THE LOW-LEVEL RF SYSTEM FOR KEKB

K. Akai, N. Akasaka, K. Ebihara, E. Ezura, M. Suetake and S. Yoshimoto
KEK, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305-0801, Japan

Abstract

This paper describes the low-level RF system for the KEK B-Factory (KEKB). The low-level system has been designed to control the cavities stably with high accuracy under an extremely heavy beam-loading. This paper also presents simulations of transient behavior of the beam and the RF system. In particular, bunch-gap transient and transient response to an accidental trip of an RF station have been evaluated. Measures have been taken to avoid a beam loss caused by the trip.

1 INTRODUCTION

The KEKB, an asymmetric energy double-ring e^+e^- collider for B-physics [1], will be commissioned in 1998. Two types of heavily-damped cavities have been developed for KEKB: the normal-conducting three-cavity system (ARES) and a single-cell superconducting cavity (SCC). Growth rate of the longitudinal coupled-bunch instabilities associated with a detuning for the accelerating mode is reduced, indebted to a large stored energy in these cavities. Even with these cavities, however, the beam-loading is so heavy that the stability of the operating RF ($\mu = 0$ mode) can be degraded in both rings and the growth rate of $\mu = -1$ mode is marginal in LER. To solve the problems, the low-level RF system has been carefully desinged, in particular, a variety of feedback loops to stabilize the RF and its interaction with the beam and a tuning control system to meet the requirements specific to the ARES.

In addition, we have developed a time domain simulation code which evaluates not only the beam-cavity interaction, but also feedback loops incorporated in the RF system. An outstanding feature is that it can include various types of independent RF systems in a ring. It enables us to simulate the bunch-gap transient in a hybrid system where both the ARES and SCC are operated (see below). Furthermore, the transient response to a trip of RF stations can be simulated, by treating the tripped cavities and operating ones as two independent systems.

2 RF SYSTEM AND PARAMETERS

Table 1 gives the RF-related machine parameters and typical RF operation parameters. In LER, only the ARES will be used, since its parameters are more suitable for the higher stored current and the lower accelerating voltage. In HER, we adopted the hybrid system with the relative phase between the ARES and SCC of 10 degrees. This scheme has an advantage to make use of the high accelerating voltage of SCC, while reducing the beam-loading to SCC.

Table 1: RF-related machine parameters and RF operation parameters.

	LER	HER	
Energy [GeV]	3.5	8.0	
Current [A]	2.6	1.1	
Beam power [MW]	4.5	4.0	
Bunch length [mm]	4	4	
RF frequency [MHz]	508.887	508.887	
Harmonic number	5120	5120	
Cavity type	ARES	SCC	ARES
Number of Cavities	20	8	12
Relative phase	$-$	10 degrees	
Total RF voltage [MV]	10	17.9	
R/Q [Ω/cav.]	14.8	93	14.8
$Q_L \times 10^4$	3.0	7.0	3.0
Input β	2.7	$-$	2.7
Voltage [MV/cav.]	0.5	1.5	0.5
Input power [kW/cav.]	375	250	340
Wall loss [kW/cav.]	154	$-$	154
Beam power [kW/cav.]	221	240	173
Number of Klystrons	10	8	6
Klystron power † [kW]	~ 810	~ 270	~ 730

† 7 % loss at waveguide system is included.

3 FEEDBACK LOOPS

3.1 RF Control System

A block diagram of one RF station for SCC is shown in Fig. 1. An RF station for ARES is basically the same, except for 2 cavities/1 klystron configuration and the tuning control system specific to ARES. In addition to the cavity feedback loops, the klystron feedback loops are implemented to stabilize the amplitude and phase of the klystron output. They reduce phase variations due to cathode voltage variations and eliminate the power supply ripples and noise around the synchrotron frequency. A direct RF feedback of the RF frequency [2] is implemented to reduce the beam-loading effects on the RF system and to improve beam stability. It has been tested using the high beam-current (500 mA) of the TRISTAN AR in 1996, and has proved to be effective in damping the $\mu = 0$ mode bunch oscillations and increasing the Robinson stability area [3]. In LER, the growth rate for the $\mu = -1$ mode is 15 ms at V_c = 10 MV or 7 ms at 5 MV, which is slightly faster than the radiation damping time of 20 ms. A feedback loop using a band-pass filter centered at the frequency $f_{rf} - f_{rev} + f_s$ will be introduced to store the design current [4].

