RECENT PROGRESS IN THE DEVELOPMENT OF THE BUNCH FEEDBACK SYSTEMS FOR KEKB

E.Kikutani, T. Kasuga, Y.Minagawa, T.Obina and M.Tobiyama,
National Laboratory for High Energy Physics,
Oho 1-1, Tsukuba-shi, Ibaraki, 305 Japan

Abstract

In KEKB, which is a B-factory project at KEK, the bunch spacing is very short, only 2 ns, and the number of the bunches comes up to about 5000 per ring. In order to cure the instabilities due to the high beam current, we will use bunch feedback systems in KEKB rings. Recently we developed the new position detection system and made a prototype of the signal process system for the feedback systems. Using these tools and accelerating cavities as the kicker we performed an experiment for checking a longitudinal feedback system. The Robinson instability which was intentionally excited was successfully damped with a short damping time.

I. INTRODUCTION

KEKB, a B-factory project at KEK in Japan, is now under construction. In KEKB, the number of bunches per beam is about 5000 and the bunch spacing is only 2 ns. Under this condition it is feared that coupled bunch instabilities due to some impedance sources limit the luminosity. In order to cure these instabilities, we will use powerful bunch feedback systems in both the transverse and longitudinal planes. We have already started the development study of the feedback systems. Up to the present our studies were mainly on the position detection system and the data process system. The results of the studies were published in the papers[1] and [2]. Recently we have improved the performance of the position detection system by increasing the detection frequency. For the data process part, we have designed and made a prototype of a signal process system, which is a 2-tap digital filter realized by a pure hardware logic. In this paper, we report the performance of these newly developed tools and result of the longitudinal feedback experiment at KEK.

II. RECENT PROGRESS OF THE POSITION DETECTION TECHNIQUE

A. 2 GHz as the detection frequency

The front-end part of the bunch feedback system is a simple RF circuit. This circuit inputs the pulses from pickup electrodes and outputs a pulse whose height is proportional to the position of a bunch. As we have explained in the previous paper[2], this output signal is obtained as the phase difference between two (quasi) sinusoidal signals, both in the longitudinal and transverse planes. The frequency of these sinusoidal signals is called the detection frequency. For the longitudinal plane, the detection-frequency component is extracted from the beam signal and its phase is compared with a standard timing signal, which is made from the accelerating RF signal. In the transverse plane, we use the AM/PM technique[4]. In this case, the two signals to be compared are obtained from pickups. In both cases, we must use band-pass filters to extract the detection-frequency component out of the beam signal.

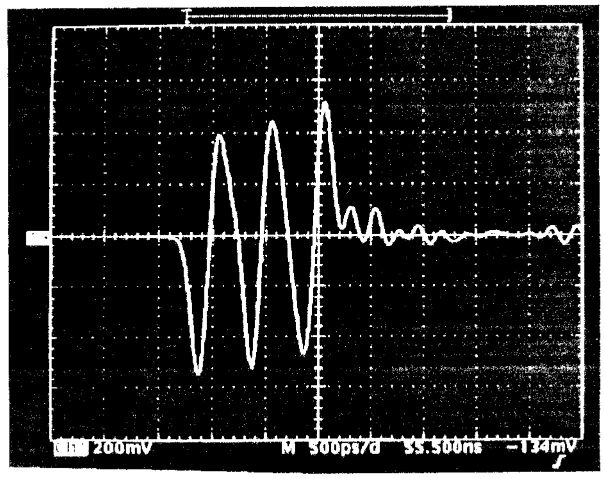

Figure 1. An oscilloscope photo of the pulse train.

We have performed many experiments to develop the front-end part of the feedback systems[1]. There, we used 1.5 GHz as the detection frequency. The main reason why we used this frequency was to avoid RF noises propagating within the beampipe of a radius of ∼50 mm. But this frequency is not high enough considering very short bunch spacing, 2 ns, in KEKB. Then, we installed a new set of pickup electrodes attached to a beampipe with a radius of 35 mm in TRISTAN Accumulation Ring at KEK (AR). With this beampipe we now can use the detection frequency of 2 GHz. Six button electrodes are used for each plane (longitudinal, horizontal and vertical) then there are 18 electrodes in total. The six pulses are combined by a power combiner to make an input of the front-end circuit. The cables connecting the electrodes and the power combiner are carefully chosen to make a 3-cycle sine-like pulse train. This cable-combiner system works as a low-Q band pass filter effectively. The pulse obtained this technique is shown in Fig. 1. We can catch that the length of the main part of pulse train is only 1.5 ns. With this technique we can measure the position of each bunch independently.

