PRESENT STATUS OF THE PHOTON FACTORY RF SYSTEM

M. Izawa, S. Sakanaka, T. Takahashi, K. Umemori, Photon Factory, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract

An rf system for the 2.5-GeV Photon Factory (PF) storage ring at KEK was commissioned 1982, and it has been upgraded step by step. The present system comprises four 500-MHz damped accelerating cavities, four 200-kW klystrons with their power supplies, and an rf distribution network. Much effort has been made for achieving high reliability of the system. We describe the present status of the system together with the developments for the last two decades.

BRIEF HISTORY

The 2.5-GeV Photon Factory storage ring was commissioned in 1982 as one of the leading synchrotron light sources in the world. In the original rf system [1], four single-cell cavities were driven by two klystrons. The system was upgraded in 1988, so that the number of klystrons increased by two to four. This upgrade removed potential limitation on the beam currents due to rf power sources.

In parallel with the above upgrade, an exhaustive study on the cavity-induced beam instabilities was carried out [1-5]. The resonance frequencies of HOMs in the cavity change with the temperature of the cavity. Therefore the coupled-bunch instabilities were expected to be correlated with the cavity cooling-water temperature. Then, a temperature stabilization and control system was incorporated in 1984. This was possibly the first experiment to control the coupled-bunch instabilities by cooling-water temperature [3]. Second, in order to damp some of the harmful higher-order-modes (HOMs) of the cavities, several HOM couplers were installed [4] to the cavities in 1986. Third, frequency tuning technique for dangerous HOMs was developed [5] and it was applied to our cavities in 1987. All HOM couplers were then removed. At the same time, both ports for the tuner and coupler were improved [6] so that some heating problems were resolved. Based on the above-mentioned research, a new HOM-damped cavity [7] was developed under collaboration with the University of Tokyo. The new cavities took over the old cavities in 1996 and 1997 [8].

Concerning to the low-level and control system, much effort was made for achieving high reliability of the rf system in order to minimize any interruptions of storagering operation. The diagnostics for any rf-related troubles is very important. We then installed a diagnostic system which can analyze both the timing and waveforms of important rf signals at each occasion of interruptions.

In order to maintain our rf system well, many components have been updated step by step. Recently, one of the four power supplies for the klystrons was updated. The new power supply was so designed as to adopt the latest semiconductor technologies.

RF SYSTEM

The present rf system comprises four 200-kW klystrons, four damped accelerating cavities, an rf distribution network and a low-level and control system. Typical operation parameters of the system are given in Table 1. Figure 1 shows a block diagram for one of the four rf stations.

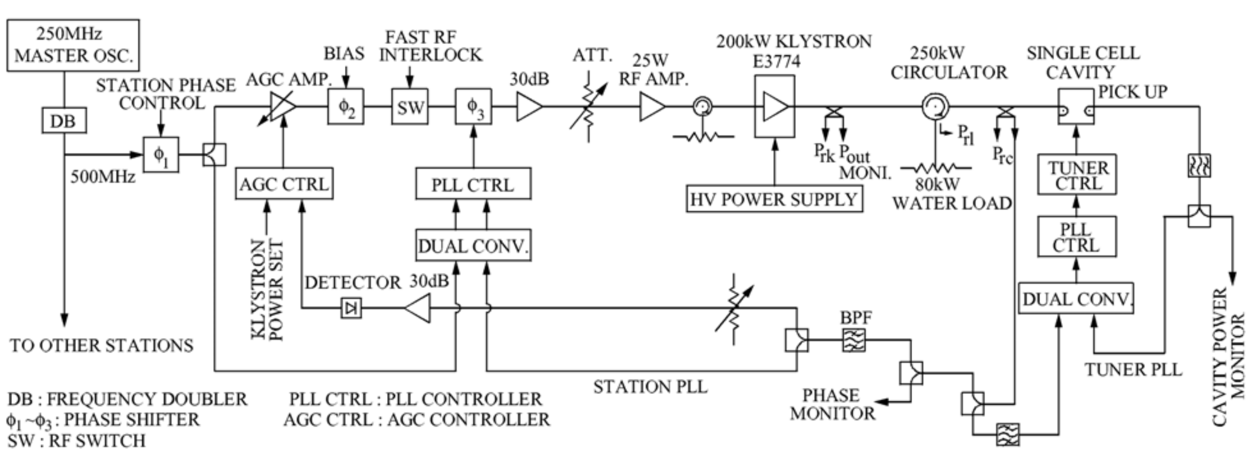

Figure 1: Block diagram of one of the four rf stations for the PF storage ring.

