RF SYSTEM FOR KEK B-FACTORY

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Abstract

This paper presents an overview of the RF system for the KEK B-Factory (KEKB). Most of the TRISTAN RF resources, except for the accelerating cavities, will be reused for KEKB. However, the RF system has been thoroughly re-examined and is being improved in order to cope with the heavy beam loading and to meet the increased demands associated with the high luminosity. A variety of new feedback loops will be incorporated into the RF system to stabilize the RF and its interaction with the beam.

1 INTRODUCTION

The KEKB consists of two storage rings asymmetric in energy, the 8 GeV high energy ring (HER) for electrons and the 3.5 GeV low energy ring (LER) for positrons [1]. To prevent the coupled bunch instabilities due to HOMs and the accelerating mode, the three-cavity accelerating system (ARES) and the superconducting damped cavity (SCC) have been developed [2]. The design and performance of the ARES and the SCC are described in the associate papers [3][4]. Since the ARES has a larger stored energy and is consequently more suitable for reducing cavity detuning, the ARES alone will be used for the LER where the beam loading is the strongest. The HER will be equipped with a combination of the ARES and SCC, which will be operated with a suitable relative phase-angle to assign higher cavity voltage (V_c) to the SCC and heavier beam loading/V_c to the ARES. Commissioning of the KEKB will begin in this October with only part of the full RF system for both rings.

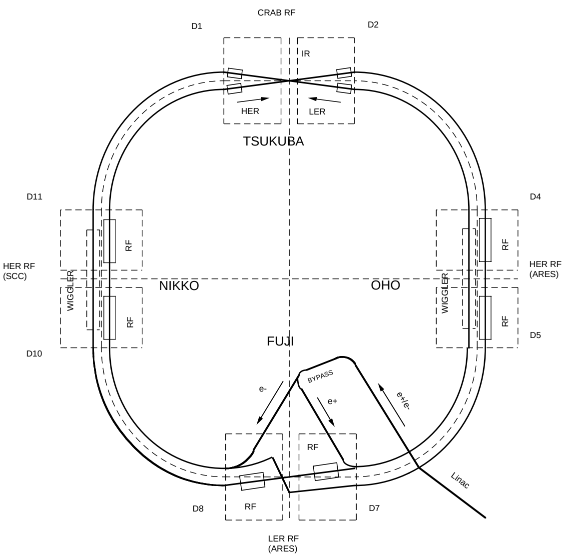

Figure 1: Layout of the RF stations around the rings.

2 SYSTEM LAYOUT

The LER will be operated with 10 klystron stations and 20 ARESs, each 2 ARESs driven by 1 klystron. The HER will have 6 klystron stations driving 12 ARESs and 8 klystron stations driving 8 SCCs. Both rings can operate with full beam current and nominal bunch-length even when one station is idle in each ring. In the commissioning phase, 12 ARESs will be operated in LER and 12 ARESs + 4 SCCs in HER, limiting the currents in the LER and HER to about 50 % and 70 % of the design values respectively. Fig. 1 shows the layout of the RF stations around the rings. Table 1 gives the RF-related machine parameters and the typical values of RF operation parameters for both rings.

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
$Q_{\rm L}$ $\times 10^4$	3.0	8.0	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

Wiggler magnets are included in LER.
† 7 % loss at waveguide system is included.

3 LOW-LEVEL RF SYSTEMS

3.1 Frequency Choice and Master Oscillators

The linac beam is required to be injected into the center of the ring RF bucket within the error of ± 30 ps [1]. To fulfill this requirement, the linac RF frequency, $f_{\rm L}$, should be phase-locked to the ring RF frequency, $f_{\rm R}$, each of which should be a multiple of a common subharmonic frequency, $f_{\rm sub}$. Under the condition that the TRISTAN RF components are reused, the frequencies $f_{\rm sub}$, $f_{\rm L}$ and $f_{\rm R}$ have been determined to be 10.385 MHz, 2856.0 MHz and 508.89 MHz respectively. The ring frequency $f_{\rm R}$ is about 0.3 MHz higher than that of TRISTAN.