B. Application of the position detection system

One application of the position detection system explained above is mode identification of the coupled bunch instabilities. We made experiments in AR to study various impedances which may cause instabilities. In these experiments, we store a number

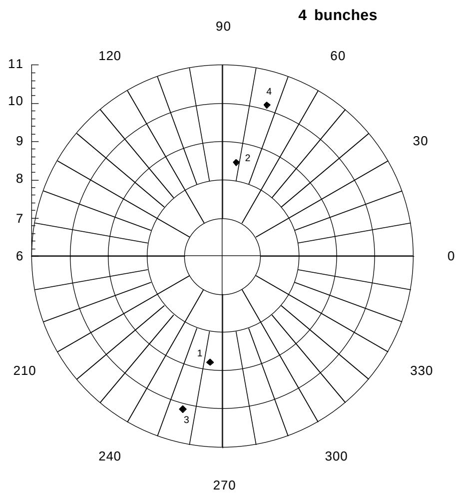

Figure 2. The complex logarithm of the FFT of the oscillation.

of bunches in the ring and observed their oscillations with our position detection system. The output of the front-end circuit is sent to a CAMAC module which packages a 500 MHz flash analog-to-digital converter chip(SONY CXA1276) and 4 kbytes memory (Fast ADC module).

The method of the analysis is as follows. The longitudinal position, that is, the timing of these bunches (here we explain the method by an example of the 4-bunch case) were recorded in the memory over 1024 turns at real time. After data-taking we perform the discrete Fourier transformation on these 4 data, namely, we get 4$\times$512 complex values that are the frequency spectrum of the oscillations. When bunches oscillate we can find peak(s) in these data. Now we pick up the value at the peak and get the complex logarithm of this value. Manifestly the argument of this complex value corresponds to the phase of the bunch oscillation and its absolute value is proportional to the logarithm of the oscillation amplitude. A typical example is shown in Fig. 2. We can easily recognize that 4 points are aligned along a line of 75 degrees and 75+180 degrees. This means that the mode of coupled bunch oscillation was 2. We know that the accelerating cavity in AR has a higher order mode the of 1463.7MHz from other measurement. This frequency is 1842 times of the revolution frequency of AR. The data strongly suggests that the bunch oscillations correspond to this higher order mode.

III. Prototype 2-tap FIR filter

In our feedback system, the signal process (phase shift by 90 degrees and elimination of DC offset) is done by a 2-tap FIR filter realized by a pure hardware system. As the algorithm of the 2-tap filter has already been given in the paper[3], we will give only a short explanation on the 2-tap digital filter here. In general, the output of an FIR filter is obtained as the linear combination of the data which have been obtained as a time series, $x(1), x(2), \cdots$. In the case of two tap filters, the linear combination is a sum of only two terms whose coefficients are 1 and -1. Then the output, y, of the filter is given by

$$y = [x(n_1) - x(n_2)]/2.$$

The filter has the favorite frequency of $1/2(n_1 - n_2)$. Here, the unit of the frequency is the reciprocal of the sampling time, which is, in our case, the revolution period of a ring. By suitably selecting the parameters, n_1 and n_2 (tap positioning), we can obtain various type of the digital filter. In the words of hardware, the filter consists of memory of some depth, a hardware for subtraction operation and a clock circuit for controlling the timing.

In order to realize the filter, a very high-speed circuit is required, because the bunch frequency of KEKB is 508 MHz. For this purpose we are now designing a 2-tap filter board which has high-speed custom IC's (GaAs gate arrays) for de-multiplexing and multiplexing and medium speed 2-tap filter logic on it.

Before the completion of the board, we made a prototype of the 2-tap filter circuit which can work under the bunch frequency of 6.4MHz. The prototype consists of a 125 MHz analog-to-digital converter chip (Analog Devices AD9002) in front-end, a 40 MHz digital-to-analog converter chip (SONY CXD1171) in back-end and circuitry of a 2-tap digital filter. The digital filter consists of an ALU (SN74HC283) that performs a subtraction operation and memories (HM62832UHP-15) which store the position of bunches through hundreds of turns. The size of memory is 4 kbytes in total. These three components of the filter are packaged in a 1-span CAMAC module. The tap positioning of the 2-tap filtering can be set through the CAMAC command very easily. We found that the 2-tap filter has the desired frequency performance in various tap positionings in bench tests with a network analyzer.

IV. FEEDBACK EXPERIMENT IN AR

A. Experimental procedure

We made an experiment of the longitudinal feedback in AR to check the performance of the position detection system and the 2-tap filter explained above. The basic experimental conditions are summarized in Table I.

