KEK Preprint 2000-41
June 2000
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Submitted to the 7th European Particle Accelerator Conference (EPAC 2000),
Vienna, Austria, June 26 - 30, 2000.

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COMMISSIONING OF THE KEKB RF SYSTEM

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Abstract

The KEKB RF system is designed to cope with heavy beam-loading and to meet the increased demands associated with high luminosity of KEKB. Two types of heavily-damped cavities, the ARES and superconducting cavities, have been operating stably. The high-power and low-level RF systems have been working well as designed. Neither the stored beam current nor luminosity has been limited by the RF system. This paper presents an overview of the commissioning status of the KEKB RF system.

1 INTRODUCTION

The KEKB, an asymmetric energy double-ring e^+e^- collider for B-physics, was commissioned in December 1998. Two types of heavily-damped cavities are used for KEKB: the ARES normal-conducting cavities [1] and single-cell superconducting cavities (SCC) [2]. The ARES is a three cavity system where an accelerating cavity is resonantly coupled with an energy stored cavity via a coupling cavity in-between. It increases the total stored energy in the cavity, while the dissipation power is kept at a reasonable level. The large stored energy in the ARES and SCC is advantageous as follows: (1) It reduces growth rate of the longitudinal coupled-bunch instabilities associated with a detuning for the accelerating mode. (2) It reduces the shift of collision point and modulation to the RF system due to bunch-gap transient effect.

Although most of the low-level and high power components for TRISTAN are reused for KEKB, various improvements and modifications have been given. The low-level RF system is thoroughly re-examined to cope with the heavy beam-loading [3].

Before the construction of KEKB, the ARES and SC cavities as well as the low-level system were tested with a high current beam up to 570 mA in TRISTAN Accumulation Ring. They showed good performances as expected [4] [5].

2 SYSTEM DESCRIPTION

Table 1 shows RF-related machine parameters as well as design 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. Each klystron drives two ARES cavities or one SCC. Table 2 shows history of upgrading the RF system. The commissioning started with 12 ARES cavities in LER and 6 ARES and 4 SC cavities in HER. In summer 1999 four ARES cavities were added in each ring. Four SCC's will be added in summer 2000 and all remaining ARES's will be installed in 2001.

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

	LER	HER	
Energy [GeV]	3.5	8.0	
Current [A]	2.6	1.1	
Energy damping time [ms]	23	23	
Radiation loss [MV]	1.6	3.5	
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	ARES	SCC
Number of Cavities	20	12	8
Relative phase	–	10 degrees	
Total RF voltage [MV]	10	17.9	
R/Q [Ω/cav.]	14.8	14.8	93
$Q_L \times 10^4$	3.0	3.0	7.0
Input β	2.7	2.7	–
Voltage [MV/cav.]	0.5	0.5	1.5
Input power [kW/cav.]	375	340	250
Wall loss [kW/cav.]	154	154	–
Beam power [kW/cav.]	221	173	240
Number of Klystrons	10	6	8
Klystron power [kW]	~ 810	~ 730	~ 270

Table 2: The number of cavities and RF stations since the commissioning.

	LER	HER	
	ARES	ARES	SCC
Dec. 1998 ~	12 (6)	6 (3)	4 (4)
Oct. 1999 ~	16 (8)	10 (5)	4 (4)
Oct. 2000 ~	16 (8)	10 (5)	8 (8)
Oct. 2001 ~	20 (10)	12 (6)	8 (8)

Numbers in ( ) are RF stations.

3 OPERATING STATUS

3.1 Cavity Performance

Achieved parameters Table 3 shows present status of the operation of the RF system. Stored beam current has been increased up to 750 mA in LER and 514 mA in HER. So far, the beam current has never been limited by the RF system, but by heating of vacuum components. Potential current limitation due to the RF system is approximately proportional to the number of cavities, i.e. the power to be delivered to beam. The present RF system could support 1.5 A in LER and 0.7 A in HER.

Every ARES has been conditioned up to 0.45 MV and SCC more than 2.0 MV. Then 7.2 MV in LER and 12.5 MV in HER can be provided. However, most of the time it has been operated at a lower voltage of 5 MV in LER and 9 MV in HER. The reason is that a longer bunch length is chosen to suppress the heating of bellows in the interaction region. Sometimes the RF voltage was raised up to 7 MV in LER and 11 MV in HER with a relatively low beam current.

