Initial Test of a Bunch Feedback System with a Two-Tap FIR Filter Board

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Abstract

Initial beam test of the KEKB bunch-by-bunch feedback system prototypes has been performed in the TRISTAN-AR on the longitudinal plane. A simple two-tap FIR filter system consisting of hardware logic's realizes the function of the phase shift by 90 degrees, the suppression of static component and the delay of up to a hundred of turns. With the prototype filter board and a longitudinal kicker, the feedback loop has been closed successfully. The shunt impedance of the kicker was estimated from the excitation amplitude and measured damping. The damping time of the system has been measured by using the single bunch Robinson instability. The feedback system stabilized the coupled bunch instability completely under 8 bunch operation.

INTRODUCTION

The rings of KEKB are designed to accumulate many bunches with huge beam current, which may cause many strong coupled bunch instabilities both in transverse and longitudinal planes. Even with the special care for the reduction of the sources of the instabilities, some dangerous impedance may remain high. Studies on the acceleration cavities predict that some modes have the growth times of the order of a few ms in transverse plane, a few 10 ms in the longitudinal plane in the worst case. Therefore, the method to analyze and suppress the instabilities has the key to achieve the designed quality of the rings. The goal of the feedback systems has been set to achieve the damping time of one ms for the transverse and 10 ms for the longitudinal planes.

We are now developing beam feedback systems with the bunch-by-bunch scheme and are installing the prototype systems in TRISTAN accumulation ring (TRISTAN-AR)(1–5). In our feedback systems, we detect oscillation of each bunch individually, shift the phase of the signal by 90° of the synchrotron frequency, then kick the bunch to damp the oscillation. We have already installed button electrodes with increased frequency response, two wideband transverse kickers, 8 transverse amplifiers of 200 W each, one longitudinal prototype kicker and two longitudinal power amplifiers of 500 W in the south straight section of AR.

In the longitudinal signal processing, we will use a two-tap FIR filter which has the function of DC suppression and the phase shift by 90°. Prior to the fabrication of the full function filter board, we have made a prototype board to prove the validity of the two-tap scheme. In this paper, we show the result

Ring		LER	HER	TRISTAN-AR	
Energy	E	3.5	8	2.5	GeV
Circumference	C	3016.26		377.26	m
Beam current	I	2.6	1.1	0.001	A
RF frequency	f_{RF}	508.887		508.58	MHz
Harmonic number	h	5120		640	
Particles/bunch	N	3.3×10^{10}	1.4×10^{10}	7.8×10^{9}	
Synchrotron tune	ν_s	$0.01 \sim 0.02$		0.02	
Longitudinal damping time	τ_e	23	23	20	ms

Table 1. Main parameters of KEKB and TRISTAN-AR.

of the beam test of the longitudinal feedback system prototype in TRISTAN-AR. We have closed the feedback loop and measured the shunt impedance of the prototype kicker. Spontaneous instability was successfully damped with enough damping rate. Also we have tried to damp coupled bunch instability under 8 bunch operation. Fabrication of the first set of full function filter board that can handle all the bunches with the minimum bunch spacing of 2 ns is under way. Related parameters of the KEKB accelerators as well as those of TRISTAN-AR (at beam test) are listed in Table 1.

EXPERIMENTAL SETUP

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

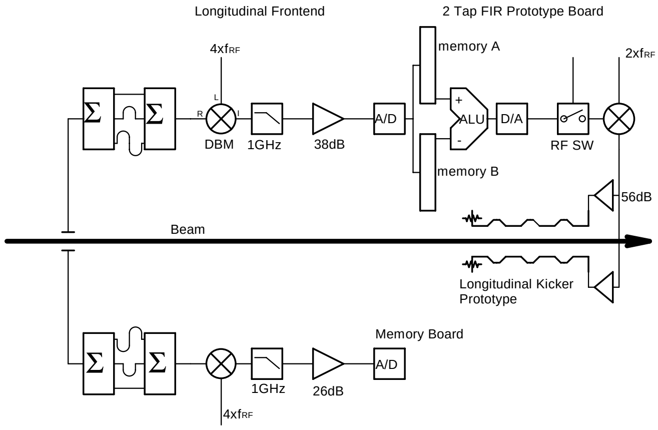


Figure. 1. Block diagram of the longitudinal feedback system prototype installed in AR.

