PB33

Beam Test of the RF Feedback for KEKB in TRISTAN MR

S. Yoshimoto, E. Ezura, K. Akai, K. Ebihara and M. Suetake
KEK, National Laboratory for High Energy Physics
1-1, Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan

Abstract

The RF feedback system for the KEK B-Factory (KEKB) has been tested using the beam of the TRISTAN Main Ring (MR). The coupled-bunch instability of the -1 mode was excited by intentionally detuning the RF cavities; it was then successfully damped by reducing their impedances with the RF feedback.

I. Introduction

A luminosity goal of KEKB is $1 \times 10^{34} cm^{-2}s^{-1}$, which requires the beam currents of 2.6 A for the 3.5 GeV positron ring and 1.1 A for the 8.0 GeV electron ring. Under usual operation, the cavity is detuned to present a matched load to the power source. For KEKB, the detuning is very large due to the high beam currents. The detuning gives the difference in the real part of the cavity impedance at the upper and lower sideband for each mode, and causes the longitudinal coupled-bunch instability. One technique to avoid the instability is to use an RF feedback around the cavity, which can reduce the cavity impedance at the synchrotron sidebands [1]. We are developing an RF feedback system using a parallel comb-filter, which enables us to adjust the feedback phase at the sideband frequencies even if a frequency-dependent group delay is present around the feedback loop.

The parallel comb-filter feedback was tested through a choke-mode cavity, and proved to be effective in reducing the cavity impedance [2]. Then, the feedback was tested using the beam of the TRISTAN MR. The purpose of the beam test was to confirm that a coupled-bunch instability caused by the cavity impedance could really be eliminated by reducing it by means of RF feedback.

II. Excitation of Instability

Under usual MR operation, an amount of cavity detuning is so small compared to the revolution frequency that the instability associated with the accelerating mode does not appear. One RF station was therefore shut off from operation, and its idling cavities were substantially detuned to make the beam unstable. An RF station has two accelerating units, each comprising a pair of nine APS (alternating periodic structure) cells. A total of thirty six cells were detuned by -88 kHz ($= f_{rev} - f_s$) in order to set the resonant frequency of the cavities to the upper synchrotron sideband of the -1 mode. Fig. 1 shows the magnitude and real part of the cavity impedance for detuned thirty six cells, with or without RF feedback. The growth time of the -1 mode dipole oscillation was calculated from the expression for equally spaced rigid bunches [3], using the machine parameters given in Table 1. The growth time due to the detuned cavities was 7.7 ms and that due to the operating cavities was 43.0 ms, giving the total growth time of 6.5 ms. The radiation damping time was 20 ms. An estimated growth time of any other mode was much slower than 20 ms.

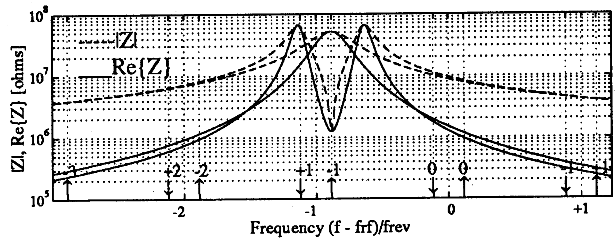

Fig. 1. Magnitude and the real part of the cavity impedance for detuned thirty six cells, with or without RF feedback.

Table 1
Machine parameters during the beam test.

e^- beam energy	8.0	GeV
e^- beam current	6.0	mA
Number of bunch	4	
Momentum compaction	1.493×10^{-3}	
RF frequency	508.6	MHz
Revolution frequency	99.3	kHz
Synchrotron frequency	11.6	kHz
Energy loss/turn	7.4	MeV
Cavity voltage	90.0	MV
Unloaded Q	39000	
Shunt impedance/m	22.5	MΩ/m
Coupling factor	1.3	
Detuning frequency	-87.7	kHz
Growth time of -1 mode	6.5	ms
Radiation damping time	20	ms

III. Feedback System

Fig. 2 shows a block diagram of the RF feedback system used in the experiment. Since only the -1

mode could be unstable, only one channel of the parallel comb-filter was used. The RF switch was used to open and close the feedback loop. In order to detect the growth and damping of the -1 mode oscillations a spectrum analyzer was used in zero-scan mode. Since there was no external signal to the system, only when the -1 mode was excited on the cavity, the system operated so as to cancel it.

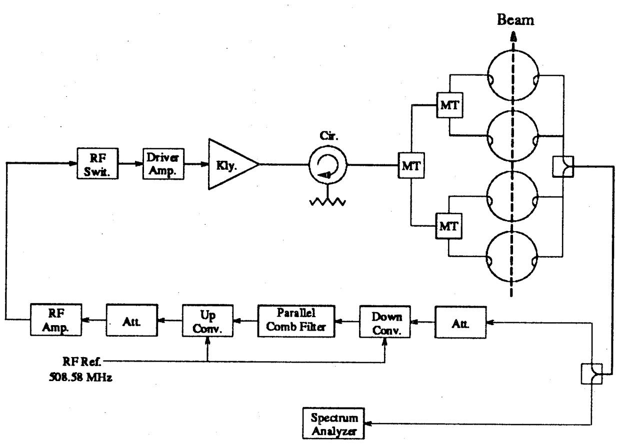

Fig. 2. Block diagram of the RF feedback system used in the beam test.