The SCC delivered the beam power of 380 kW per cavity, which is much more than the design value. The delivered beam power by the ARES in HER has achieved close to the design value. Although the beam power by the ARES in LER is relatively low due to the current limitation, the property has been tested up to 170 kW per cavity by shifting the RF phase of each cavity one by one so that much larger power is delivered by the cavity.

The HOM dampers, made of SiC for the ARES and Ferrite for the SCC, have been working well. Up to 2.6 kW power has been absorbed by the damper. No sign of coupled-bunch instabilities caused by HOM's of the cavities has been observed.

Table 3: Achieved and design paremeters as of Jun. 2000.

	LER	HER	
	ARES	ARES	SCC
Beam current [mA]	750	514	
	(2600)	(1100)	
Operating voltage [MV]	5	9	
	(5~10)	(10~18)	
No. of cavities	16	10	4
	(20)	(12)	(8)
Voltage/ cav. [MV]	0.31	0.35	1.38
(conditioned up to)	0.45	0.45	>2.2
	(0.5)	(0.5)	(1.5)
Total Beam power [MW]	1.2	2.1	
	(4.5)	(4.0)	
Beam power / cav. [kW]	75	130	380
(by shifting RF phase)	170		
	(225)	(170)	(250)
HOM power / cav. [kW]	0.6		2.6
			(5.0)

Numbers in ( ) are design values.

Trips of cavities Trip rate of the four SCC's in total is about once per six days during the physics run. It is caused by cavity quench or arcing at the input couplers. Most of them occurred at the outermost two cavities, D11A and D11D. Although the driving RF is switched off by a quench detector or arc sensors, the quench lasts due to the beam-induced power, which results in helium pressure rise and evaporation of a large amount of helium. Then the beam should be aborted in most cases. The helium pressure and level is recovered in ten minutes.

Trips of the ARES cavities are caused by coupler arcing, reflection or vacuum pressure rise, etc. At the beginning of the commissioning the trip rate was relatively high, but after several months operation it is reduced. Recently almost no trip occurs except for two cavities (D4B#1 and D4C#2). The trip rate of these two cavities are about once per day.

3.2 Longitudinal Collision Point

The shift of longitudinal collision point due to beam instabilities or errors in the RF system can degrade the luminosity because of the short bunch length and small β_y^*. It should be kept typically within 1 degree. As described below, it is kept stably and no luminosity degradation has been attributed to the RF system.

Bunch gap transient In order to avoid ion-trapping and to allow for rise time of a beam abort kicker, 10 % of the ring is not filled with the bunches. The effect of the bunch gap transient has been simulated [3]. With the current operating parameters, the RF phase of each ring is modulated by 2 $\sim$ 3 degrees. It is relatively small for the high beam current owing to the large stored energy of the ARES and SCC, although not very small because of the relatively low operating voltage and the long gap length. The collision point shift is further reduced to $\pm$ 0.3 mm, since a large part of the modulation in each ring is cancelled out. It is much smaller than the present bunch length of 6mm. Consequently, we do not need any compensation for the gap transient so far.

RF phase stability The RF reference line is stabilized within 1 degree [6]. Data from the Belle detector shows no big drift of the collision point throughout the physics run.

At the beginning of the commissioning, we observed zero-mode synchrotron oscillation of $\pm$ 0.5 degree or more due to phase noise in the RF system. After a zero-mode damper was installed, it is sufficiently reduced to $\pm$ 0.05 $\sim$ 0.1 degree.

The synchronous phase changes according to the bunch current change from collision start to run end. With the measured loss factor of about 40 V/pC in each ring [7], it is about 1 degree. It can be compensated by shifting the RF phase according to the beam current, if necessary.

Instabilities For a large circumference ring with a high beam current the longitudinal coupled-bunch instabilities of the $-1, -2, -3$ modes, and so on, can be strongly excited due to a large detuning for the high beam current. In KEKB, the large stored energy of the ARES and SCC reduces the detuning frequency by an order of magnitude. In the present operation it is 5 ~10 kHz, which is much smaller than the revolution frequency of 99.4 kHz. Thus the instability is sufficiently suppressed and no sign of the instability has been observed. A simulation showed, however, the instability can occur with much higher beam current at a relatively low operating voltage. In this case the -1 mode damper using a parallel comb filter [8] will be installed to cure it.