Table 1: Typical parameters of the rf system for the 2.5-GeV Photon Factory storage ring.

Typical rf frequency f_{rf}	500.1 MHz
Harmonic number h	312
Momentum compaction α	0.0061
Typical rf voltage V_c	1.7 MV
Radiation loss/turn*) U_0	399 keV
Synchrotron frequency f_s	22.7 kHz
Beam current (initial) I_0	450 mA
Total klystron power P_k	287 kW
Total beam power P_b	179 kW
Dissipated power/cavity P_{c1}	27 kW
Shunt impedance/cavity R_{sh1}	6.8 MΩ
Cavity coupling coefficient β	2.3

*) Insertion devices are not included.

Power Sources

An rf power is supplied by using four 200-kW klystrons (Toshiba E3774). Under a typical high voltage of 40 kV with a current of 7.25 A, an output power at saturation is about 165 kW; the gain is about 50 dB at low power and about 45 dB at saturation. These klystrons have been operated very stably; there have been no trips due to klystrons during last year. Because of much margin in the rf power, we can operate the PF storage ring using only three rf stations. This function was very useful in the past occasions of serious troubles in power supplies.

There are four high-voltage power supplies for the klystrons. One of the power supplies was updated in 2003 while three of them are old ones which were fabricated during 1979-1987. Each old power supply comprises an automatic voltage regulator (AVR), a step-up transformer with a rectifier, and a crowbar circuit which is used to protect the klystrons in cases of internal discharges.

The new power supply comprises a step-down transformer, a voltage regulator using thyristors, a step-up transformer with a rectifier, and a fast high-voltage switch for klystron protection. A unique feature of this power supply is the fast high-voltage switch which is made up of 80 insulated gate bipolar transistors (IGBT). This switch can turn the high-voltage off within a few tens of microseconds in case of any discharge in the klystron. Figure 2 shows a picture of the high voltage cabinet including an IGBT bank for the above switch. Measured stability of an output voltage was about 1% (peak to peak) and about 0.07% (r.m.s.) under an input voltage fluctuation of 4% (peak to peak) during one day. This power supply was installed in summer, 2003, and it has been working very well for about six month.

Damped Accelerating Cavities

Typical rf voltage of about 1.7 MV is produced by using four damped accelerating cavities. These cavities (see Fig. 3) are made of OFHC copper pre-processed by HIP. Due to its simple inner shape as well as to its effective cooling structure, this cavity can manage very high dissipation power of about 130 kW which corresponds to an rf voltage of about 0.95 MV/cavity.

Figure 2: High voltage cabinet of the new klystron power supply

In order to propagate high-frequency HOMs out of cavity, these cavities have large beam ports of 140 mm in diameter. The powers of the higher-order modes above cutoff frequencies (1.64 GHz for monopole modes, 1.26 GHz for dipole modes) are then dissipated in microwave absorbers which are made of silicon-carbide (SiC). The absorber assemblies were fabricated using a shrink-fit technique, which can provide good thermal contact between the SiC duct and a surrounding copper pipe.

Since the cutoff frequencies of the beam ports are not high enough, some dangerous higher-order modes having high coupling impedances remain in the cavity. The resonant frequencies of these HOMs are adjusted upon installation so as not to coincide with coupled-bunch mode frequencies. This adjustment was carried out by choosing appropriate protrusions of two fixed tuners. The most essential thing for this tuning technique [5] is to estimate accurately the HOM frequencies under high-power operation from the measured data under low power.

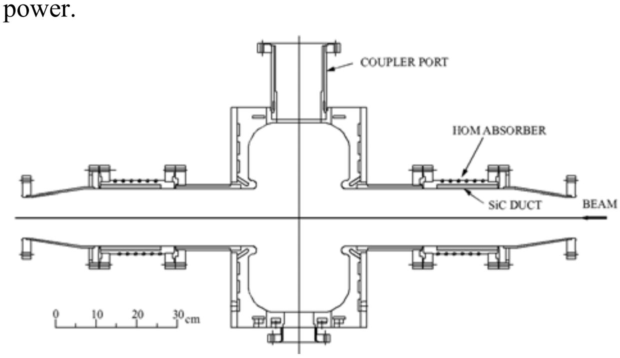

Figure 3: Cross section of the damped accelerating cavity for the PF storage ring.

By the use of both the HOM damping and the HOM tuning, we could avoid any cavity-induced coupled-bunch instabilities almost completely. Some longitudinal coupled-bunch instabilities are still observed at high currents, however, they should be due to many cavity-like transitions in the vacuum ducts. These longitudinal instabilities can be suppressed [9, 10] by using an rf phase-modulation technique.

