DESIGN OF THE KEKB RF SYSTEM

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Abstract

An RF system for KEKB to be commissioned in FY1998 has been designed. The key issue in the KEKB RF system is to solve problems arising from an extremely heavy beam loading, since the stored current is much higher than that of any exsisting storage rings. This paper describes an overall view of the requirements and the design of KEKB RF system.

I. INTRODUCTION

An asymmetric two-ring electron-positron collider for B-physics (KEKB) will be commissioned in FY1998. The RF-related machine parameters are listed in Table I [1]. The total RF voltage is required to provide the short bunch length (σ_z=4mm) and the desired synchrotron tune (ν_s). From a beam dynamics requirement the synchrotron tune should be variable in a range from 0.01 to 0.02 in order to find the best operation point avoiding synchrotron-betatron coupling resonances. Then the RF voltage should be variable in a range of 5∼10 MV (LER) and 10∼20 MV (HER). Wiggler magnets are probably installed in LER in order to reduce the damping time from 43ms to 23ms, and to control the emittance. The beam power in LER is then increased from 2.7 MW to 4.5 MW.

We must overcome several problems arising from an extremely heavy beam loading on RF cavities. A high stored current with many bunches causes strong coupled-bunch instabilities. A coupled-bunch instability due to the accelerating mode occurs, because of a large detuning frequency caused by the heavy beam loading, compared with a small revolution frequency (large circumference ring). If we use conventional normal-conducting damped cavities, the growth rate is extremely high. Thus one of the key issues for the KEKB RF system is how to avoid this instability.

Other requirements for the cavity related with the heavy beam loading are: the higher order modes (HOM's) should be sufficiently damped to avoid coupled-bunch instabilities, an input coupler should be able to handle 500 kW, and HOM absorbers attached to the cavity should work normally with 10 kW of HOM power. In addition, the heavy beam loading needs to be taken into account when we design the low level RF control system.

Table I
RF-related machine parameters

Ring	LER	HER	
Particle	positron	electron	
Energy	3.5	8.0	GeV
Beam current	2.6	1.1	A
Bunch length	0.4		cm
Energy spread	7.4×10^{-4}	6.7×10^{-4}	
Bunch spacing	0.59		m
Synchrotron tune	0.01∼0.02	0.01∼0.02	
Mom. compaction	$1 \sim 2 \times 10^{-4}$	$1 \sim 2 \times 10^{-4}$	
Energy loss/turn	$0.81^{\dagger}/1.5^{\dagger\dagger}$	3.5	MeV
RF voltage	5∼10	10∼20	MV
RF frequency	508.887		MHz
Harmonic number	5120		
Damping time	$43^{\dagger}/23^{\dagger\dagger}$	23	msec
Radiation Power	$2.1^{\dagger}/4.0^{\dagger\dagger}$	3.8	MW
HOM Power	0.57	0.14	MW
Total Beam power	$2.7^{\dagger}/4.5^{\dagger\dagger}$	4.0	MW

† — without wiggler
†† — with wiggler

II. RF SYSTEM

A. Accelerating cavity

In order to avoid the coupled-bunch instability caused by the accelerating mode, a new normal-conducting cavity scheme referred to as accelerator resonantly coupled with an energy storage (ARES) was proposed at KEK [2] [3] [4]. It employs an energy storage cavity which couples to an accelerating cavity via a coupling cavity in between. A large stored energy in the storage cavity reduces the detuning frequency by an order of magnitude. The instability is sufficiently suppressed with this scheme. A 1/5 scale cold model of ARES was tested and the design principle was proved [5].

The accelerating cavity of ARES must be a damped structure. We adopted a HOM-damping scheme with a coaxial waveguide equipped with a notch filter to block the accelerating mode [6] [7]. Based on the calculated R/Q values and the Q values of HOM's, the growth time of the fastest growing mode is about 60 msec in the longitudinal case and 30 msec in the transverse case [1]. A prototype cavity was fabricated and tested in a high power operation. It was successfully tested up to 110 kW of wall dissipation which corresponds to a gap voltage of 0.73 MV, that is beyond the design value [8].

Superconducting cavity is fairly immune against the instability caused by the accelerating mode. Although the growth time is still faster than the radiation damping time in the case of LER, we obtained a reasonable parameter set in the case of HER, where it is sufficiently slow. The growth time of the instability due to the HOM's is also slower than the radiation damping time in HER. Thus the superconducting cavity is considered another candidate in HER. Prototype cavities were tested in liquid helium. The design values of the gap voltage and the Q-value were achieved [9].

A beam test of ARES and a superconducting cavity in TRISTAN-AR is scheduled in 1996. The cavities will be tested with a stored beam of up to 500 mA.