Position Detection System

The longitudinal position of a bunch is measured with the wideband phase detection system which is capable of distinguishing individual signals from the bunches with the bunch spacing down to 2 ns. Signal from a button electrode is divided into three branches by a power combiner and summed up again by another power combiner. As the lengths of the delay cables which connect the two combiners are designed to have the time difference of $\alpha + \mathrm{n}\lambda/c$ (n = 0,1,2), where α is constant and λ is the wavelength of the detection frequency, this system works as an FIR bandpass filter with the center frequency of nc/λ. The detection frequency is chosen to be the 4-th harmonic of the RF frequency, that is 2.034 GHz in our case. The output of the filter is a burst of sine-like signal with the length less than 2 ns.

Using a double balanced mixer (DBM, R&K M-21), the sine-line burst is multiplied by the reference signal which is quadruple of the RF signal. By rejecting the higher-frequency component with a low-pass filter (LPF, f_c=1 GHz) from the output of the IF of DBM, baseband signal of a synchrotron oscillation is detected as the form of $\sim I_b \Phi \sin(\omega_s t)$ if the amplitude Φ is small.

We have used two independent set of detection system; one for the feedback signal and the other for only monitoring of the oscillation. Position signal for the feedback system is amplified with three stage amplifiers with a total gain of 38 dB. For the bunch oscillation monitor, we have used two stage amplifiers with a total gain of 26 dB.

Two Tap FIR Filter Complex

The signal process, the function of which are the phase shift by 90° and the elimination of static (DC) component, is performed with a 2-tap FIR filter realized by a simple hardware system. The response of a 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 selecting suitable tap positions, that means by selecting the address-shift of the memory, we can tune the center frequency and the group delay of the filter.

Prior to the fabrication of the filter complex with full function, which will be shown in the last section of this paper, we have examined the feasibility of the filter scheme with a simple prototype board. The prototype board works only below the system clock of 6.4 MHz that corresponds to the 8 equally-spaced bunch operation of AR. It has an 8-bit 125 MHz FADC (AD9002) for the digitizer, and has the memory for 4096 turns of bunch position on single bunch mode. The board is packaged in a 1-span CAMAC module.

For the bunch position monitor, we have used a 500 MHz FADC board (REPIC RPC-250) which is packaged in a 1-span CAMAC module. It has 4096 bytes of memory per channel.

Feedback Kicker

The R&D for the KEKB longitudinal kicker has been centered on the wideband device, which is based on series stripline structure (the series drift tube type), originally proposed by G. Lambertson(6). A combination of the beam pipe and the inner electrodes creates a coaxial structure of the characteristic impedance of 25Ω. RF power fed by power amplifiers propagates as the TEM wave along the structure. It has four electrodes connected with the delay lines. The carrier frequency is 1 GHz, which is double of the RF frequency. The ideal shunt impedance ($R_{sh} = V_{kick}^2/(2P_{in})$) is 1.6 kΩ and the bandwidth will be less than 125 MHz. This kicker has two input ports of 50Ω and two output ports.

We have prepared two wideband amplifiers with the maximum power output up to 500 W each (R&K A0812-6057). One amplifier consists of 164 GaAs FETs (Fujitsu FLL120MK) and forms complete A-class structure. The bandwidth is about 250 MHz (890 MHz $\sim$ 1144 MHz) with the total gain of 60 dB. The measured time response of the amplifier from 5% to 95% of full power was about 2.5 ns.

