THE -1 MODE DAMPING SYSTEM FOR KEKB

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Abstract

We have developed the -1 mode damping system for KEKB. It was tested using the beam of KEKB LER, and proved to be effective in damping the coupled-bunch instability of the -1 mode associated with the accelerating mode. This system was incorporated into the RF system and has been stably operating in LER. The instability is suppressed by the damper and the beam current has been increased up to 1.86 A. We also discuss the requirements for the damper for upgrading to SuperKEKB.

INTRODUCTION

In electron storage rings, resonant frequency of the fundamental cavity mode should be detuned downwards from the RF frequency in order to compensate for the reactive component of the beam loading. Since the amount of the detuning is proportional to the beam current, it can exceed the revolution frequency in a large storage ring with a high beam current such as B-factories. The growth rate of the instability can be much larger than the radiation damping rate. One of the key issues for the B-factory RF system is how to avoid this instability.

PEP II and KEKB have chosen different approaches to solve the problem. PEP II uses a combination of feedback loops that reduces the impedance seen by the beam. KEKB, on the other hand, uses innovative normal-conducting cavities called ARES [1] and single-cell superconducting cavities (SCC) [2]. High stored energy in these cavities reduces the detuning frequency and thus suppresses the instability.

During the operation of KEKB, the instability is sufficiently suppressed in HER up to the design beam current of 1.1 A. In LER, however, it turned out that the instability is not cured only by the ARES scheme. The instability occurred at 1 A, much lower than the design beam current. We have developed the -1 mode damping system to cure the problem. After being tested in LER, it began operating for physics run.

In this paper we describe the -1 mode damping system, the beam test results and the operating status. We also discuss requirements for the damper for future upgrade toward SuperKEKB.

SYSTEM DESCRIPTION

Figure 1 shows the block diagram of the -1 mode damping system. A beam signal from a pickup electrode is down-converted to the baseband frequency, then filtered to pick up the -1 mode signal using a digital filter. After being up-converted to the RF frequency and adjusted in phase, it is fed back to the RF signal path to the cavity.

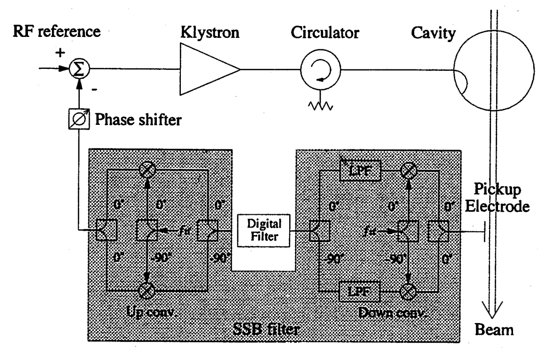

Figure 1: Block diagram of the -1 mode damping system.

The feedback is carried out only in the lower side of the RF frequency by using a single-side-band (SSB) filter that cuts the signal in the upper side of the RF frequency. The advantage of the SSB method is that the impedance at the upper side of the RF frequency that contributes to damp the -1 mode is not affected by the feedback. Figure 2 shows the measured transfer function of the SSB filter. It is seen that the filter rejects the signal in the upper side of the RF frequency.

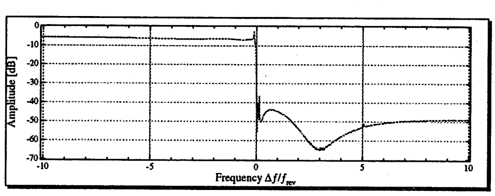

Figure 2: Measured transfer function of the SSB filter.

We have developed a new digital filter and replaced the analog one [3]. Figure 3 shows the measured transfer function of the digital filter. In order to adjust the center frequency of the filter to the synchrotron upper sideband, the frequency offset relative to the revolution frequency (99.4 kHz) can be changed from 0 to -3 kHz by a 20 Hz step.

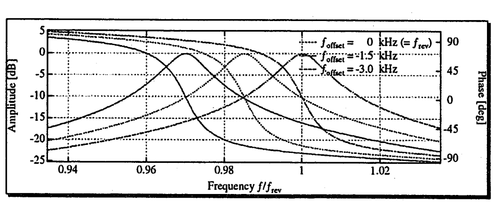

Figure 3: Measured transfer function of the digital filter.

