DEVELOPMENT OF A LONGITUDINAL FEEDBACK SYSTEM FOR COUPLED BUNCH INSTABILITIES CAUSED BY THE ACCELERATING MODE AT SuperKEKB

Kouki Hirosawa*,[1], Kazunori Akai[1,2], Eizi Ezura[1,2], Tetsuya Kobayashi[1,2],
Kota Nakanishi[1,2], Michiru Nishiwaki[1,2], Shin-ichi Yoshimoto[1,2],
[1]SOKENDAI, Tsukuba, Ibaraki, Japan
[2]KEK, Tsukuba, Ibaraki, Japan

Abstract

SuperKEKB design is based on a nano-scheme at interaction region and high beam current. Coupled-bunch instabilities (CBI) caused by accelerating mode grows more severe as the beam current increases. In the KEKB operation, the resulting lowest mode of CBI (called μ = -1 mode) is suppressed by the existing RF system and CBI dampers. We estimate that SuperKEKB design current will cause CBI, which include more high modes (μ = -2, -3 modes). Therefore, we developed a new CBI damper that can suppress μ = -1, -2, -3 modes. In tabletop measurements, performance of the new CBI damper is satisfactory in terms of our required specifications. In this paper, the characterization results of the new CBI damper are reported.

INTRODUCTION

SuperKEKB is a high-luminosity asymmetric electron-positron collider upgraded from KEKB. The SuperKEKB Phase-I commissioning was operated from February to June in 2016, and the Phase-II will be carried out from January in 2018. Table 1 provides the main parameters of SuperKEKB [1] for this study.

The SuperKEKB storage ring consists of a 7 GeV high-energy ring (HER) for electrons and a 4 GeV low-energy ring (LER) for positrons. We reuse the KEKB RF system, which has two cavity types. HER contains a normal conducting cavity, ARES, and superconducting cavity (SC), and LER contains only ARES [2]. ARES is a cavity uniquely developed for KEKB. It has a three-cavity structure: an accelerating cavity is coupled with an energy storage cavity via a coupling cavity in order to reduce cavity-detuning by beam loading [3]. The major difference between SuperKEKB and KEKB is increase in the beam current. CBI is one of the problems for large beam current in a storage ring. It becomes serious as beam current increases. In the KEKB operation, the lowest mode of CBI called μ = -1 mode had been excited, and we suppressed it by using the CBI damper, which corresponds to only μ = -1 mode [4]. While upgrading to SuperKEKB, we predict that μ = -1, -2 mode instabilities will be excited at design beam current (LER: 3.6 A, HER: 2.6 A).

Figure 1 is an illustration of CBI-excitation by cavity-detuning under the influence of large beam current. In this figure, Δf represents the quantity of cavity-detuning depending on beam current, and $Z^{||}$ is the longitudinal impedance of a cavity. An optimum resonance frequency for acceleration decreases as the beam current becomes large, and the closer it is to the CBI-excitation modes, the larger the instabilities grow. Growth rate of CBI τ_μ^{-1} is given by

$$\tau_\mu^{-1} = AI_0 \sum_{p=0}^{\infty} \{ f_p^{(\mu+)} \mathrm{Re} Z^{||}(f_p^{(\mu+)}) - f_p^{(\mu-)} \mathrm{Re} Z^{||}(f_p^{(\mu-)}) \} \tag{1}$$

$$f_p^{(\mu+)} = (pM + \mu) f_0 + f_s$$
$$f_p^{(\mu-)} = \{(p+1)M - \mu\} f_0 - f_s$$
$$f_{rf} = h f_0 \quad ,$$

where A is a coefficient determined by beam operation parameters, and I_0 is the beam current. Figure 2 shows growth rate of μ = -1, -2,-3, -4 modes in LER and HER. Threshold for instability is a yellow line that denotes the radiation damping rate. We find it necessary to suppress the μ = -1 mode, and RF control is considerably severe without suppressing the μ = -2 mode. For instance, a dotted curve in Fig. 2 indicates μ = -2 mode growth rate in the case when a cavity is parked with 150-kHz detuning.