BEAM TEST OF THE LONGITUDINAL SYSTEM ON TRISTAN-AR

Selection of the Tap Positions

The center frequency, phase shift and the delay of the two-tap FIR filter is determined by the selection of the tap positions. As the sampling frequency was $8 \times f_{rev}$, the difference between the tap number should be $n_1 - n_2 = 8 \times \mathrm{i}$ and should be near to the synchrotron frequency, that is $(n_1 - n_2)/8 \sim f_{rev}/f_s/2$. The position of the first tap, n_1, determines the phase shifts and should be selected to coincide the burst output of the amplifier and the beam passage. We at first searched for the best tap position to maximize the loop gain of the feedback system by exciting the synchrotron oscillation with the positive feedback loop. The best tap position was (249, 65) for positive loop for the accelerating voltage V_c=1 MV. The tap difference of (249-65)/8=23 agrees with the measured synchrotron frequency of 19.5 kHz.

Measurement of Shunt Impedance of the Kicker

The realistic shunt impedance of the kicker is very important for the development and selection of the final kicker system for KEKB. If we know the maximum amplitude of the longitudinal oscillation excited by our feedback system in the positive feedback mode, the natural damping time of the beam and the input power to the kicker, we can estimate the shunt impedance of the kicker by comparing the results from simulations. In the single bunch mode, as the Robinson damping mechanism may strongly contribute to the longitudinal damping, we must measure the realistic damping time at first. We have measured the bunch oscillation turn by turn in time domain just after the positive feedback has suddenly turn off. Figure 2 shows an example of the measured damping (a) and excitation (b) behavior with the V_c=1 MV and the beam current of 0.7 mA. The fitted damping time was 2 ms, which is much faster

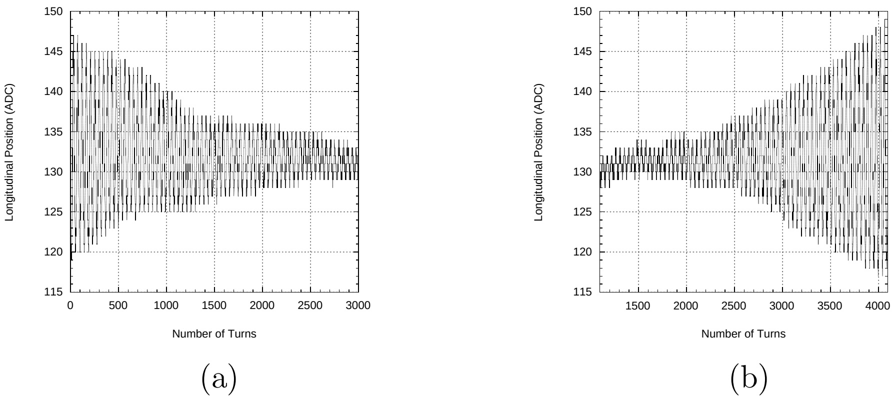


Figure. 2. Damping (a) and excitation (b) of longitudinal oscillation just after the positive feedback loop has suddenly opened/closed. The natural damping time (a) was about 2 ms and the excitation time (b) was about 1.5 ms.

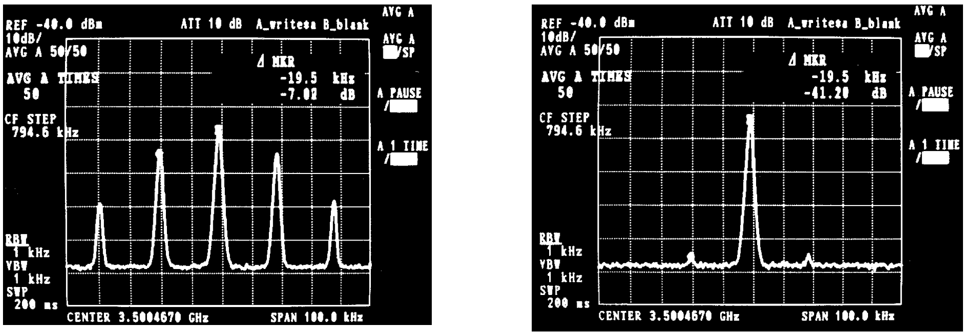
than the radiation damping time of about 20 ms.