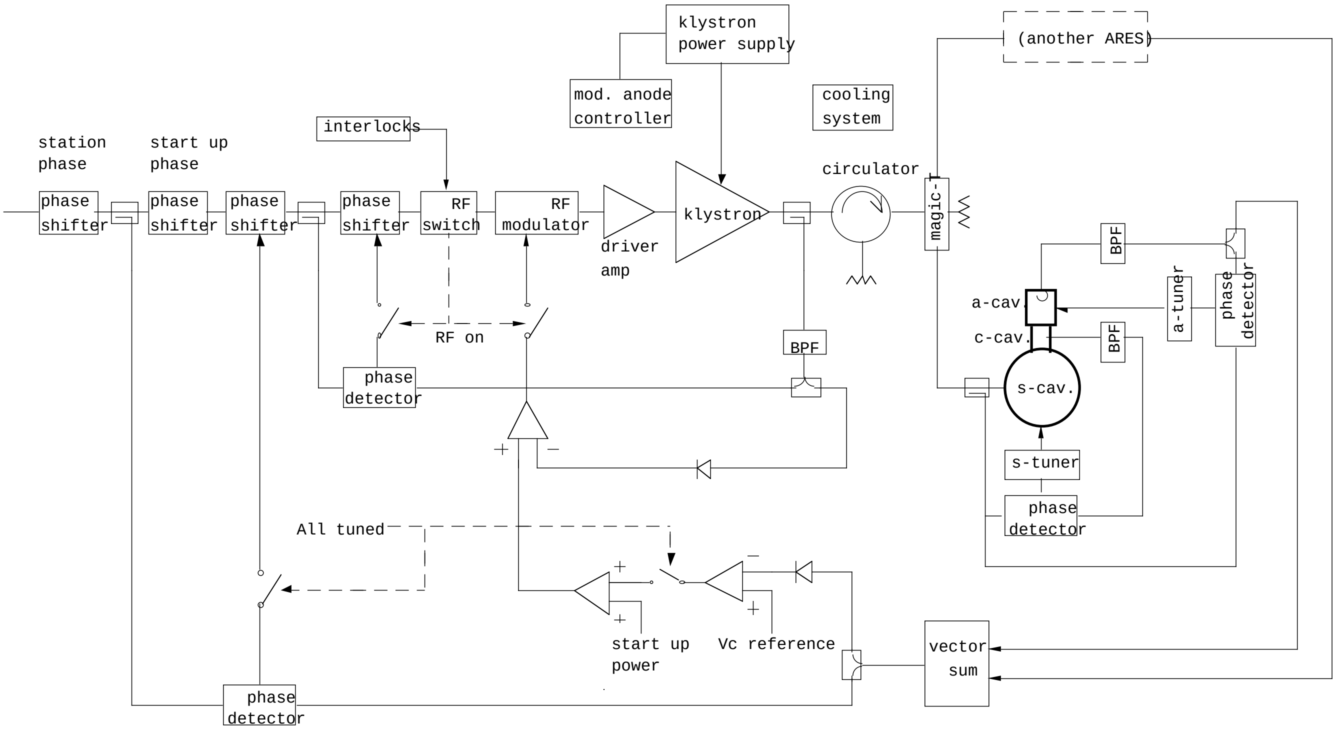

Figure. 1. A block diagram of each RF unit.

B. System layout and operating parameters

The RF stations for LER will be located in Fuji straight section and those for HER in Oho and Nikko straight sections.

A block diagram of each RF unit is shown in Figure 1. A 508 MHz 1MW CW klystron will feed the power to two ARES cavities or one superconducting cavity via WR1500 wave guides. A circulator protects the klystron from reflection RF power coming back toward the klystron.

The RF operation parameters were optimized for both cases of $\nu_s = 0.01$ and 0.02 taking followings into account.

- The growth time of the instability due to the accelerating mode should be slower than the damping time.
- It should also meet the full wiggler option in LER.
- The high power system should be stably operated.

The thus-determined parameters are shown in Table II. The number of klystrons needed in LER and HER is about the same as that having been used in TRISTAN. The existing klystrons, together with the power supply systems and the cooling systems for the klystrons, wave guide components, magic tees and circulators will be re-used in KEKB. It greatly help reduce the construction cost. Furthermore, the long-term operation of TRISTAN has proven the reliability and stability of our high power system up to 800 kW.