Table I
Condition of Experiments.

beam energy	2.5 GeV
circumference/revol. freq.	377 m/795 kHz
beam current	$3 \sim 5$ mA
synchrotron frequency/ν_s	20 kHz/0.025

Because the longitudinal kicker is still on the design stage, we used the accelerating cavities as a longitudinal kicker. Due to the narrow bandwidth of the cavity, we can make the experiments only with single bunch. But an experiment with the closed loop of the feedback system is essentially important particularly for checking the performance of the signal process system. In AR there are two RF stations, EAST and WEST, each of which has 4 accelerating cavities. Our kicker was 4 cavities in the WEST. The position detection system and the signal process system sit on the southern part of AR. The processed signal was transferred through a coaxial cable of length of $\sim$ 140 m to the WEST and the accelerating signal was phase-modulated by this processed signal.

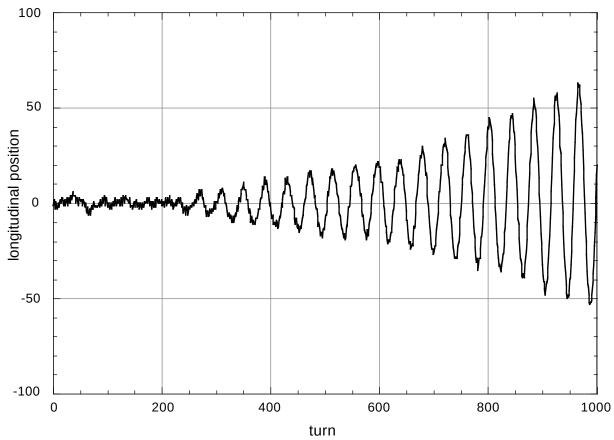

Figure 3. The observed oscillation just after the feedback was turned off. The horizontal axis is the turn number and the vertical axis is the longitudinal position in an arbitrary unit.

The longitudinal oscillation was excited by intentionally shifting the resonant frequency of the cavities to arise the Robinson instability. By tuning the resonant frequency shift, we can control the growth rate of the instability.

The tap positions of the 2-tap filter were chosen to be ($n_1 = 3, n_2 = 22$). The difference of the position, $22 - 3 = 19$, was determined by the condition, $n_1 - n_2 \simeq 1/2\nu_s$. On the other hand, the absolute positions of the taps depend on the delay of the whole feedback loop. We determined the suitable tap positions through this experiment.

B. Result

By setting the tuning angle of the accelerating cavities to be $+10$ degrees, we were able to excite constant longitudinal oscillation. By the measurement with a spectrum analyzer, we found the clean synchrotron side-bands in the both sides of a revolution peak. The power of the side bands were lower than the revolution peak by 30 dB and higher than background level by about 30 dB. When we closed the feedback loop the side-bands disappeared.

Next we increased the tuning angle to the positive direction and found the side-bands appeared again. After that, the gain of the feedback was increased. Then the side bands disappeared again. With these procedure we found that the instability with the growth time of about 0.1 ms could be damped by our feedback system.

We observed 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 it was completely independent of the feedback loop. By this system we could observe the change of the oscillation around the moment of feedback on/off. An example of the observed data is shown in Fig. 3. We catch that the oscillation grows with the growth time of about 300 turns or 0.36 ms.

V. SUMMARY

We have developed a new position detection systems for the longitudinal and transverse planes with the detection frequency of 2 GHz. Through the experiments performed in AR, we have established a bunch-by-bunch position-detection technique even in the bunch frequency of ∼500 MHz. Applying this technique, we observed the bunch oscillation in AR. When the ring was operated with 4 bunches, we succeeded in identifying the mode of the coupled bunch instability by analyzing the data taken by our system.

The design and the fabrication of the prototype of the 2-tap filter completed recently. The frequency performance was measured in a bench and expected characteristics were obtained. This prototype was actually used in the longitudinal feedback experiment in AR.

The experiment of the longitudinal feedback has also been performed. The kicker for the feedback 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 filter system is powerful for the signal processing of the longitudinal bunch feedback systems.

References

[1] E. Kikutani et al., “Development of Bunch Feedback System for KEKB”, Proceedings of the 4-th European Particle Accelerator Conference (EPAC94).

[2] E. Kikutani et al., “Front-End Electronics for the Bunch Feedback Systems for KEKB”, Proceedings of the Beam Instrumentation Workshop (BIW94), Vancouver, Canada, October 2-6, 1994. This paper is also available as KEK Preprint 94-131.

[3] The feasibility of using the 2-tap FIR filter for the bunch feedback systems was originally discussed by F. Pedersen in Workshop, ”Factories with e^+e^- Rings”, Benalmadena, Spain, November, 1992. .We also discussed the feasibility in the paper, E. Kikutani et al., “Two Tap Digital Filters for the KEKB Bunch Feedback Systems”, KEK Report 94-5.

[4] The AM/PM technique is explained, for example, in the paper by R.E. Shafer, “Beam Position Monitoring”, in “AIP Conference Proceedings 212”.