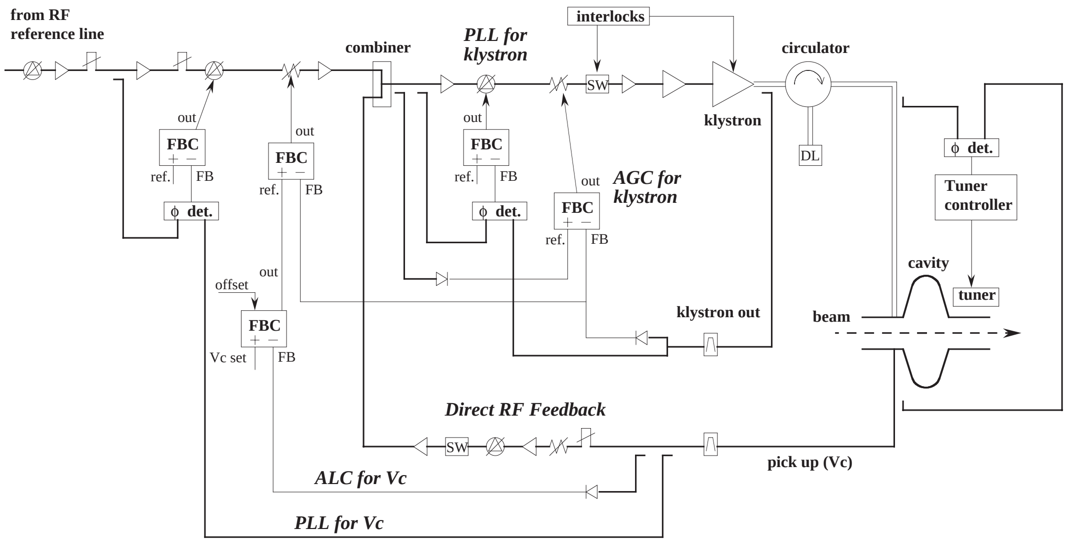

Figure 1: Bloack diagram of low-level feedback loops of one RF station for SCC.

3.2 Tuning Control System

The ARES is tuned in such a way that the phase of the energy-storage cavity is locked to that of the incident RF and the phase of the accelerating cavity is locked to that of the coupling cavity (Fig. 2). This tuning method ensures a power minimum operation under any beam loading conditions, and is the best solution we have reached after intensively studying the tuning accuracy and stability of several possible methods [5].

When an RF station operating at the nominal power is tripped off, the resonant frequency of the ARES decreases at first by about 100 kHz in about 80 s and then turns to increase, due to thermal deformation properties of the end plates of the storage cavity. The frequency of tripped cavities should be kept around ¡ 50kHz away from the RF frequency, i.e. , at the middle of the two consecutive revolution harmonics, in order to reduce both the coupled-bunch driving force of the ¡ 1 mode and the beam-induced power at the RF frequency. It can be done by switching the reference phase from the incident RF to the beam phase (Fig. 2).

4 BUNCH-GAP TRANSIENT

In both rings a 5% gap (0:5„s) will be introduced to allow for a rise time of a beam-abort kicker. It also works as an ion-clearing gap in HER. The gap modulates the amplitude and phase of the accelerating voltage. As a result, the beam phase is shifted bunch-by-bunch. In addition, the longitudinal shift gives rise to a horizontal displacement at the colliding point (CP), when the crab crossing is introduced.

Fig. 3 shows the transient response in HER, simulated in the time domain. The cavity phase modulation is 3.1 degrees in SCC and 1.5 degrees in ARES, respectively. The beam phase is modulated by 2.7 degrees. In the case of LER, where only the ARES cavities are operated, the simulated phase modulation was compared with the result obtained analytically from the transfer functions [6]. They were in good agreement. The results of the beam modulations are summarized in Table 2. The phase modulation is small, owing to the large stored energy in the ARES and SCC. No significant luminosity reduction due to the rela-

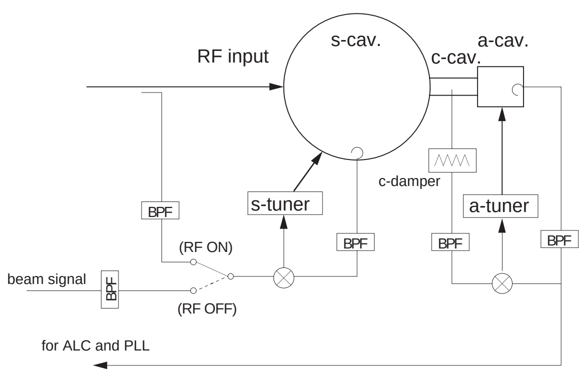

Figure 2: Block diagram of the tuning control system for ARES.

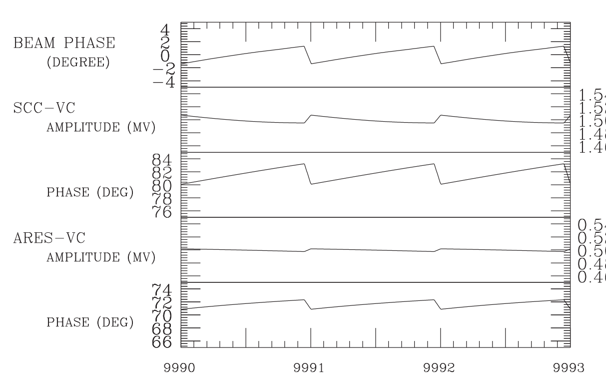

Figure 3: Transient response of the hybrid system in HER to a 5% gap.