The longitudinal distribution of the zero cross point of a bunch signal from the button electrode was measured with the digitizing oscilloscope (HP 54121T). When the total input power to the kicker was about 640 W, the maximum amplitude of the longitudinal oscillation was 60 ps. To make such oscillation in the simulation, it is necessary to have the kick voltage of about 1300 V per turn. Comparing these data, the shunt impedance R_{sh} of the kicker was estimated to be $(1300^2)/640/2 = 1.3$ kΩ, that is about 80 % of the ideal one.

Damping of the Single Bunch Oscillation

We can excite the longitudinal oscillation by intentionally shifting the resonant frequency of the cavities to arise the single-bunch Robinson instability. By tuning the resonant frequency, we controlled the growth rate of the instability. With setting the detuning angle of the accelerating cavities to be $+9°$, we excited constant longitudinal oscillation without losing the beam. Figure 3 (a) shows the beam spectrum with the detuning angle of $+9°$ with the beam current of 0.7 mA. The maximum amplitude of the oscillation was about 50 ps. With closing the negative feedback loop, we succeeded in damping the oscillation completely, as shown in Fig. 3(b).

The observed residual oscillation was about 4.3 ps in standard deviation, that is the jitters of the measuring system. The input power to the kicker in the



(a) (b)

Figure. 3. Beam spectrum without feedback system(a) and with the feedback system(b). The longitudinal oscillation was excited artificially by tuning the resonant frequency of the cavities.

stationary state was about 16 W. Figure 4 shows the damping of the oscillation just after the feedback loop was closed. The damping time was 1.9 ms. The

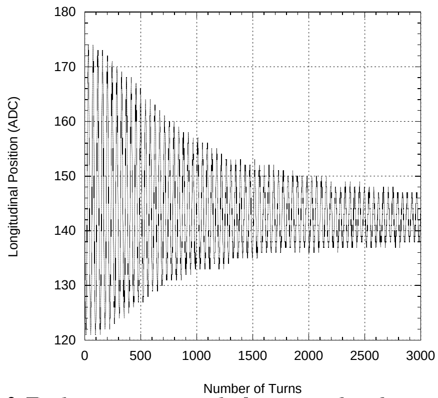
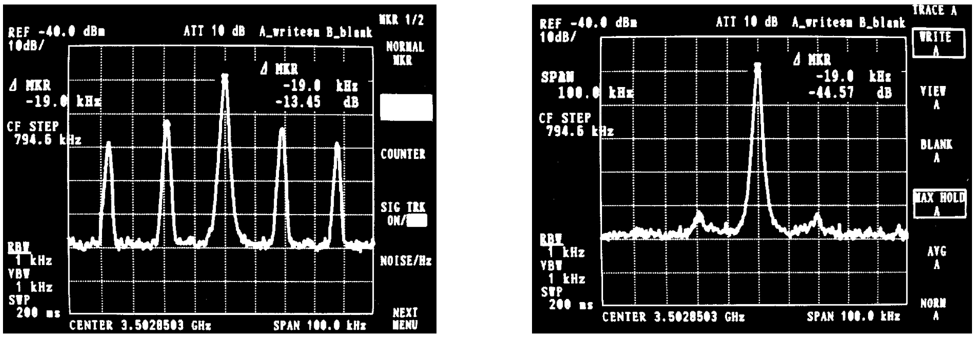


Figure. 4. Damping of Robinson instability with the negative feedback on. The damping time is 1.9 ms.

feedback system has damped the oscillation completely up to the detuning angle of $+30°$. When the detuning angle was $+35°$, the residual amplitude was increased to 5.9 ps. Nevertheless, we did not lose the control the oscillation. The input power to the kicker in the stationary state was about 84 W.

