PB12

Longitudinal Bunch Feedback System with a Two-Tap FIR Filter Prototype

Makoto Tobiyama, Eiji Kikutani and Yasuyuki Minagawa*
National Laboratory for High Energy Physics, 1-1 Oho, Tsukuba 305, Japan
*The Graduate University for Advanced Studies, 1-1 Oho, Tsukuba 305, Japan

Abstract

Feasibility of the prototype digital filter for the longitudinal bunch feedback system for KEKB rings has been examined in TRISTAN-AR. Detected longitudinal positions for individual bunches were digitized and recorded on memories. The hardwired FIR filter with 2 tap was used to shift the phase over 90° and to suppress the unnecessary DC component. The feedback signal was supplied to beam in the form of the phase modulation of accelerating cavities. The feedback system worked with the loop gain up to 30 dB. Detuning the RF cavities to excite single bunch Robinson instability with the feedback working, the instability was completely suppressed even under the growth time of 0.3 ms.

I. Introduction

In a storage ring which accumulates many bunches with high beam current, such as KEKB rings, strong coupled-bunch instabilities with many modes will occur both in transverse and longitudinal planes. To cure the instabilities, we are now developing bunch-by-bunch feedback systems for KEKB accelerators[1]. In the longitudinal plane, a digital filter of two-tap FIR scheme will be used to shift the phase of the detected position signal over 90° and to suppress the unnecessary static (DC) component.

Prior to the fabrication of the filter complex with full function, which will work for 5120 bunches with 508 MHz of system clock, we have examined the feasibility of the two-tap FIR scheme with a quick-prototype board. Using the RF cavities as the kicker, the longitudinal feedback loop was closed for single bunch beam in TRISTAN-AR at 2.5 GeV. Feedback parameters such as the loop gain or the damping time was measured successfully. Related parameters for TRISTAN-AR at the feedback experiment are listed in Table I.

Energy	E	2.5	GeV
Circumference	C	377.26	m
Beam current	I_b	$1 \sim 4$	mA
RF frequency	f_{RF}	508.5808	MHz
RF voltage	V_{RF}	$1 \sim 1.5$	MV
Harmonic number	h	640	
Synchrotron tune	ν_s	$0.025 \sim 0.032$	

Table I
Main parameters for TRISTAN-AR with the prototype longitudinal feedback

II. Experimental Setup

A block diagram of the longitudinal feedback system prototype at TRISTAN-AR is shown in Fig. 1. The system consists of the position detection part, phase shifter filter part and kicker part.

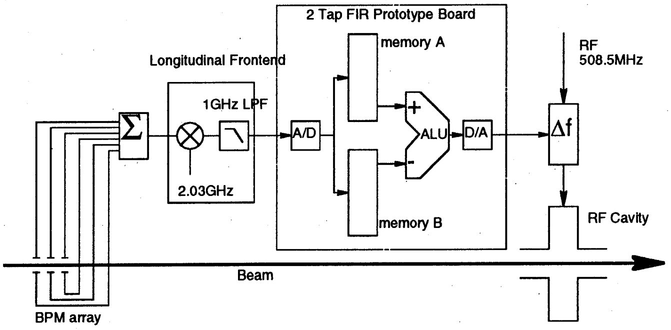

Figure. 1. Longitudinal bunch-by-bunch feedback system prototype at TRISTAN-AR. The phase of the detected longitudinal signal is shifted by 90° with the 2-tap FIR filter made of pure hardware logic circuit. RF cavities were used as the longitudinal kicker.