OPERATION OF THE -1 MODE DAMPER

Necessity of the -1 mode damper

According to a calculation, the growth rate is about the same as the radiation damping rate at 2 A in LER. It turned out, however, that the -1 mode instability occurred at 1 A, much lower current than the expectation. One reason is that the operating RF voltage is lower than the design value. Another possible reason is that the feedback loop in the RF system for the zero-mode stabilization may affect the -1 mode impedance.

In order to increase the beam current, it was decided to implement the -1 mode damping system that we had developed as a backup scheme for the ARES.

Beam Test Results

A preliminary experiment of the -1 mode damping system was carried out in LER in December 2001. The instability was excited by intentionally detuning two ARES cavities by -60 kHz. The -1 mode damper was implemented in one of eight RF stations. The experimental procedure is as follows:

- The synchrotron upper sideband frequency is measured by a spectrum analyzer.
- The center frequency of the filter is adjusted to the upper synchrotron sideband.
- The feedback phase is adjusted using a phase shifter so as to minimize the amplitude of the -1 mode.

Figure 4 shows the measured spectrum of the -1 mode with and without the feedback. The amplitude of the -1 mode upper synchrotron sideband decreased by 15 dB when the feedback loop was closed. Figure 5 shows the change of the measured amplitude of the -1 mode oscillation when the feedback is switched off. The amplitude rapidly increases until the beam is finally lost. Thus the effectiveness of the damper was demonstrated.

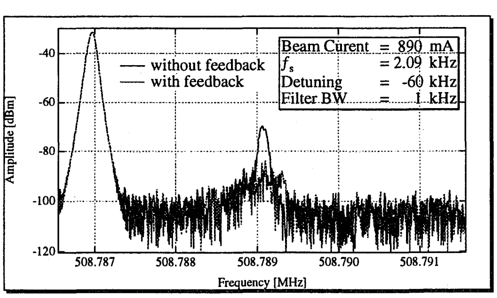

Figure 4: Measured spectrum of the -1 mode with and without the feedback in LER.

Operating Status

After this experiment, the -1 mode damper was incorporated into the RF system and has been operating stably.

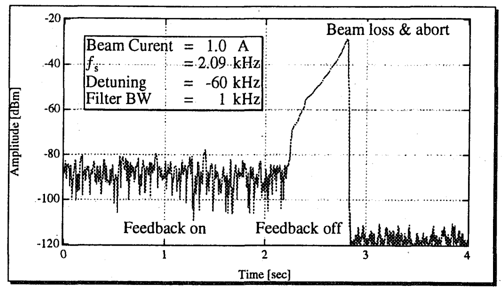

Figure 5: The change of the amplitude of the -1 mode oscillation when the feedback is switched off.

Figure 6 shows the effect of the feedback during a beam injection. When the feedback is off, the beam current is saturated at 1 A and even the beam loss occurs. After the feedback is switched on, the beam current can be increased. Figure 7(a) and (b) show measured spectrum of the -1 mode without and with the feedback. When the feedback is off at 1 A, the amplitude at the upper synchrotron sideband of the -1 mode is about the same as that of the revolution harmonic frequency (Figure 7(a)). Thus a strong oscillation is excited. With the feedback on, the oscillation is sufficiently damped (Figure 7(b)) and the beam current can be increased up to 1.86 A. It means that the feedback damping time is faster than 8.5 ms.

The present limitation of the beam current in LER is not caused by the -1 mode instability. The beam current is rather determined in view of optimizing the luminosity.

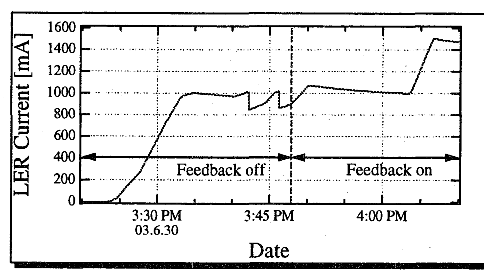

Figure 6: LER beam injection with and without the feedback.

TOWARD SUPERKEKB

SuperKEKB is planned as an upgrade of KEKB to increase the luminosity by several ten times. In SuperKEKB the LER beam current will be increased from 2.6 A to 9.4 A. With the existing ARES cavities the detuning frequency becomes close to the revolution frequency and the growth rate of the -1 mode is 5631 sec^{-1}, nearly two orders of magnitude larger than that of KEKB.

