.

The hardware and software associated with the bunch's digital signal processing was obtained from I-tech. The diagnostics that can be performed by this equipment will be developed in house.

Analogue Back End and Kicker

The analogue backend (figure 6) amplifies the signal from the digital electronics ready to be fed to the stripline kickers. The amplifier has a bandwidth of 700 kHz - 250 MHz and has a linear phase response to avoid signal distortion which can lead to excitation of some modes.

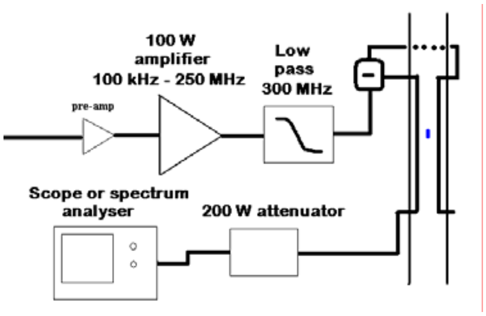


Figure 6: The configuration of the analogue back-end electronics.

The kickers (figure 7) are designed to have a high shunt impedance. The value of shunt impedance is a measure of the bunch deflection that is obtained for a given input power. To improve the kick strength further, the kickers are fed differentially by using a 180 deg splitter which operates over the full bandwidth and power of the amplifier.

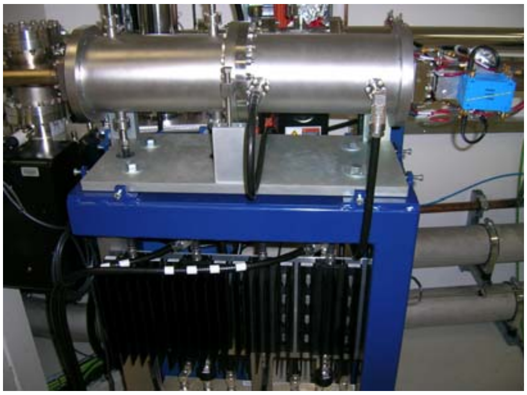


Figure 7: The kickers are seen along with the attenuators. Behind the attenuators are the low-pass filters and splitter for each channel (x and y).

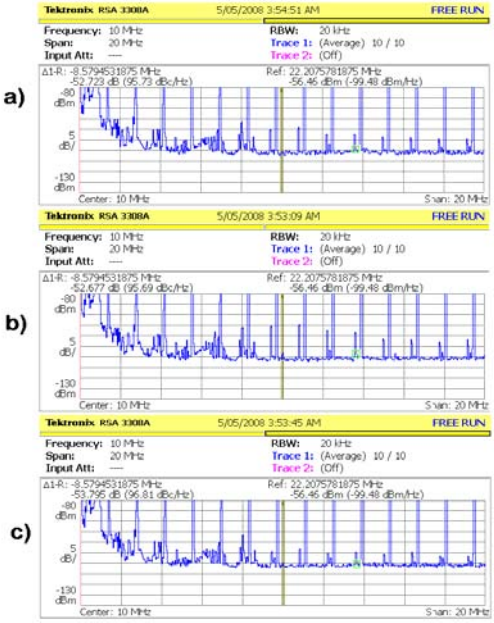
INITIAL RESULTS

During commissioning the 3 main adjustments have been made to improve the damping:

- Loop gain
- Bunch signal phase delay in the Digital processing
- Total signal delay

Initially, a simple two tap FIR filter was used used for the main digital signal processing. We were able to excite or damp the modes by choosing the appropriate phase for the filter (figure 8).

We also found that we were able to increase the current at which the onset of instabilities occured. Under these conditions the feedback was switched off and current was lost from the ring. This is a very good indication that the feedback is functioning in the desired way.



Tektronix RSA 3308A 5/05/2008 3:54:51 AM FREE RUN
Frequency: 10 MHz
Span: 20 MHz
Input Att: ---
RBW: 20 kHz
Trace 1: (Average) 10 / 10
Trace 2: (Off)
Δ1-R: -8.5794531875 MHz -52.723 dB (95.73 dBc/Hz)
Ref: 22.2075781875 MHz -56.46 dBm (-99.48 dBm/Hz)

Tektronix RSA 3308A 5/05/2008 3:53:09 AM FREE RUN
Frequency: 10 MHz
Span: 20 MHz
Input Att: ---
RBW: 20 kHz
Trace 1: (Average) 10 / 10
Trace 2: (Off)
Δ1-R: -8.5794531875 MHz -52.677 dB (95.69 dBc/Hz)
Ref: 22.2075781875 MHz -56.46 dBm (-99.48 dBm/Hz)

Tektronix RSA 3308A 5/05/2008 3:53:45 AM FREE RUN
Frequency: 10 MHz
Span: 20 MHz
Input Att: ---
RBW: 20 kHz
Trace 1: (Average) 10 / 10
Trace 2: (Off)
Δ1-R: -8.5794531875 MHz -53.795 dB (96.81 dBc/Hz)
Ref: 22.2075781875 MHz -56.46 dBm (-99.48 dBm/Hz)

Figure 8: The response to a two tap filter a) off b) on but exciting the modes c) on with 180 degrees flip and damping the modes.

CONCLUSIONS

We have produced a bunch-by-bunch feedback system which has been shown to have a damping effect on the oscillation modes of the beam.

The installation of the final front end unit will provide an improved damping effect. The development of the digital diagnostic tools will also allow a much better characterisation of the feedback loop. Removing the residual offset in the BPM will allow a higher loop gain.

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