A. Longitudinal position detection system

The longitudinal position of a bunch is measured with the wideband phase detection system which is capable to distinguish individual signals from the bunches with the bunch spacing of 2 ns. Signals from the longitudinal aligned series button electrodes are combined with the period corresponding to the 4-th harmonic of the RF frequency, that is 2.034 GHz in our case. Clearly this circuit makes an FIR band pass filter with the first center frequency of 2.034 GHz. The output is, therefore, a burst sine-like pulse train signal. Three pairs of electrodes installed in the south interaction region in AR were used[2]. Here, because of the narrow size of the vacuum chamber, 70 mm in inner diameter around the pickups, we can use the beam signal up to 2.6 GHz without being bothered by heavy noise that propagate in the vacuum chamber just as the microwave in a circular wave guide.

The pulse train is expressed by

$$I_b \cos(n\omega_{RF}t + \Phi \sin(\omega_s t))$$

where $n = 4$ and Φ and ω_s are the amplitude of the synchrotron oscillation and the angular synchrotron frequency, respectively. By multiplying the reference signal with a double balanced mixer (DBM, R&K M-21), a wideband homodyne phase detector is formed. The IF output of the DBM becomes

$$I_b \cos(n\omega_{RF}t + \Phi \sin(\omega_s t)) \times \sin(n\omega_{RF}t)$$
$$= \frac{I_b}{2}(\sin(2n\omega_{RF}t + \Phi \sin(\omega_s t)) - \sin(\Phi \sin(\omega_s t))).$$

By rejecting the higher frequency component with a low pass filter (LPF, f_c=1 GHz), baseband component of the synchrotron oscillation is detected as the form of

$$I_b \sin(\Phi \sin(\omega_s t)) \sim I_b \Phi \sin(\omega_s t).$$

The linear bunch current dependence of the output, that means the current dependence of the loop gain, is not so severe problem because the growth rates of the instabilities will also depend on the bunch current and will be slower than the linear dependence in many cases.

B. Two-tap FIR filter prototype board

In our feedback system, the signal process (phase shift by 90° and elimination of static (DC) offset) is performed with a 2-tap FIR filter realized by a simple hardware system. As the algorithm of the 2-tap FIR filter has been described elsewhere[3], we will give only a short explanation on the filter. The response of the FIR filter has the form of the linear combination of the data which have been obtained as a time series, $x(1), x(2), \cdots$. The 2-tap filter has only two terms the coefficients of which are 1 and -1 so the output has the form of

$$y(n) = x(n_1) - x(n_2).$$

and has the favorite frequency of $1/2(n_1 - n_2)$. By suitably selecting the tap positions, n_1 and n_2, that means by selecting the address-shift of the memory, we can tune the center frequency and the group delay of the filter.

The quick-prototype board we have made does not use digital demultiplexing technique. Therefore it works only below the bunch frequency of 6.4 MHz. This board consists of a 125 MHz ADC (AD9002) in the front-end and a 40 MHz DAC (SONY CXD1171) in the back-end circuit, full-adders (SN74HC283) and two sets of memories (HM62832UHP-15) in the digital filter. The size of the memory is 4 k bytes in total. The board is packaged in a 1-span CAMAC module. The tap positioning of the filter is set through the CAMAC command very easily. Figure 2 shows the modulation input for the beam and the output of the filter. An example of the frequency response is shown in Fig. 3.

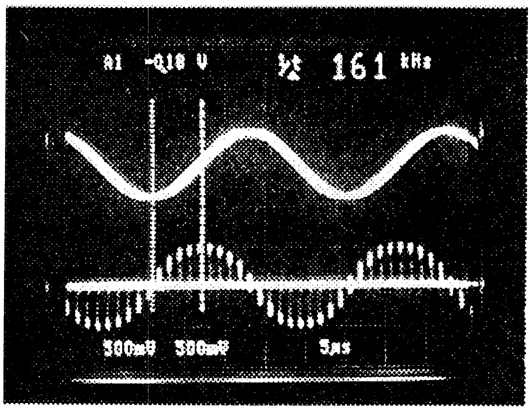

Figure. 2. Synchrotron oscillation modulation signal for the beam (upper trace) and the output of the filter (lower trace). The clock of the filter was 8 × f_{rev}, though there was only one bunch.