A master oscillator has been developed to generate the highly stable phase-locked frequencies, $f_{\rm sub}$, $f_{\rm L}$, and $f_{\rm R}$. Their frequency stabilities are now being precisely measured for short term (jitters) as well as for long term (drifts). The master oscillator, named the linac/ring master, is located at the linac control room, from which $f_{\rm R}$ is sent to the ring control room via the RF reference line. The rings have their own master oscillator which is normally locked to the linac/ring master. When some frequency change is required in the rings, the ring master is unlocked from the linac/ring master, changed its frequency in maintaining phase continuity and then relocked without loss of the beam.

3.2 RF Reference Line

The RF signal from the ring master will be provided for the RF stations via RF reference lines shown in Fig. 2. Each

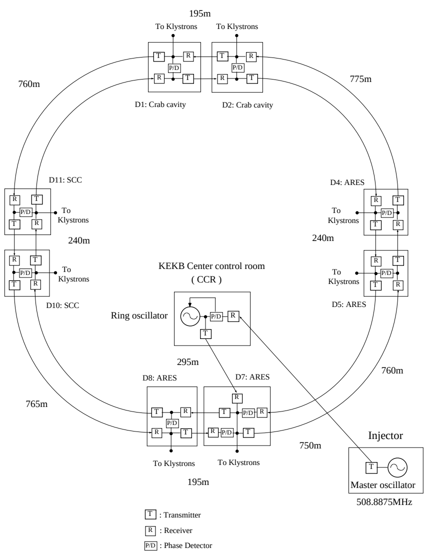

Figure 2: Layout of RF reference lines for KEKB.

segment of the reference line is phase stabilized by its own independent feedback system, which uses a second subharmonic signal returned from the end of each line [5]. Two independent reference lines will be in operation; one reference line transmits the RF signal clockwise and the other line counterclockwise. The phase difference between the two lines are always monitored at each location (D1, D2, etc.). When a reference line has a trouble, this configuration makes it possible to instantly detect a troubled segment and switch to another reference line in a short time. The phase error around the ring can be held below 1 deg. The RF signal is also required as a timing reference for the physics experiments and bunch monitoring. For this use, fiber-optic reference lines will be constructed by the commissioning time.

3.3 Feedback Loops

A block diagram of one RF station for ARES is shown in Fig. 3. An RF station for SCC is basically the same, except for 1 cavity/1 klystron configuration and the controls and interlocks specific to SCC. In addition to the cavity feedback loops, the klystron feedback loops will be implemented to stabilize the amplitude and phase of the klystron output. They will 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 will be introduced 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 0-mode bunch oscillations and increasing the Robinson stability area [6].

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. 4). 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 [7].

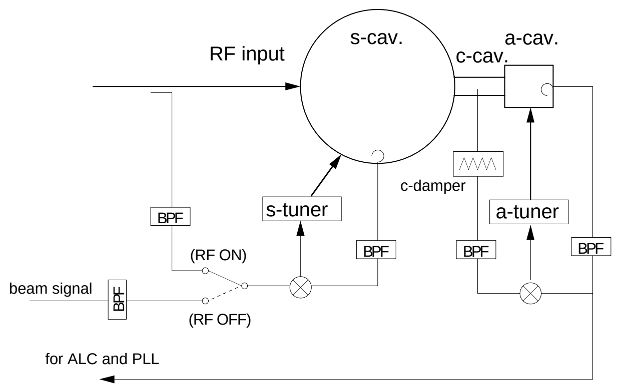

Figure 4: Block diagram of the tuning system for ARES.

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 the increase. This peculiar detuning behavior during the cooling process results from thermal deformation properties of the end plates of the storage cavity. The frequency of tripped cavities should be kept around -50 kHz 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 -1 mode and the beam-induced power at the RF frequency. For tuning the tripped cavities, the phase of the beam will be used as a reference phase, since the incident RF is no longer available.