IV. Experimental Results

The experiment was carried out at 8 GeV with four equally spaced electron bunches, which make the beam current of about 6 mA. Although it could be increased to over 10 mA, the -1 mode oscillation was most severe around 6 mA. Fig. 3 shows the spectra of the beam-induced cavity voltages. The revolution harmonics of the beam current are shown in Fig. 3 (a), where the highest peak results from the impedance of the cavities tuned at the RF frequency. Fig. 3 (b), (c) and (d) show the signals around $f_{rf} - f_{rev} = 508.48$ MHz. When the cavities were not detuned, only the steady spectrum of the revolution harmonic was seen at 508.48 MHz (Fig. 3 (b)). When the cavities were detuned by -88 kHz, the instabilities, especially of the -1 mode, appeared as shown in Fig. 3 (c). The spectrum disappeared after the feedback loop was closed (Fig. 3 (d)). With the feedback, however, there appeared the bump between the revolution harmonic $(f_{rf} - f_{rev})$ and its upper sideband $(f_{rf} - f_{rev} + f_s)$, a cause of which is not clear yet. One may also note that, when the loop was closed, the noise floor was raised due to the noise amplification around the loop.

Fig. 4 shows the amplitude versus the time of the -1 mode oscillation, which was excited by detuning the cavities without feedback. The increase of the amplitude was limited by some unknown damping mechanism, and turned to the decrease. Then, at a certain small amplitude, where a growth rate exceeded a decreasing damping rate, the amplitude began to increase again. This behavior repeated with a period of about 80 ms. The beam thus survived in spite of being unstable, though the life time was shortened to several tens of minutes from a normal value of several hundred minutes.

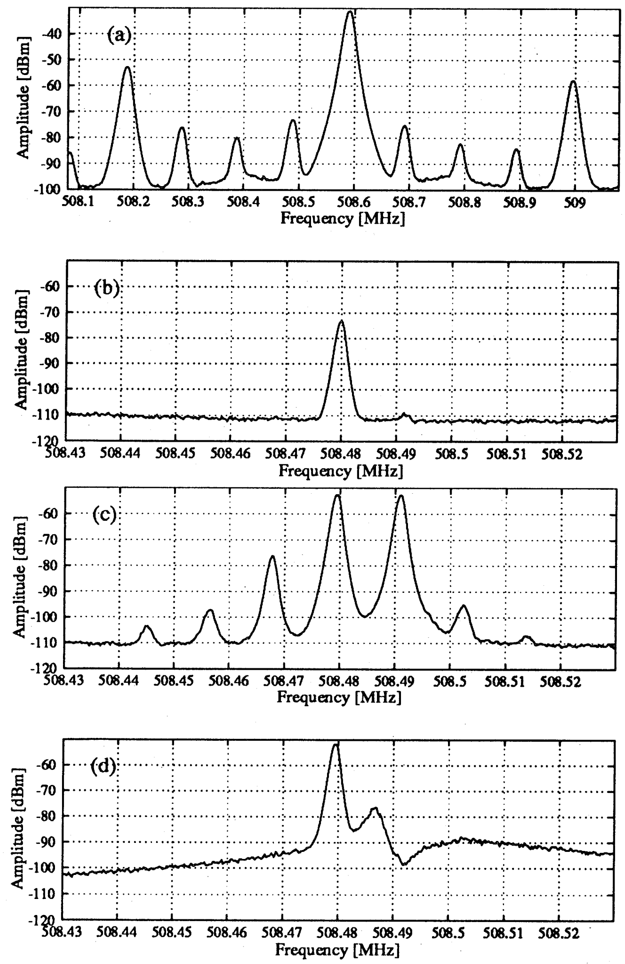

Fig. 3. Spectra of the beam-induced cavity voltages.

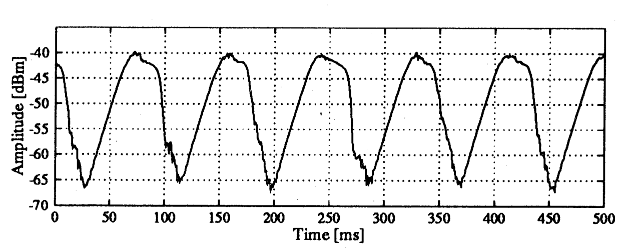

Fig. 4. Amplitude versus time of the -1 mode oscillation excited by the detuned cavities without RF feedback.

