The 9th Symposium on Accelerator Science and Technology, Tsukuba, Japan 1993

Conceptual Design of RF Control System for the KEK B-Factory

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Abstract

In this paper we discuss issues which must be taken into account when designing RF control system for the KEK B-factory. Most of them arise from extremely large beam current required to achieve high luminosity.

I. INTRODUCTION

An asymmetric two ring electron-positron collider for B-physics (B-factory) is being planned at KEK [1]. It consists of 8 GeV (HER) and 3.5 GeV (LER) rings in existing TRISTAN tunnel. In order to attain high luminosity required for the B-factory, stored beam current should be much larger than any other existing accelerators.

Main issues to be solved regarding RF system arise from the extremely heavy beam loading of both the fundamental mode and higher order modes of accelerating cavities. External Q of higher order modes should be sufficiently lowered to avoid coupled bunch instability. Three types of damped cavities are being developed at KEK; two-cell Palmer-type normal conducting cavity [2], normal conducting three-cavity system using a storage cavity [3,4], and superconducting cavity [5]. They will be tested in TRISTAN-AR with large beam current in 1995. With these damped cavities and bunch-by-bunch feedback system, the coupled bunch instability arising from higher order modes is expected to be cured. The extremely heavy beam loading of the fundamental mode gives rise to several problems, which should be taken into account when we design RF control system.

In this paper we discuss issues which are characteristic of the B-factory RF system arising mainly from the extremely heavy beam loading of the fundamental mode. First, we estimate RF parameters for the three types of damped cavities being developed. Secondly, we discuss issues mainly relating to the heavy beam loading. Finally we give a brief description of the RF control system.

II. DESIGN CONSIDERATION

A. RF Parameters

Table 1 and 2 summarize main RF parameters to reach the luminosity of 10^{34} $cm^{-2}s^{-1}$. Since it is not yet decided which one of the three types of cavities will be used, we list here for each case. Total accelerating voltage is another uncertainty; either higher voltage for the original lattice design or lower voltage for low-α-lattice [6]. We assume here the higher accelerating voltage since it is easier to reduce voltage than to increase it. We also assume the loss parameter in the whole ring is about 60 V/pC. Although this value may not be accurate, it does not affect the parameters significantly since single bunch current is small on account of large number of bunches.

Table 1. Main parameters for the KEK-B factory

			LER	HER
Circumference		m	3018	
Luminosity		$/cm^2s$	1×10^{34}	
Bunch spacing		m	0.6	
RF frequency		MHz	508.6	
Energy	E	GeV	3.5	8.0
Beam current	I	A	2.6	1.1
RF voltage	Vc	MV	20	47
Radiation loss	Pb(rad)	MW	2.4	4.5
HOM loss	Pb(HOM)	MW	0.84	0.15
Total loss	Pb(total)	MW	3.2	4.7
Synchronous angle	φ	degree	86.5	84.8

B. Tolerance for the Control

In order to get short bunch length we have large accelerating voltage compared with one-turn energy loss, which makes the synchronous angle close to 90 degree. Small difference in RF phase of one cavity from another gives rise to large difference in beam power and reflection power. Although bunches pass on appropriate phase given by the total accelerating voltage, we need to control the phase of each cavity accurately enough to avoid large input and reflection power due to the deviation of the phase. Figure 1 shows necessary input power to maintain the accelerating voltage as a function of the error of the phase. It can be seen that the phase of each cavity needs to be controlled with an accuracy of about 1 degree in order not to cause excess input power.

Cavity tuning performs to keep relative phase of the input power and the cavity field constant. Phase error of the cavity tuning loop causes excess input power. Figure 2 shows necessary input power to maintain the accelerating voltage as a function of the tuning error.

C. Coupled Bunch Instability Driven by Fundamental Mode

Cavity tuning is usually controlled to compensate reactive component of beam loading in order to make the input power minimum. In the B-factory this makes a large detuning due to the heavy beam loading. If we use normal conducting