Observation by spectrum analyzer shows that other modes of synchrotron oscillation is much smaller than the zero-mode. Once a strong synchrotron oscillation was excited by a high Q mode of an old type of movable masks in LER. After replacing it with another type where SiC dampers are installed, the oscillation disappeared. Coupled-bunch oscillation caused by HOM of cavities has never been observed both longitudinally and transversely. It shows good damping property of the cavities.

3.3 Cures for Trips with Heavy Beam-Loading

An outstanding feature of the KEKB RF system is that up to two ARES stations can trip without beam loss, and that tripped stations can be turned on again without losing a high current stored beam, after the trouble is cleared. Considering the trip rate and refilling time, it remarkably contributes to improve the integrated luminosity. This is done as follows.

1. When one or two ARES stations trip, still sufficiently high RF voltage is provided by other operating stations. The shift of collision point due to the voltage change is compensated by shifting the RF phase.
2. Resonant frequency of the tripped ARES cavities tends to decrease at first by about 100 kHz in about 80 s and then turns to increase due to thermal deformation properties of the storage cavity of ARES. In order to avoid the -1 mode instability caused by the tripped cavities and a large amount of beam-induced power that can damage the cavity or high power system, it is kept around the middle of the two consecutive revolution harmonics by measuring the relative phase between the beam signal and the beam-induced voltage [3].
3. The tripped stations are turned on again with carefully designed parameters and control sequence. It minimizes the disturbance to both the beam and the tripped RF stations. It is done without losing the high current circulating beam.

3.4 System Reliability

The RF system has been stably operated for physics run: beam loss or machine down time due to RF troubles is very small. For example, in about 300 hours physics run operation from October 1999 to January 2000, total loss time due to any RF troubles is only 10 hours. Similarly, it is 11 hours in April and 14 hours in May. The items are: 13 hours for cooling system of ARES, 8 hours for the high power system, 7 hours for the low-level system, and 6 hours for the recovery from SCC quenches and a vacuum pump trouble. It should be noted that no big trouble is attributed to the cavities. Most serious troubles encountered to the cavities so far are as follows:

- The rubber vacuum seal at the flange connection between the storage and coupling cavity of one ARES (D8C#1) was burned. It was detuned until the storage cavity was replaced. In 1999 summer shut down, every ARES cavity in LER was vacuum-sealed by welding the stainless steel lips at the flange connection after removing the rubber seal.
- Vacuum pressure in one ARES (D8D#2) became worse compared with other cavities. It turned out that plating solution trapped in a welding defect leaked out. This cavity had been detuned for two months. After baking in winter shut down of 1999, it returned to operation.
- A door-knob transformer at the input coupler was burned. It was suspected to be caused by bad brazing.

4 CONCLUSIONS

The KEKB RF system was constructed and has been operating stably since the commissioning. The performance of the ARES and SC cavities is excellent. The low-level and high power RF system are working well as designed with the heavy beam-loading.

5 REFERENCES

[1] T. Kageyama et al., "The ARES Cavity for KEKB", Proc. of e^+e^- Factories'99, Tsukuba, Sep. 1999.

[2] T. Tajima et al., "The Superconducting Cavity System for KEKB", PAC'99, New York, Mar. 1999.

[3] K. Akai et al., "The Low-Level RF System for KEKB", EPAC'98, Stockholm, Jun. 1998.

[4] T. Furuya et al., "Beam Test of a Superconducting Damped Cavity for KEKB", PAC'97, Vancouver, May, 1997.

[5] K. Akai et al., "Beam Test of a Direct RF Feedback System for KEKB", 11th Symp. on Accel. Sci. and Tech., Harima, Japan, Oct. 1997.

[6] K. Ebihara et al., "RF Reference Line for KEKB", 12th Symp. on Accel. Sci. and Tech., Riken, Saitama, Oct. 1999.

[7] T. Ieiri et al., "Measurement of Longitudinal Coupling Impedance at KEKB", 12th Symp. on Accel. Sci. and Tech., Riken, Saitama, Oct. 1999.

[8] E. Ezura et al., "RF Feedback for KEKB", Workshop on Collective Effects and Impedance for B-Factories, KEK, Tsukuba, Jun. 1995.