2.3 Low-Level and Control System

As shown in Fig. 1, our low-level system can stabilize both amplitude and phase of the cavity-input rf wave, as well as can tune the cavities. Beam-loading compensation is done via computer control, which includes both changes in the beam current and in the gaps of several insertion devices.

Our computer-control system was fully upgraded in 1998. In the new system, several control programs run on a workstation while operator-interface programs run on a personal computer, communicating through a network.

In order to improve the reliability of the rf system, it is essential to diagnose the causes of any troubles quickly. Figure 4 shows our rf protection system with its diagnosing instruments. When a large reflected rf is detected from the cavities or from other components, rf switches are turned off quickly. At a such occasion, all logic signals concerned are recorded using a logic analyzer. At the same time, such important signals as listed below are recorded using five 4-channel digital oscilloscopes: i) reflected rf from the cavities, ii) picked-up rf from the cavities, iii) output rf from the klystrons, and iv) beam signal from a button electrode. The above information is very useful for guessing the cause of the troubles. For example, if the beam signal dropped after an rf trip, we could consider that the beam dump should be caused by some rf trouble. Next, we paid attention to an rf station which tripped first, and then, looked at whether an rf output from the klystron stopped before or after the protection signal. In this way, we could sometimes find or guess a bad component in our system.

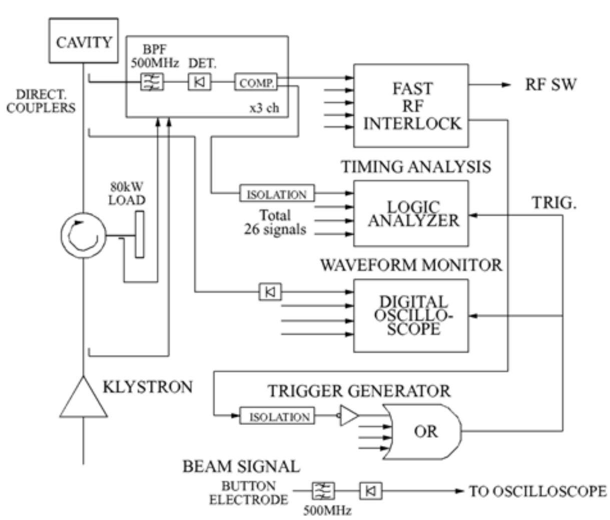

Figure 4: RF protection and its diagnostic system.

OPERATION

During user runs, an initial beam current of about 450 mA is stored. Thanks to the very long lifetime of about 58 hours (at 450 mA), the beams are injected only once a day. In order to improve the Touschek lifetime as well as to suppress the longitudinal instabilities, an rf phase is modulated at about two-times the synchrotron frequency [9,10].

During the operation time of about 5000 hours per year, the rf system has been working very stably. Table 2 shows a summary of unscheduled beam dumps during user time (4608 hours in total) in 2003. The stored beams were lost only ten times. The beam dumps due to the rf system, including potential ones, were only four times. This very stable operation was achieved by both very stable high-power devices and by the well maintained components.

Table 2: Number of unscheduled beam dumps at the PF storage ring during user operations in 2003.

Total number of beam dumps	10
due to rf system (including probable cases)	4
due to earthquake	2
due to user's mistake	3
due to magnet power-supply failure	1

CONCLUSIONS

During the past two decades, the rf system for the Photon Factory storage ring was upgraded step by step. The present system incorporates four damped accelerating cavities having high stability and well established power sources. The diagnostic system for any rf-related troubles allowed us to find possible causes of problems very quickly. The rf system has been working very stably with extremely low trip rate.

REFERENCES

[1] Photon Factory Activity Report 1982/83, KEK.
[2] H. Kobayakawa et al., Jpn. J. Appl. Phys. **25** (1986) 864.
[3] Photon Factory Activity Report 1983/84, KEK, IV-6.
[4] M. Izawa et al., Jpn. J. Appl. Phys. **26** (1987) 1733.
[5] H. Kobayakawa et al., Rev. Sci. Instrum. **60** (1989) 1732.
[6] S. Tokumoto et al., KEK Internal 88-6 (1988).
[7] T. Koseki et al., PAC'95, p. 1794.
[8] M. Izawa et al., J. Synchrotron Rad. **5** (1998) 369.
[9] S. Sakanaka et al., Phys. Rev. ST Accel. Beams **3** (2000) 050701.
[10] S. Sakanaka et al., EPAC'00, p. 690