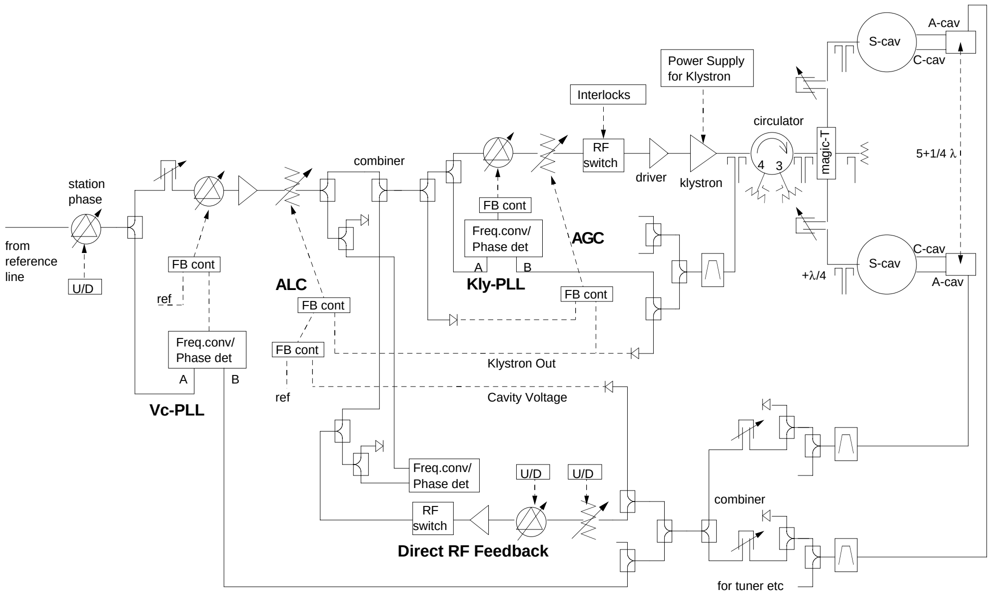

Figure 3: Block diagram of one RF station for ARES.

3.4 Computer Interface

The RF system will be operated by the computer control system based on EPICS. The computer monitors the operating parameters such as the power, voltage and phase of every part and takes appropriate action to keep the system working properly. For example, it can detect phase errors among the RF stations from unbalanced beam loading and will correct a phase of each station so that the balance can be restored. The computer interface also monitors the operating environment of the klystrons, circulators, cavities, and so on. This includes temperature, vacuum, water flow, air flow, and warns of abnormal operating conditions and shuts off components if necessary. A software for cavity processing has been developed on the basis of EPICS and is now used for automatically processing the manufactured ARESs up to 180 kW.

4 HIGH POWER RF SYSTEM

Each high power RF system consists of a 1 or 1.2 MW klystron, its power supply (PS), 1 MW circulator, WR-1500 waveguide components, etc. A newly-developed 1.2 MW load will replace an existing 250 kW load, since the beam-induced power can reach 1 MW in the case of the klystron tripping off at full beam. In the RF system where one klystron feeds two ARESs, the waveguide length and the cavity location are so arranged that the power from the two in-phase cavities is absorbed into the 1.2 MW load at the magic T. This arrangement shields the circulator from the large power from the cavities [8].

Various improvements and modifications have been given to the klystrons to get characteristics upgrading and higher stability [9] [10]. Difficulties, such as positive and negative spikes of anode current, sideband oscillation and fast self-recovery breakdown in particular, which are caused by improper arrangement of gun structure and/or back streaming electrons, have been extensively studied and solved by finding causes and remedies [9].

The klystron PSs have been improved to eliminate misfiring of the crowbar circuit, which had been a long-standing trouble with the PS in TRISTAN operation. Fiber-optic links have been introduced to shut out incoming noise to the control units of the crowbar, and measures have been taken for preventing corona discharge which emits electrical noise, a possible cause of false triggering. The layout of the high power RF equipment for KEKB requires that the length of some coaxial cables between a PS and a klystron be longer than 30 m, which yields a cable stored-energy of over 10 J at 90 kV cathode voltage. We found out, however, by measurements and estimates that only a small part of the energy stored in the cable is absorbed at the arcing when it occurs in the klystron. The conclusion is that, even if a crowbar circuit is placed more than 200 m away from a klystron, it can still be effective in protecting the klystron.

5 REFERENCES

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