For target beam current at SuperKEKB, we have developed a new CBI damper [5], which corresponds μ = -1, -2, -3 mode. In Phase-II commissioning, it is expected that this new damper system will function effectively.

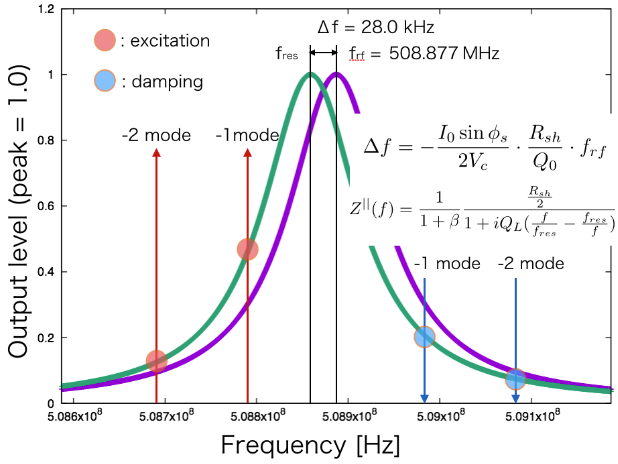

Figure 1: Illustration of cavity impedance and CBI mode.

---

[*] hirosawa@post.kek.jp

Table 1: SuperKEKB and Cavity Parameter

parameters	value	
for SuperKEKB	LER	HER
$Energy : E$	4.0GeV	7.0GeV
$Beam\ current : I_0$	3.6A	2.62A
$Mom.\ compact. : \alpha_c$	3.25×10^{-4}	4.55×10^{-4}
$Synch.\ freq. : f_s$	$2.43kHz$	$2.78kHz$
$Harmonic\ number : h$	5120	
$RF\ frequency : f_{rf}$	508.877 MHz	
$f_0 = f_{rf}/h$	99.39 kHz	
Number of cavity	22	ARES 8, SC 8
for Cavity	ARES	SC
$V_c/cavity$	0.5MV	1.5MV
R_s/Q_0	15Ω	93Ω
Q_0	1.1×10^5	2.0×10^9
coupling factor :β	5.0	4.0×10^4

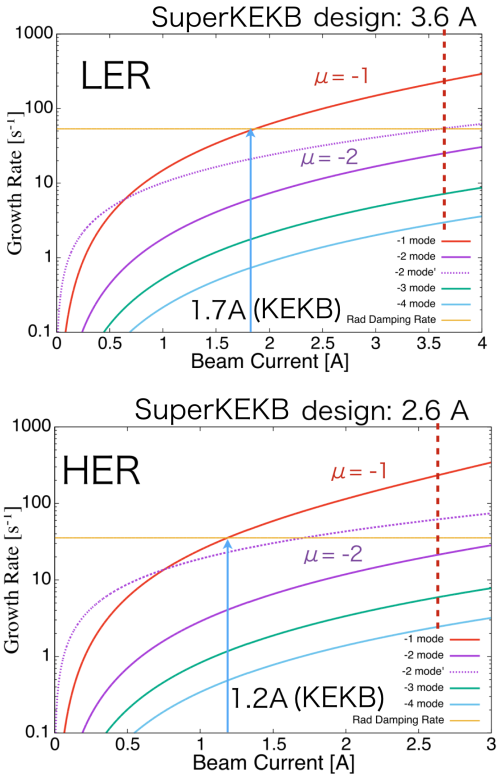

Figure 2: Growth rate by beam current. Dotted curve indicates μ = -2 mode in the case of a cavity parked with 150-kHz detuning.

NEW CBI DAMPER FOR SuperKEKB

The schematics of the components of a new damper are shown in Fig. 3. This set of components acts as a filter that makes pass in such a manner that only CBI mode frequencies ($f_p^{(\mu+)}$) are cancelled. To suppress CBI, cavity or beam pickup signals filtered by this system are fed back into a cavity [4]. Following conventional strategy, we attenuate the impedance of the lower side compared to f_{rf}, which has an excitation effect (see Fig. 1), and maintain that of the higher side.