Table II
RF Operation Parameters for the ARES Cavity

		LER		HER	
Energy	GeV	3.5		8.0	
Current	A	2.6		1.1	
Beam power	MW	4.5		4.0	
RF voltage	MV	5	10	10	20
Synchrotron tune		0.01	0.02	0.01	0.02
# of Cavities		10	20	20	40
R/Q	Ω/cav	12.8		12.8	
Q_0		1.33×10^5		1.33×10^5	
Q_L	$\times 10^4$	2.6	3.8	4.0	5.0
Input β		4.05	2.52	2.35	1.67
Voltage	MV/cav	0.5	0.5	0.5	0.5
Input power	kW/cav	595	371	345	246
Wall loss	kW/cav	147	147	147	147
Detuning freq.	kHz	15.9	16.7	6.7	7.0
Growth time†	msec	54	36	420	250
# of Klystrons		$10^{\dagger\dagger\dagger}$	10	10	20
Klystron power††	kW	640	800	740	530

Wiggler magnets are included in LER.
† — Coupled-bunch instability due to the accelerating mode.
†† — 7 % loss at wave guide, circulator, magic tee etc. is taken into account.
††† — In this case one klystron feeds one cavity.

C. Feedback loops

Each RF unit has feedback loops to control the cavity field, the klystron output and cavity tuners. Phase detection is conducted at an intermediate frequency of 1 MHz. The cavity phase should be controlled with an accuracy of less than 1 degree to maintain the colliding point at the minimum β^* and to avoid excess generator power into the cavity. We will improve the accuracy of existing RF reference system and phase control modules having been used for TRISTAN. In addition, we will use a computer-aided phase correction scheme, where the input power, reflection power, and cavity voltage of every cavity are measured and then the phase error of each cavity is calculated and corrected. This correction scheme takes advantage of the high beam-induced voltage.

The ARES requires two tuner control loops, as seen in Figure 1; one is for the accelerating cavity and the other for the storage cavity. The accelerating cavity tuner is controlled by its phase with respect to the input phase, which is the usual way to compensate for the reactive component of the beam loading. The storage cavity tuner is controlled not by its own phase but by the phase of coupling cavity; otherwise the tolerance would be extremely severe [10].

The R&D work is in progress for an RF feedback system using a parallel comb filter [11]. It reduces the coupling impedance at the upper synchrotron sidebands of revolution harmonic frequencies. It will be applied to provide additional damping for the accelerating mode instability, when necessary.

D. Bunch gap transient

The effect of a bunch gap was evaluated [12]. In order to prevent an ion trapping, a 5% ∼ 10% bunch gap will be introduced in HER. The bunch gap, however, modulates the accelerating field and the synchronous phase. The luminosity can be reduced by the displacement of the collision point from the optimum point with the minimum β^*. The calculated bunch phase modulation is summarized in Table III. Note that the phase modulation is much smaller owing to the large stored energy, compared with the case of conventional normal-conducting damped cavities where it amounts to 20 ∼ 30 degrees. The displacement of the colliding point can be further reduced by introducing a corresponding gap in LER, which makes a similar gap transient response in LER to that in HER. Figure 2 shows the relative bunch phase without and with the compensation gap. The displacement is reduced to less than 0.5 degree (=$0.2\sigma_z$), which is acceptable.

Table III
Bunch phase modulation due to a bunch gap

cavity in HER	gap length (%)	bunch phase modulation (p-p, degree)	
		with compensation gap?	
		no	yes
ARES	10	2.7	∼ 0.3
	5	1.3	∼ 0.1
SCC	10	4.9	∼ 0.5
	5	2.4	∼ 0.3

III. CRAB SYSTEM

The crab crossing is considered a viable fall-back solution to the problems encountered with the finite angle (±11 mrad) crossing scheme. As a crab cavity we adopted the design of superconducting squashed crab cavity developed under KEK-Cornell collaboration [7]. The R&D is in progress aiming at fabricating full scale niobium cavities in three years [13].

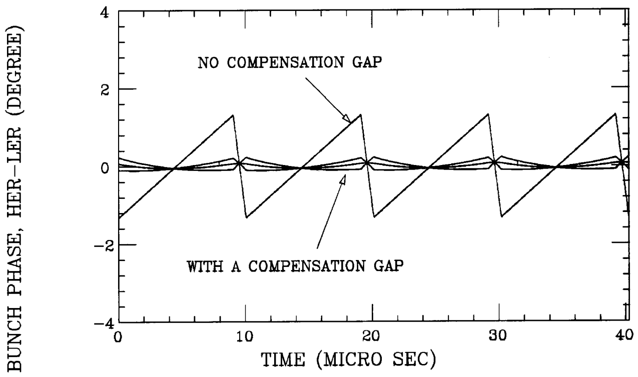

Figure. 2. Bunch phase modulation due to a bunch gap and the effect of a compensation gap. The bunch current in the compensation gap is set 50, 55, 60% of that of other bunches.

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