C. Feedback kicker

Because the longitudinal kicker is still on the design stage, we used the accelerating cavities as a longitudinal kicker. In AR, there are two RF stations, EAST and WEST, each of which has 4 APS cavities of 9 cell structure. Our kicker was 4 cavities of the WEST station. We modulated the phase of the accelerating RF signal at the low level circuit. The feedback filter and the phase shifter at WEST station was connected with a coaxial cable of length of about 140 m. As the passband of the cavity is fairly narrow, we can only use single-bunch beam for the feedback experiment.

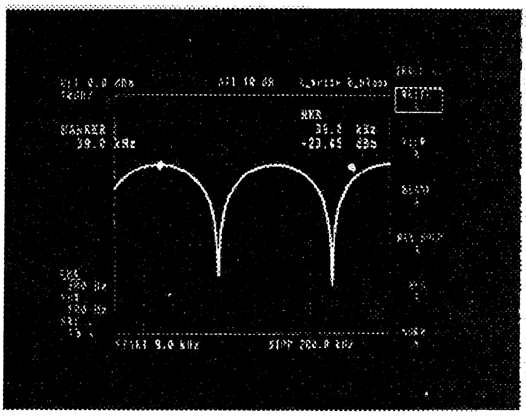

Figure. 3. An example of the frequency response of the filter.

III. Result and discussion

At first, the longitudinal oscillation was excited artificially with the phase modulation of the EAST cavities. Under the condition, we tuned the tap positions of the filter to maximize the loop gain of the feedback. The tap position was chosen to be (n_1 = 30, n_2 = 182), where the clock frequency of the filter was 8 × f_{rev}. The difference of (182-30)/8=19 agreed with the synchrotron tune of $1/2\nu_s \sim 20$ clearly. With increasing the analog gain, it began to excite an oscillation with some other frequencies than the synchrotron frequency which virtually limited the gain of the loop. The maximum gain of the feedback was about 20 dB. Note that this gain does not show the maximum gain of the feedback loop for instabilities because the energy of the excitation was supplied continuously under the condition.

Next, the longitudinal oscillation was excited by intentionally shifting the resonant frequency of the cavities to arise the single-bunch Robinson instability. By tuning the resonant frequency shift, we controlled the growth rate of the instability. With setting the tuning angle of the accelerating cavities to be +10°, we could excite constant longitudinal oscillation without losing the beam. Figure 4 shows the beam spectrum before and after the closing feedback loop at the detunig angle of the RF cavities of +10°.

The synchrotron sidebands were suppressed below the noise level. That clearly shows the loop gain is grater than 30 dB.

We have increased the detuning angle of the cavities to excite the Robinson instability with the gain of the feedback loop increasing to find the break point where feedback are no longer works correctly. We found that the growth time of the instability was about 0.1 ms at the break point.

