A SYSTEMATIC STUDY OF A TRANSVERSE FEEDBACK SYSTEM WITH A TWO-TAP FIR FILTER

Y. Minagawa, The Graduate University for Advanced Studies, KEK, Japan
E. Kikutani, M. Tobiyama and S. Kurokawa, KEK, Japan

Abstract

Performance of a transverse feedback system with a simple 2-tap FIR filter was experimentally studied in TRISTAN AR. The 2-tap FIR filter eliminates DC components and change the amount of necessary phase shift by the tap-position. An ADC, a 2-tap FIR filter logic and a DAC are packaged in a single-width CAMAC module, which is also equipped with large-size memory, where the bunch oscillations over thousands of turns are recorded. In the experiments, we kicked the beam transversely to create a large amplitude oscillation and then turn on the feedback system to damp this oscillation. By analysing the data stored in the memory we investigated the relation between the tap-position and the damping rate, with various tap-positions for a given tune and with various tunes for a given tap-position. The results agreed with a calculation.

1 INTRODUCTION

Recently, the number of machines which store a very large number of bunches are increasing remarkably. They are (will be) used for factories (B, Φ, τ etc.) or light sources. How to cure possible coupled bunch instabilities is a common problem for these machines. A straightforward way of the cure is to suppress them with bunch feedback systems. However, due to the large number of bunches, the systems would be a complex of a large number of parts some of which are completely identical. In such situation, the digital signal process would be a good solution.

It is very attractive for us to apply the 2-tap digital filter technology to the bunch feedback systems. In ordinary methods, it is usual to prepare two position monitors which are separated by 90 degrees in the betatron phase, But if we use the 2-tap technology, essentially only one position monitor is necessary. In fact, in CESR at Cornell, they operate the feedback systems with the 2-tap filter successfully[1]. In the previous paper[2], we have investigated the feasibility of applying the 2-tap filter for the bunch feedback systems and found that it can be a good tool for the signal process system. To confirm the result, we made a series of feedback experiments in TRISTAN Accumulation Ring(AR) at KEK. In this paper we describe the results of these experiments.

2 FEEDBACK GAIN OF THE SYSTEM

The output signal $y(n)$ of the FIR filter is described by the linear combination of the input signals $x(n)$ which are given as a time series:

$$y(n) = \sum_{k=0}^{N} a(k)x(n-k). \tag{1}$$

The 2-tap FIR filter has only two coefficients which are 1 and -1. So the output signal has the form of

$$y(n) = x(n_1) - x(n_2). \tag{2}$$

When we apply this 2-tap filter to the feedback, it is convenient to introduce a parameter G which we call the ***net gain***[2]. This parameter is expressed as the product of the gain of the filter and the sine of the phase shift due to the filter plus betatron phase advance from the monitor to the kicker:

$$\begin{aligned} G &= -\sin(2\pi\nu\frac{n_2-n_1}{2}) \\ &\quad \times \sin\left(-2\pi\nu(\frac{n_1+n_2}{2}+1)+\frac{\pi}{2}\right), \end{aligned} \tag{3}$$

where ν is the betatron tune. Actual damping rate is given by $G\times g_0$, where g_0 is the damping rate of the feedback with the phase advance of exactly 90 degrees. We found that we can obtain the reasonable damping rate in the wide range of ν=0.1$\sim$0.45 by carefully choosing the tap-position of the 2-tap FIR filter. Figure 1 shows the maximum net gain and the tap-position as function of ν.

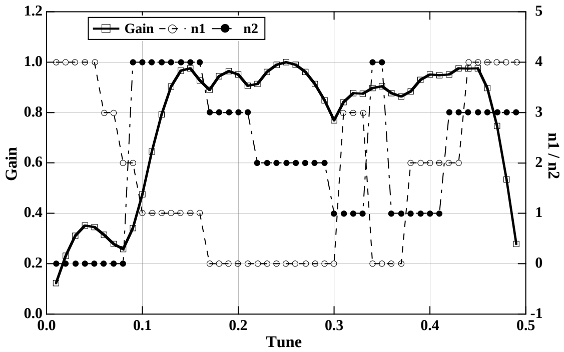

Figure 1: The graph of the maximum net gain and the tap-position as function of ν. The maximum tap-position is restricts to 4.

3 TOOLS AND METHODS OF THE EXPERIMENTS

3.1 General environment

AR is an electron storage ring which is operated in the energy range of $2.5 \sim 6.5$ GeV. The experiments were carried out mainly with a single bunch at 2.5 GeV and the bunch current was $1 \sim 2$ mA.

A block diagram of the feedback system is illustrated in Fig.2. The feedback system consists of pickup electrodes with an AM/PM detector, the 2-tap FIR filter for a digital signal processing and a kicker system.