Our damper system consists of an analog single-sideband filter (SSBF) and a digital bandpass filter (DF) as shown Fig. 3. The fundamental method of this system is based on the KEKB damper. There are two steps for feedback (FB) signal processing. First, only signals of frequency lower than f_{rf} are made to pass by the SSBF. The RF signals input as the external reference for Up/Down convert (IQ modulation/demodulation). Secondly, only frequencies of CBI modes ($-\mu f_0 - f_s$) are picked up by the DF, which acts as bandpass filter as shown Fig. 3. The parameter ω in the figure corresponds to the frequency of the CBI mode. The digital signal processing of the DF is performed by an FPGA Evaluation Kit (XILINX KC705). In FPGA, sine waves are generated by the numerically controlled oscillator (NCO) method.

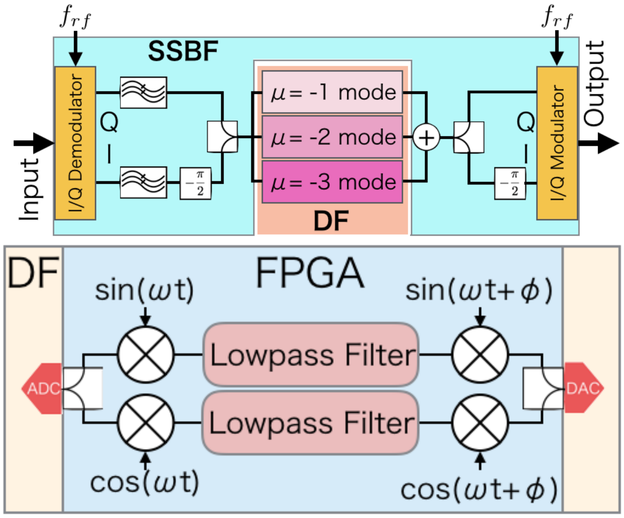

Figure 3: Block diagram of the new CBI damper (Top) and the digital bandpass filter (Bottom).

PERFORMANCE OF NEW COMPONENTS

We have produced two SSBFs for LER and HER. The evaluation result of SSBF performance is shown in Fig. 4. Frequency characteristics of transmission measured by network analyzer are plotted for both in the figure. The characteristics of the KEKB damper is also shown in the figure for comparison. While the KEKB damper has a rejection of 40 dB for the stopband, a new damper gives 80 dB rejection. With respect to the flatness of passband, a new damper has a very flat characteristic in an effective interval of frequency (μ = -1, -2, -3 mode excitation). The performance of the new damper is improved obviously.

Similarly, we evaluated the DF using the network analyzer. Figure 5 shows results of DF transmission measurement for various frequency offsets and bandwidth. These characteristics satisfy its specification and agree very well with the calculated value.

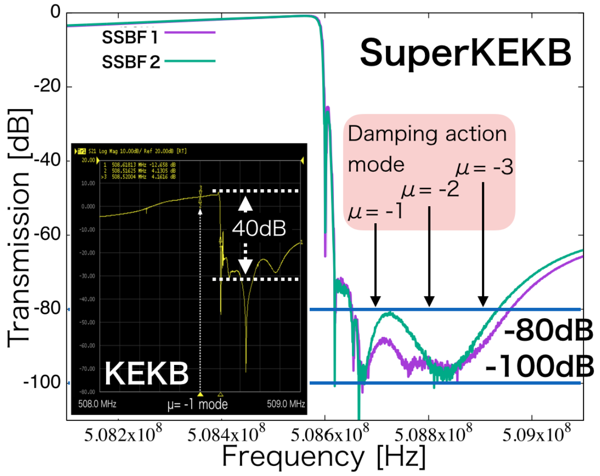

Figure 4: Frequency characteristics of SSBF transmission and that of KEKB damper.

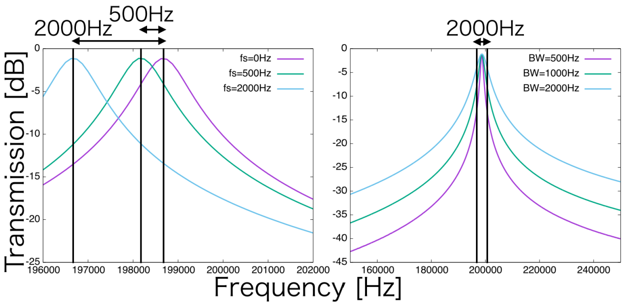

Figure 5: DF frequency characteristics for difference offsets (0 Hz, 500 Hz, 2 kHz) (left) and for DF bandwidth change (500 Hz, 1 kHz, 2 kHz) (right).