Although a highly improved -1 mode damper may be able to cure the instability, it is also desired to relax the requirement for the damper, if possible. Consequently, it is planned to modify the ARES so that the ratio of stored energy in the accelerating (U_a) and storage cavity (U_s) will

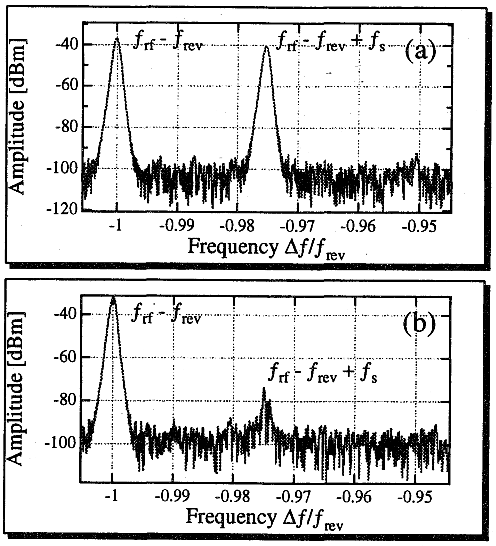

Figure 7: Measured spectrum of the -1 mode in LER (a) at 1.0 A without feedback, and (b) at 1.8 A with feedback.

be changed. It increases the total stored energy and thus decreases the detuning frequency to some extent. Table 1 shows RF parameters for various values of the stored energy ratio. The larger ratio gives the lower growth rate. On the other hand, the power dissipation at the cavity wall increases as the energy ratio. The ratio $U_s/U_a = 15$ is considered to be the optimum value. Then the growth rate is reduced to 659 $\sec^{-1}$. Figure 8 shows the calculated growth rate as a function of the beam current for this case.

With the modification of the ARES, the required damping time for the -1 mode damper is 1.5 ms. The growth rate of the -2 mode also exceeds the radiation damping rate. The existing -1 mode damper needs to be improved to decrease the damping time and to include the -2 mode. In addition, the damper will need to be implemented in every RF station, instead of only one station in KEKB.

It is also expected that other modes of coupled-bunch instabilities can be excited due to a possible imbalance of the impedance at the 0 and π modes of the ARES caused by the large detuning of the accelerating cavity [4]. Since the frequency of these modes is more than 4 MHz apart from the RF frequency, which is outside the bandwidth of klystrons, it cannot be cured by the RF control system including the -1 mode damper. A longitudinal bunch-by-bunch feedback system may be needed to cure it, while an effort to avoid the instability by optimizing the cavity parameters is under way.

Table 1: RF parameters for SuperKEKB LER

U_s/U_a		9	15	18	
Beam current			9.4		A
Bunch length			3		mm
Radiation loss			1.23		MeV/tern
Unloaded Q		1.11	1.27	1.32	$\times 10^5$
Cavity voltage			0.5		MV/cav
# of cell			28		
R/Q		15	9.4	7.9	Ω/cav
Coupling factor		5.4	4.1	3.8	
Detuning frequency		71.5	44.8	37.6	kHz
Power dissipation		150	210	240	kW/cav
Growth rate	$\mu = -1$	5631	659	365	$\sec^{-1}$
	$\mu = -2$	240	52.2	31.3	$\sec^{-1}$
	$\mu = -3$	56.4	9.6	4.5	$\sec^{-1}$

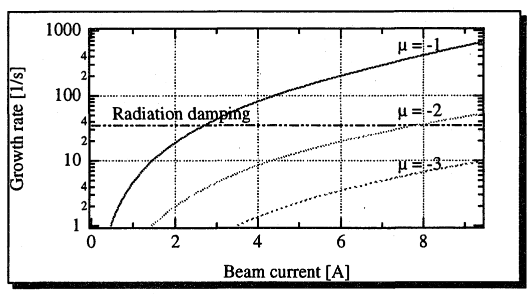

Figure 8: Calculated growth rate of the coupled-bunch instabilities due to the accelerating mode for the case of $U_s/U_a = 15$ in SuperKEKB.

SUMMARY

We have developed the -1 mode damping system to cure the coupled-bunch instability due to the accelerating mode of cavities. Even with the high stored energy scheme (ARES and SCC) of KEKB, the instability occurred at 1 A in LER without the damper. We tested the damper in LER and proved its effectiveness in damping the instability. The damper was incorporated into LER and has been stably operating. The instability is completely suppressed by the damper and the beam current has been successfully increased up to 1.86 A.

In SuperKEKB, the instability will be much severer. The damping system needs to be improved to achieve the damping time of 1.5 ms and to implement the -2 mode damping, provided that the ARES is modified to increase the stored energy.

ACKNOWLEDGEMENTS

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