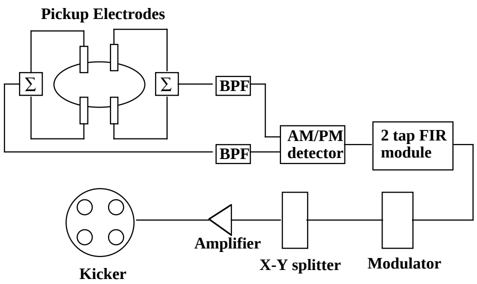

Figure 2: Block diagram of the feedback system.

3.2 Position monitor

As a pickup we used a set of 4 ordinary button electrodes. The position of the beam is reconstructed by an AM/PM detector which has been developed for a single-pass monitor[3]. The detector can observe the signal of up to 4 bunches in AR, namely up to 3.2 MHz of the bunch frequency.

3.3 Prototype of the 2-tap FIR filter board

The prototype of the 2-tap filter board consists of an 8-bit ADC, an FPGA (Field Programmable Gate Array), two sets of RAMs and a 10-bit DAC. It is compactly packaged in a single-span CAMAC module. The position signal from the AM/PM detector is stored in two sets of the RAMs turn by turn after digitized by the ADC. The 2-tap operation is carried out as follows; A pair of data is fetched from appropriate addresses of the RAMs and the FPGA subtracts the data of one RAM from the other RAM. The addresses correspond to the tap-positions, n_1 and n_2, in the 2-tap FIR filter. After all process the output of the filter is sent to the DAC.

3.4 Kicker system

The signal processed in the 2-tap FIR filter is transported to the kicker system[4]. This system consists of a modulator, power amplifiers and a kicker itself. The kicker is composed of 4 electrodes and each electrode is a cylindrical rod with the length of 1.92 m. Under typical condition, the damping time of the feedback system is 0.5 ms.

3.5 Experimental procedure

In AR, there is no heavy impedance source which can arise strong instabilities. Thus, we artificially excited the betatron oscillation to be damped by our feedback system by kicking the beam with a kicker magnet for the injection. The magnet kicks the beam in horizontal plane, then we prepared a feedback system only in horizontal plane.

The damping rate observed in the experiment is the sum of the damping of the feedback and the natural damping which are radiation damping plus the head-tail damping. To extract the damping rate of the feedback system alone, we need to subtract the effect of the natural damping from that of the experimental data. The rate of the natural damping was easily measured by the experiment with the feedback off. Examples of the obtained data in feedback off and on, respectively, are shown in Fig. 3.

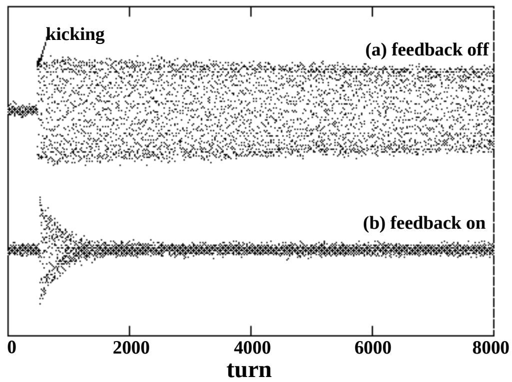

Figure 3: The observed oscillations with feedback off (a) and with the feedback on (b). The transverse oscillation was excited by a kicker magnet for the injection.

4 EXPERIMENTAL RESULTS

When we performed the experiments, the following were the check points.

- the damping rates as a function of the tap-position for a given tune
- the damping rates as a function of the tune for a given tap-position
- the damping rates measured with 3 bunches

4.1 Damping rates for a given tune

In the experiments, we measured the damping rates with various tap-positions for several fixed tunes, 0.100, 0.236, 0.295, 0.470 and 0.593. The observed damping rates at ν = 0.100 as well as the calculated ones are shown in Fig. 4.

We obtained the damping rate more than 2000 s^{-1} and the results of the measurement agreed with calculations. Also at other tunes ν = 0.236, 0.295, 0.470 and 0.593, the results of the measurement agreed with calculations.

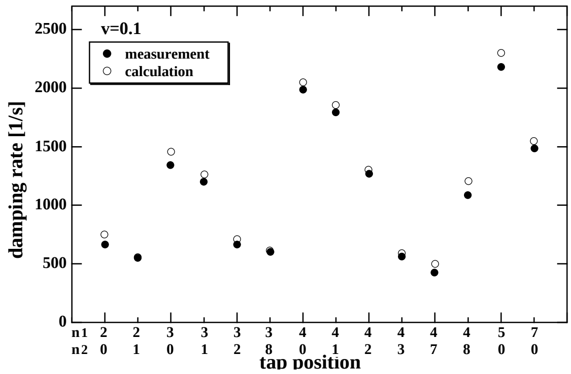

Figure 4: The observed damping rates and the calculated ones under various tap-positions at ν=0.100.