CHARACTERISTICS OF A FB LOOP

For practical use, we evaluated the FB loop characteristics of the CBI damper with a simulant cavity (Q = 9000). Figure 6 shows a block diagram of the FB loop (Top) and the measurement results (Bottom). For the measurement, the damper consisted of one SSBF and three parallel DFs for μ = -1, -2, -3 modes. This simulant cavity has large insertion loss of approximately 30 dB; therefore, amplifiers were interposed. As the phase of each DF output is adjustable independently, we can control the phase parameters for each mode according to the FB loop condition. In the measurement, we optimized phases for a good characteristic by changing 5° or 10° from $\mu = -1$ to $\mu = -3$ in order.

According to Fig. 6, impedance of the simulant RF-cavity decreased only at $\mu = -1, -2, -3$ mode depending on loop-gain. The desired result was obtained in FB loop performance for practical beam operations. Furthermore, we expect that flexible correspondence can be made in actual beam operation, as variable parameters for DF are the phase, frequency offset, bandwidth, and output gain.

SUMMARY

In order to reach the target beam current of SuperKEKB, suppression of CBI due to the accelerating mode is indispensable. In SuperKEKB, we conjecture that μ = -2, -3 mode CBI, which was negligible in KEKB, will be excited besides μ = -1 mode. Therefore, we have developed the new CBI damper for SuperKEKB to suppress these CBI modes. According to results of characteristic evaluation, the new SSBF provides an 80-dB reduction for stopbands, and passbands exhibit good flatness. In the FB loop characteristics, impedance damping is confirmed at the respective CBI modes.

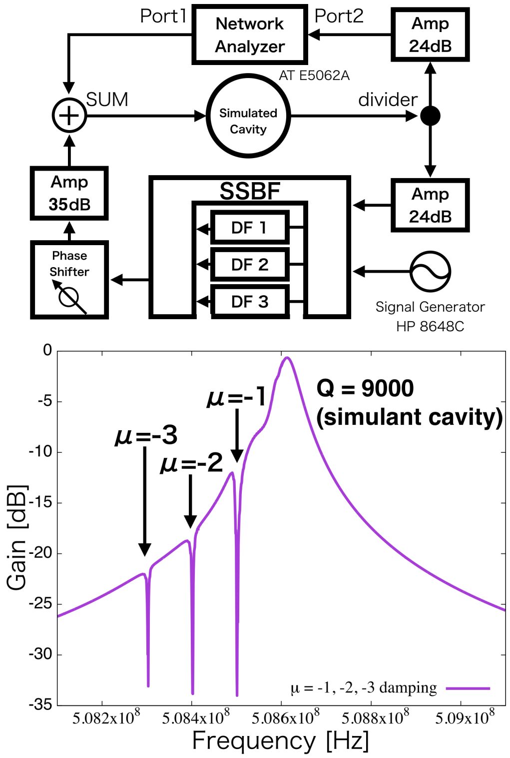

Figure 6: Block diagram for the FB loop evaluation (Top), and the damping characteristics for the FB loop (Bottom).

From the results of tabletop measurements, it can be expected that the new CBI damper system will function effectively in beam commissioning. A high power test is planned with the actual RF system before the commencement of Phase-II. Practical damper adjustment should be performed in the Phase-II commissioning simultaneously, as scheduled from January 2018.

REFERENCES

[1] Y. Ohnishi *et al.*, Prog. Theor. Exp. Phys., 03A011 (2013)

[2] K. Akai *et al.*, Nucl. Instr. Meth. A. 499, pp. 45-65 (2003)

[3] T. Kageyama *et al.*, Proc. of PASJ2011, pp. 1245-1249 (2011)

[4] S. Yoshimoto, KEK Internal 2013-2, pp. 1-6 (2013)

[5] K. Hirosawa *et al.*, Proc. of PASJ2016, TUP012 (2016)