Damping of the Coupled Bunch Oscillation

As the filter system can handle 8 bunches with the system clock of 6.4 MHz, we tried to damp spontaneous coupled bunch oscillations of 8 equally-spaced bunch operation. Figure 5(a) shows the beam spectrum with the total beam current of 4 mA, *i.e.*, the bunch current was about 0.5 mA. Heavy and unstable coupled bunch oscillation was observed. This oscillation was completely damped with the feedback loop closed, as shown in the beam spectrum in Fig. 5(b). The residual oscillation was about 4.5 ps. With increasing the beam



(a) (b)

Figure. 5. Beam spectrum without the feedback (a) and with the feedback system (b) under 8 bunch operation.

current, transverse oscillations started to grow with the beam loss even if we damped the longitudinal oscillation.

FULL FUNCTION FILTER BOARD AND ITS APPLICATION

The fabrication of the first set of the full function board has almost finished. Figure 6 shows an photograph of the filter board. The board has the

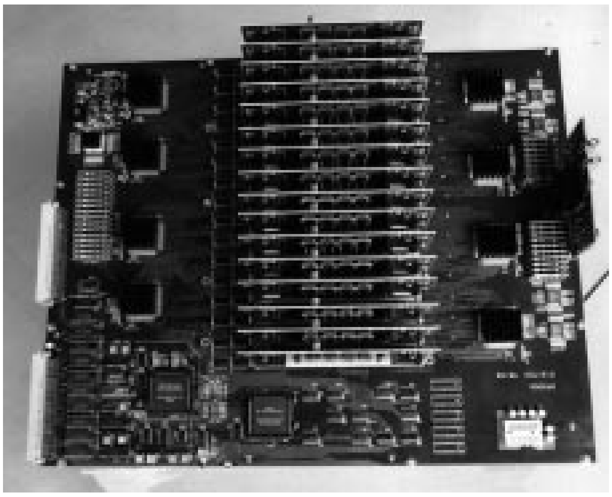


Figure. 6. Schematic view of full function filter board.

size of 366.71×400 mm and is controlled through a VME interface. Detailed explanation is given elsewhere(5), we therefore describe it briefly here. It has one ADC daughter card and 16 memory-ALU daughter cards on a mother board. We adapted a MAX101 for the ADC, TQ6122-M for the DAC. On the mother board there are eight custom GaAs LSIs; four fast data demultiplexers (FDMUX, Oki GHDK4211) and four fast data multiplexers (FMUX, Oki GHDK4212). The fast ECL signal from the ADC card the transfer rate of which 255 Mbytes/s is demultiplexed with the FDMUXs to 32 channels TTL signal (16Mbytes/s), through the memory-ALU block that forms a 2-tap FIR filter, multiplexed with the FMUXs to 255 Mbytes/s ECL signals. The memory has the depth of about 100 turns of revolutions per every bunch for KEKB rings. We use FPGAs with the function of a subtracter and the bit shifter on the memory-ALU block.

We designed the mother board so that it can be a mother board also for a transient recorder by replacing the memory-ALU daughter board with a dense memory board and by replacing the address control FPGAs on the mother board. In our design, the maximum memory we can mount on the board will be about 40 MB. Combining the memory board and the feedback system enables us to measure the growths of the instabilities very clearly. We are now planning to use the memory board for the study of the photo electron instability which will be held on late 1996 at BEPC ring in Beijing, China.

SUMMARY

We have examined the feasibility of the bunch-by-bunch feedback system scheme with the two-tap FIR filter board in TRISTAN-AR. The shunt impedance of the longitudinal kicker prototype has been measured with the measurement of the damping time and the maximum excitation amplitude. Estimated shunt impedance agreed with the expected value within 80%. This encourage us to proceed the development of this kind of kicker.

The damping time of the feedback system has been measured with the artificially excited Robinson instability. The instability has been suppressed completely with the feedback system. Even under the heavy instability condition, our system did not lose controllability. In the 8 bunch operation, our feedback system has succeeded in suppressing the coupled bunch instability.

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