Table 2: Bunch position shift due to 5% gap in both rings.

	LER	HER
Current [A]	2.6	1.1
Phase modulation (p-p) [deg]	3.5	2.7
Δz (p-p) [mm]	5.7	4.4
Δx at CP (p-p) [mm]	0.063	0.049
Δz (relative) † [mm]	$\pm$ 0.3	
Δx (relative) †† [mm]	$\pm$ 0.007	

† $(\Delta z_{her} - \Delta z_{ler})/4$ and †† $(\Delta x_{her} - \Delta x_{ler})/2$

tive longitudinal and transverse displacement at the CP is expected. The response of the direct RF feedback loop to the gap was also simulated. The input power and phase are modulated only by a few kW and a few degrees, respectively. Consequently, no gap-transient adaptive feedforward loop is necessary for KEKB.

It should be noted, however, that the response of the coupling cavity of ARES is very fast, because of its low Q-value [5]. In LER, the extracted power from the coupling cavity to the damper changes from 4 kW to 77 kW at the gap and the average power is 8 kW, in the case of $Q = 50$.

5 TRANSIENT AT ONE STATION TRIP

5.1 Beam Loss due to Trip

When some trouble occurs in the RF system, the RF input power will be switched off to protect the cavities and klystrons. In order to save refilling time and to prevent background noise at the detector, it is desired that the circulating beam should survive at an accidental trip of an RF station. Although we have sufficiently high over-voltage ratio with 10 or 14 stations, even one station trip can cause a beam loss due to the heavy beam-loading. Fig. 4 shows simulation results of transient response of the beam, the tripped RF station and other operating cavities. It was found that without any feedback the deviation of the beam energy exceeds dynamic aperture (about 1 %) in less than 100 turns, which means the beam will be lost in 1 ms. The reason is as follows. When the trip occurs, the one-turn energy loss is increased due to beam-induced power at the tripped cavity. Then the beam shifts forward and the phase of beam-induced voltage changes, which results in the decrease of the accelerating voltage of other operating cavities.

5.2 Possible cures

We have studied two possible cures for the beam loss. The first one is further detuning from the optimum tuning. It is effective, since the beam-induced power at the tripped cavity is reduced and the operating cavities are matched to higher beam-loading. A simulation showed that the beam survives when the loading angle is shifted by -20 degrees. Another measure is the direct RF feedback loop. A simulation was also done with the direct RF feedback included.

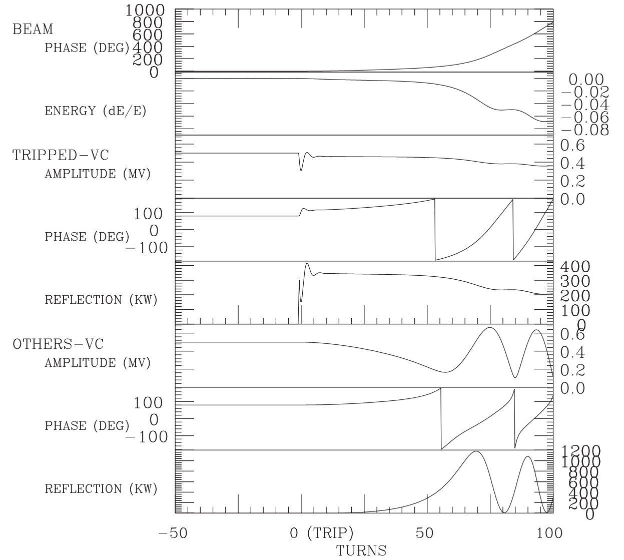

Figure 4: Transient response to one station trip.

The loop gain of 2 and the loop delay of 5 μ sec were assumed, which are quite conservative. As shown in Fig. 5, the beam survives after an initial oscillation.

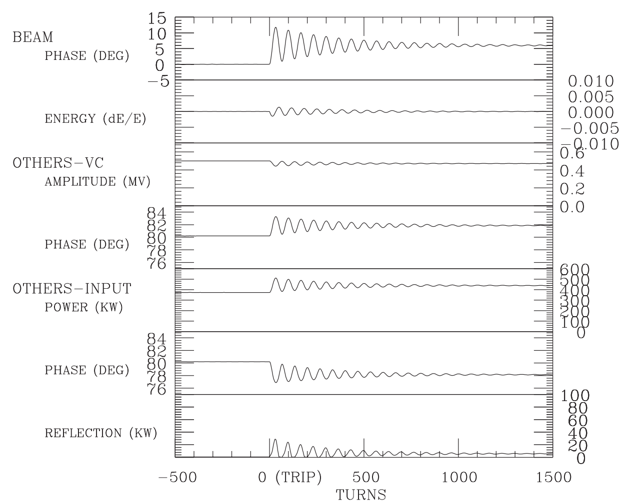

Figure 5: Transient response to a trip with the direct RF feedback loop on.

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