4.2 Damping rates for a given tap-position

We scanned the tune around 0.235 and 0.295 with fixed tap-positions. The results obtained around ν = 0.235 and the corresponding calculations are shown in Fig. 5. The damping rates as functions of tunes reproduce those from the calculation.

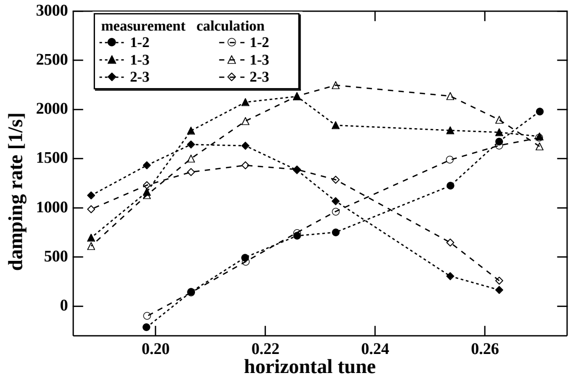

Figure 5: The damping rates as functions of tune along ν=0.235. The data were taken for several tap-positions. In the figure, for example, 1-2 means the tap-position of n_1=1 and n_2=2.

4.3 Damping rates measured with 3 bunches

When the ring is operated with multiple bunches, the trailing bunches should suffer from the influence of the leading bunches. We checked whether our feedback system act normally or not under this condition. The detector circuit of our feedback system can detect the beam position up to 4 equally spaced bunches in AR. The actual feedback experiments were performed with 3 bunches which occupied the 3 RF buckets out of the equally spaced 4 buckets. Examples of the observed data in feedback off and on, respectively, are shown in Fig. 6. The dependence of the damping rates on the tap-position is shown in Fig. 7. The feedback system worked well and the results of the measurement agreed with calculations.

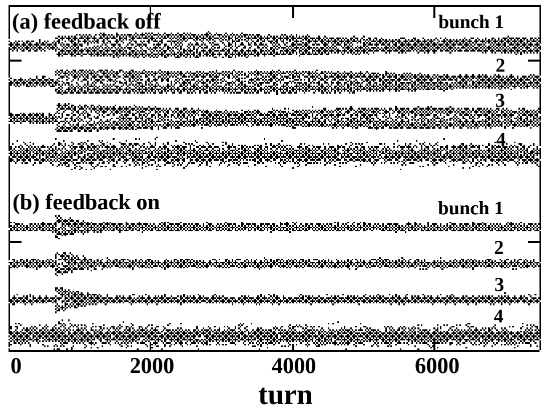

Figure 6: The observed oscillations with feedback off (a) and with the feedback on (b) in 3 bunches. Bunch 4 is absent in this data.

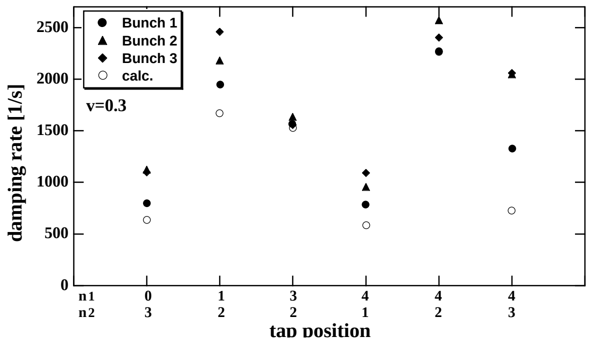

Figure 7: The damping rates of the experimental results and the calculations in 3-bunch operation with ν=0.300.

5 SUMMARY

We have studied experimentally the performance of the transverse bunch feedback systems based on the 2-tap FIR filter. We obtained reasonable damping rates by choosing optimum tap-positions for given tunes. In addition, the observed damping rate as a function of the tune reproduced the calculated one very well.

6 ACKNOWLEDGEMENTS

The authors would like to thank Y. Funakoshi, T. Ieiri, K. Mori, M. Arinaga for their collaboration.

7 REFERENCES

[1] J.T. Rogers, et al., Proc. of the 1995 Particle Accelerator Conf., 1995, 2426.

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

[3] M. Arinaga, et al., Proc. of the 9th Symp. on Accelerator Sci. and Technology, KEK, 1993, 379.

[4] T. Ieiri, et al., Proc. of the 5th Symp. on Accelerator Sci. and Technology, KEK, 1984, 157.