Table 2. Main RF parameters for the KEK-B factory for three types of cavities

		LER			HER		
		2 cell Palmer	nc. with storage	SC	2 cell Palmer	nc.with storage	SC
R/Q	Ω/cell	196	13.6	95	196	13.6	95
Q		27800	176000	-	27800	176000	-
R	MΩ/cell	5.45	2.40	-	5.45	2.40	-
# of cells		48	36	10	120	80	20
Vc	MV/cell	0.42	0.56	2.0	0.39	0.59	2.35
Pc	kW/cell	31	129	-	28	144	-
Pb	kW/cell	67	89	321	39	58	233
Pb+Pc	kW/cell	99	218	-	67	202	-
β coupling		3.10	1.69	-	2.38	1.40	-
QL		6800	65000	2×10^5	8200	73000	2×10^5
Δf detuning	kHz	310	16	31	139	6.4	11
# of cells/klystron		8	4	2	8	4	2
# of klystrons		6	9	5	15	20	10
Total Power	MW	4.7	7.8	3.2	8.0	16.0	4.7

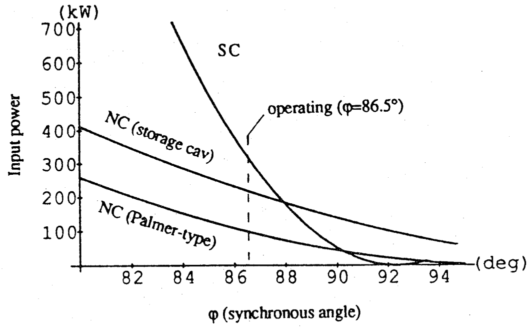

Figure 1. Necessary input power to maintain the accelerating voltage as a function of the phase error.

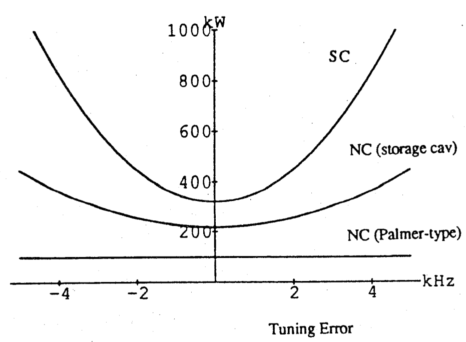

Figure 2. Necessary input power to maintain the accelerating voltage as a function of the tuning error.

cavities this amounts to 310 kHz for LER, that is three times as much as the revolution frequency (f_{rev}) and causes several modes of coupled bunch instability. Figure 3 shows growth rate of these modes. The growth rate is so large that it can hardly be cured with a bunch-by-bunch feedback system. Efforts to solve this problem are in progress on two fronts; cavity itself and RF control. A high-Q storage cavity connected to the accelerating cavity reduces the detuning frequency drastically since it stores large amount of electromagnetic energy, that reduces total R/Q by an order of magnitude while keeping shunt impedance high [4]. Superconducting cavity does not suffer from this problem owing to its high accelerating gradient and lower R/Q.

Cures from the control side are RF feedback system either direct or with a comb filter and installation of damper cavities tuned at the damping side of the coupled bunch instability. If we use the storage cavity system or superconducting cavity, the load on the feedback system is by far lighter.

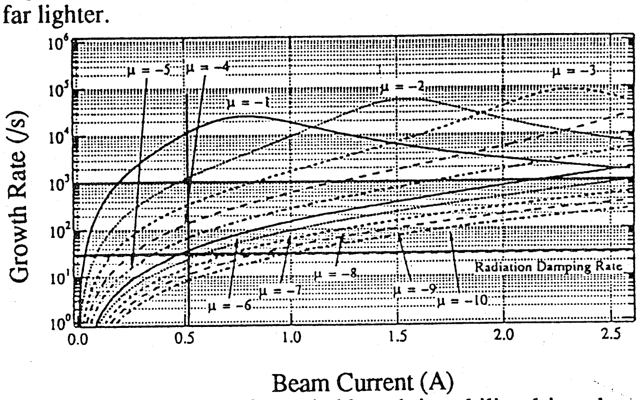

Figure 3. Growth rate of coupled bunch instability driven by the fundamental mode.

D. Gap Transient

A gap in the bunch train is probably the most effective solution to prevent ion trapping in the electron ring, which causes instability due to coupling of ion and electron motion. The gap, on the other hand, modulates phase and amplitude of the accelerating field and the bunch spacing. This may cause problems for RF system and luminosity degradation. To estimate the effect of the gap we have been making two different approaches; one is to evaluate a transfer function of beam-cavity system and the other is to make use of a simulation code tracing the bunch motion turn-by-turn. Figure 4 shows modulation of bunch spacing in the case of 10 % gap calculated with the transfer function. The simulation code gave similar results in the case of small current. To prevent luminosity degradation it is proposed to introduce partial filling in the positron ring [7].