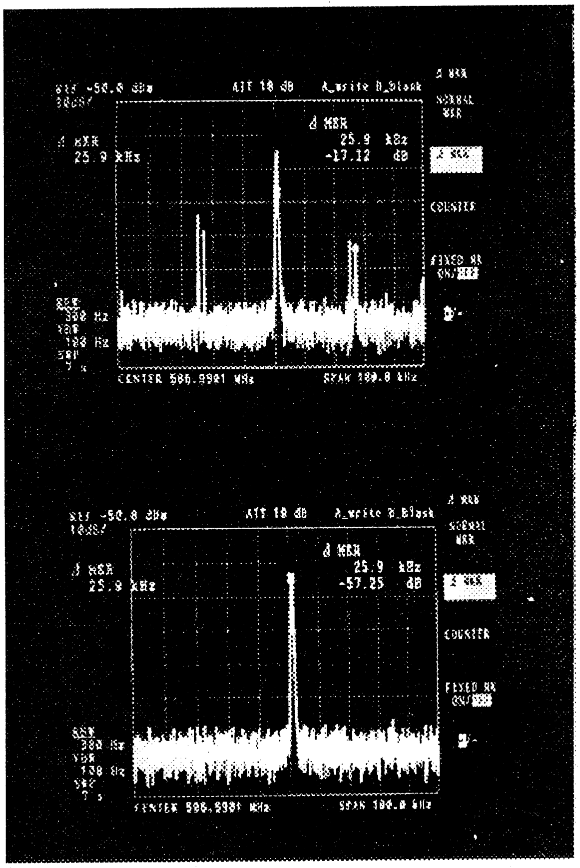

Figure. 4. The beam spectrum before (upper) and after (lower) the closing of the longitudinal feedback loop.

We measured the oscillation also by a turn-by-turn position detection system. The front-end circuit of the measurement system was equivalent to that of the feedback system but completely independent of the feedback loop. By this system we observed the change in the oscillation around at the very moment of the feedback on/off. Examples of the observed data are shown in Fig. 5. We have caught the growth of the oscillation with the maximum growth time of about 300 turns or 0.36 ms.

When we change the RF voltage, the shift in the synchrotron frequency occurs that loses the gain of the feedback system. Our filter worked well with the RF voltage 1 MV and 1.5 MV by selecting suitable tap positions for each operation. This shows the good flexibility of the feedback system under various conditions.

IV. Summary

We have examined the feasibility of the bunch-by-bunch feedback scheme with the two-tap FIR filter quick-prototype in TRISTAN-AR. The frequency performance was measured in a bench and expected characteristics were obtained by the quick-prototype board.

The experiment of the longitudinal feedback has also been performed. The kicker for the system was not an actual one but the accelerating cavities. The oscillation was safely damped by the feedback system and the damping time of, roughly, 0.1 ms was obtained. Based on the experiment, we have confirmed that the 2-tap FIR filter system is powerful enough for the signal processing of the longitudinal bunch feedback system.

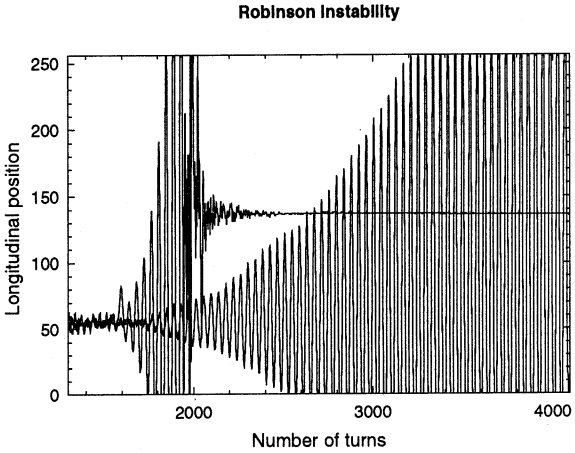

Figure. 5. The observed oscillations just after the feedback was turned off. The abscissa is the turn number and the ordinate is the longitudinal position in an arbitrary unit. The slow oscillation corresponds to the growth time of about 1 ms and the fast one corresponds to about 0.3 ms.

We are now installing a longitudinal kicker with the bandwidth of 125 MHz with the expected shunt impedance of about 1.1 kΩ at TRISTAN-AR. With the power amplifiers that can supply up to 0.5 kW to the kickers, we expect the maximum feedback voltage of about 900 V/turn. This value corresponds to the damping time of about 7 ms at the saturating amplitude of $\Delta E/E$=0.1%.

References

[1] E. Kikutani, et. al., in Proceedings of 1995 IEEE Particle Accelerator Conference, Dallas Texas. U.S.A./ KEK Preprint 95-20.

[2] E. Kikutani, et. al., AIP Conference Proceedings 333, (363) 1995.

[3] E. Kikutani and Y. Minagawa, KEK Report 94-5, 1994.