The damping rate of the -1 mode, α_{-1}, and the damping time $\tau_{-1}(= 1/\alpha_{-1})$ are given by

$$\alpha_{-1} = \alpha_{rad} + \alpha_{imp} + \alpha_{FB}, \tag{1}$$

$$1/\tau_{-1} = 1/\tau_{rad} + 1/\tau_{imp} + 1/\tau_{FB}, \tag{2}$$

where α_{rad} is the radiation damping rate, α_{imp} the damping rate due to cavity impedance and α_{FB} the damping rate due to RF feedback. τ_{rad}, τ_{imp} and τ_{FB} are the damping time due to radiation, cavity impedance and RF feedback respectively. A negative τ_{imp} indicates the excitation of instability, and an unstable oscillation will occur when

$$-\tau_{imp} < \tau_{rad} + \tau_{FB}. \tag{3}$$

The idling cavities were detuned by −88 kHz throughout the feedback experiment. Fig. 5 shows a typical amplitude behavior of the −1 mode oscillation. The amplitude began to increase exponentially when the loop was opened at 0 ms, and turned to decrease when the loop was closed at about 90 ms. This figure clearly shows the effectiveness of the RF feedback. The bottom figures show expanded views just after the loop off and on.

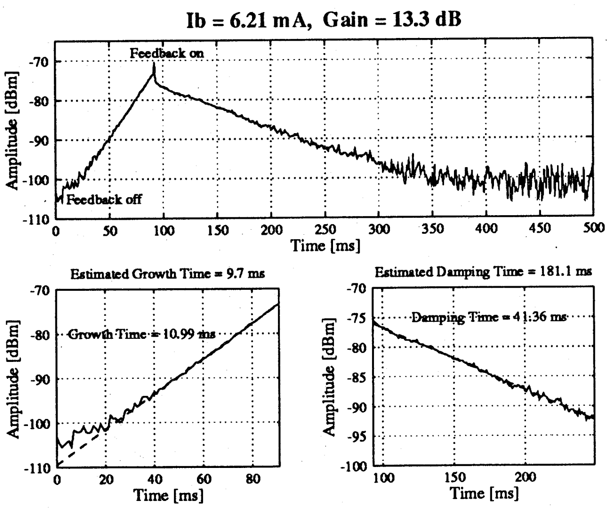

Fig. 5. Amplitude versus time of the −1 mode oscillation when the feedback loop was opened, and then closed after a short period of time.

The growth time was measured from the initial slope of the increasing amplitude when the feedback loop was opened. The measured growth time was 9.9 ms on the average of ten measurements, and varied between 9.1 ms and 11.0 ms. The growth time, obtained from the estimated τ_{rad} and τ_{imp}, was 9.7 ms, which agreed well with the measured value.

The damping time was measured from the initial slope of the decreasing amplitude when the feedback loop was closed. In order to exclude any nonlinear effect from the measurements, the loop was closed while an amplitude was still very small. The measurement was repeated two or three times for each loop gain of 13.3, 15.3, 17.3 and 22.3 dB. Fig. 6 shows the measured and estimated damping times as a function of the loop gain. The crosses show the measured points, while the solid line represents the damping time derived from the estimated τ_{rad}, τ_{imp} and τ_{FB}. The broken line represents the estimated minimum damping time, which would be obtained with an infinite loop gain.

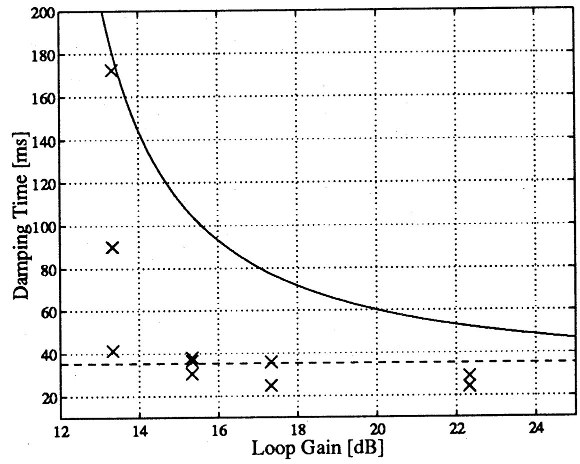

Fig. 6. Measured and estimated damping times as a function of the loop gain.

V. Discussion

A threshold gain is defined here as a loop gain at which a combined damping time of τ_{rad} and τ_{FB} is equal to a growth time, $-\tau_{imp}$. The measured threshold gain was about 12 dB, which was in good agreement with the estimated threshold of 12.5 dB. However, in the region above the threshold, the measured damping times were much shorter than the estimated ones. Besides, some of the measured points are found below the broken line. This may suggest that the experiment included some factor which we did not take into account.

Since the measured damping time varied more than we had expected, we felt concern about the stability of the feedback system operating at a very low RF power. If the gain fluctuation was the only cause of the measured damping time variation, a range of fluctuation would be about 10 dB. Later we measured the system stability under very low power operation, and found out that either the frequency converter or the parallel comb-filter had a rather large phase fluctuation. Though we have not yet evaluated its effect on the gain variation, it may be responsible to some extent for the measured damping time variation.

VI. Acknowledgments

We would like to thank the members of the operating group for their help in carrying out the beam test.

References

[1] D. Boussard et al. , IEEE Trans. Nucl. Sci. Vol. NS-30, No. 4, p. 2239, (1983).

[2] S. Yoshimoto et al. , contributed to 1995 IEEE PAC and Int. Conf. High Energy Accelerators, Dallas, Texas, 1995.

[3] for example, C. Pellegrini et al. , PEP-258, Oct. 1977.