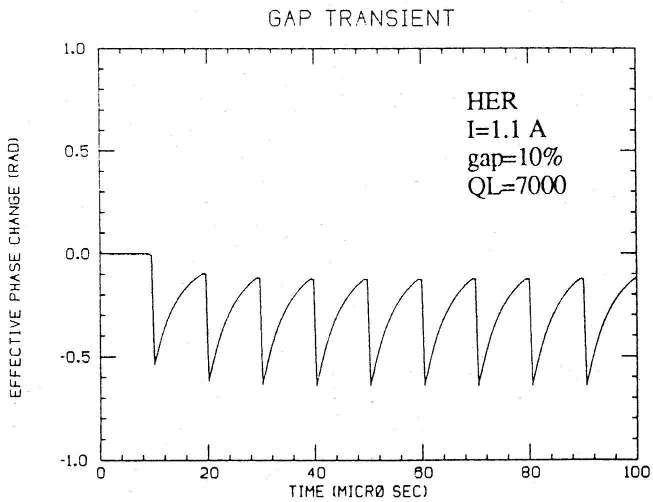

Figure 4. Modulation of bunch spacing in the case of 10 % gap in HER calculated with the transfer function.

E. Change of Synchrotron Frequency

If the synchrotron frequency (f_s) is lower than the bandwidth of the cavity, restoring force for coherent longitudinal oscilation of beam is not the cavity voltage, but the generator voltage. Then the synchrotron frequency for the coherent oscilation becomes lower when the beam current increases. This does not happen for coupled bunch mode of non-zero because f_s+m*f_{rev} is usually larger than the band width. However, does this happen for the m=0 mode. Figure 5 shows the f_s as a function of the beam current for the case of the Palmer-type cavity. F_s decreases from the design value of 6.4 kHz to 0.6 kHz for the maximum current in LER. Although the beam-cavity system itself is stable until the f_s reaches zero (static Robinson limit), stability of total system including feedback loops can be affected. For example, band width of the loop may be limited up to the lowerd value of f_s. We are now evaluating the effect of changing of f_s for the total system.

F. Recovery Sequence

It is necessary to keep stable operation; (1) to store the beam stably even if some klystrons are switched off due to some interlock actions and (2) to switch on the tripped klystrons without affecting the circulating beam. As for the former there is little problem because the over-voltage-ratio is high. The latter condition needs to be treated carefully because of the high beam induced voltage with the large beam current. We treated the same subject for the superconducting cavities in TRISTAN and the recovery sequence has operated well [8]. For the B-factory more sophisticated sequence will be necessary since the beam current is much larger. Following is a possible solution:

(1) Detune the cavity to a safe position.
(2) Switch on the RF with klystron phase and amplitude loop closed but with cavity field phase and amplitude loop open. The klystron output is controlled to give appropriate generator current which is dependent on the beam current.
(3) Tune the cavity smoothly and close the tuning loop.
(4) Close the cavity field loop.

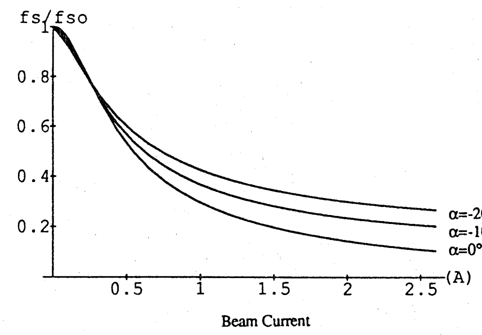

Figure 5. Change of coherent synchrotron frequency as a function of the beam current for the case of the Palmer-type cavity. α is the phase difference between generator current and cavity voltage.

III. RF CONTROL SYSTEM

RF control system for the KEK B-factory should include following components.

(1) Ordinary feedback loops commonly used in storage rings; cavity tuning loop, phase and amplitude control loops for klystron output, phase and amplitude control loops for cavity field.
(2) Cures for the fundamental-mode coupled-bunch instability and the bunch gap; RF feedback, feedforward correction for the beam loading, damper cavity.
(3) Auxiliary phase control; a real time phase correction scheme which measures input power, reflection power and cavity voltage of all cavities, calculates phase deviation, and corrects the phase at low level may be helpful to control the phase of each station with a required accuracy.

IV. REFERENCES

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