

IMPROVEMENTS IN THE RF SYSTEM FOR THE PHOTON FACTORY ADVANCED RING (PF-AR)

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Abstract

The Photon Factory Advanced Ring (PF-AR) is a 6.5-GeV synchrotron light source at KEK. An rf system for the PF-AR can provide an rf accelerating voltage of about 16 MV. During an upgrading project for the PF-AR, we carried out some improvements in the rf system. This paper reports these improvements, as well as the present operation status of the system.

INTRODUCTION

The PF-AR is a 6.5-GeV dedicated synchrotron light source at KEK. An rf system for the PF-AR comprises two 1-MW klystrons, an rf distribution network, and six accelerating cavities [1, 2]. Each cavity is an alternating periodic structure (APS) [3], having eleven accelerating cells and ten coupling cells. This cavity can produce high accelerating voltages with small space. Two and four cavities are housed in the east and the west rf sections, respectively. A block diagram of the west rf station is shown in Fig. 1. Typical rf-related parameters are listed in Table 1.

An upgrading project [4] for the PF-AR was carried out during 2001. As one of the goals of this program, we anticipated to increase the beam current from 40 mA to 60-70 mA. To this end, we made some improvements in the rf system, which includes: 1) remodeling the crowbar circuit in the klystron power supply, 2) temperature stabilization of the cavity cooling water, 3) reinforcement of higher-order-mode (HOM) loads for the cavities, and 4) renewal of the control system.

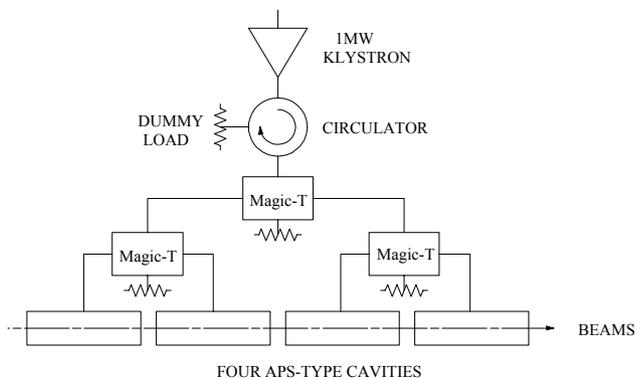


Figure 1: Block diagram of the west rf station.

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Table 1: Principal parameters of the PF-AR rf system under user operation (6.5 GeV) and at injection (3 GeV).

Beam energy	E	6.5 GeV	3 GeV
Typical rf voltage	V_c	16 MV	3.3 MV
Radiation loss/turn	U_0	6.66 MeV	302 keV
Transverse damping time	τ_x	2.5 ms	25 ms
Longitudinal damping time	τ_z	1.2 ms	12 ms
Synchrotron frequency	f_s	42.6 kHz	29.8 kHz
Total klystron power	P_k	982 kW	43 kW
Total beam power	P_b	400 kW	18 kW
Dissipated power/cavity	P_{cl}	94 kW	4 kW
Typical rf frequency	f_{rf}	508.567 MHz	
Harmonic number	h	640	
Momentum compaction	α	0.01264	
Maximum beam current	I_0	60 mA (at present)	
Shunt impedance/cavity	R_{sh1}	75.6 M Ω	

IMPROVEMENTS IN RF SYSTEM

Improvement in Crowbar Circuit

Higher beam currents require us to operate the klystron at higher voltages of more than 80 kV. In such cases, high reliability of the crowbar circuits [2], which are used to protect the klystrons under discharges, is particularly important. In order to achieve higher reliability, we improved the crowbar circuit in the klystron power supply.

The crowbar circuit is relatively sensitive to some electrical noise since it is triggered by a signal from a fast-response current transformer. From a long-term experience at KEK, we were convinced that the primary source of wrong triggers should be due to some noises which were caused by corona discharges in the circuit case. In order to prevent such corona discharges, we remodeled the crowbar circuit so that all high-voltage components, such as ignitrons, resistors and a discharger, were placed in insulating oil. In addition, the main part of the circuit was housed in a separate tank from the other parts. Thus improved crowbar circuit has been operated very well for more than one year without any wrong triggers.

Stabilization of Cooling Water Temperature

Each cavity is cooled by a water flow of about 250 lit./minute. Since the higher-order-mode frequencies of the cavities can be affected by the cooling-water temperature, it is desirable to stabilize the temperature in order to avoid cavity-induced coupled-bunch instabilities. For this purpose, a temperature stabilization system was constructed in fiscal year 1997. This system (see Fig. 2)

can stabilize the temperature of the cooling water by exchanging its heat with separate cold water. The cold water is provided by two chillers. Because each cavity has a separate heat exchanger, we can set up the water temperature for each cavity independently. This function is very useful for finding an optimum set of temperatures during operations. Since the beams are injected at lower energies (2.5-3 GeV), it is essential to optimize various operating conditions under injection. A typical tuning range of the water temperature is about 23-29°C.

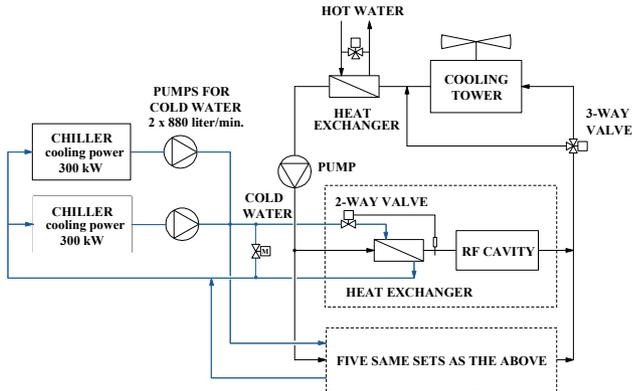


Figure 2: Temperature stabilization system for the cavity cooling water. Blue lines indicate a cold water route.

Reinforcement of Cavity HOM Loads

Each cavity is equipped with twelve higher-order-mode (HOM) couplers [5] which can damp some harmful HOMs. Each HOM-coupler was terminated by an air-cooled, 1-kW dummy load. Since we anticipated higher HOM power after the upgrade, we replaced all 70 dummy loads to water-cooled, 3-kW ones.

Because these loads are installed in the ring tunnel under high x-ray backgrounds, they should be highly resistant to radiation, as well as to flame. Direct water-cooled mechanism, which is adopted in some commercially available loads, are not suitable because the radiation can easily damage rubber seals for the cooling water. We therefore adopted indirect water-cooled loads, which were newly developed in Nihon Koshuha Co., Ltd.

A drawing of the new 3-kW load is shown in Fig. 3. The heart of the load is three beryllium-oxide (BeO) plates having resistive-stripe coatings on them. Input HOM power is dissipated in these resistive stripes. The BeO plates touch tightly to a water-cooled copper block via a thermally conductive compound. These resistive stripes are connected in series by copper bridges.

The voltage standing-wave ratio (VSWR) of the completed dummy loads were less than 1.5 within a frequency range of 0.5-1.5 GHz, and less than 2.0 within 1.5-2 GHz. We installed these dummy loads on the top of the cavities. The waterway of six dummy loads was connected in series, and a water flow of 15 lit./minutes was supplied per each route. Figure 4 shows the installed dummy loads.

These HOM loads have been working very well after the commissioning. Typical dissipated power per load was

about 560 W under the beam current of 57 mA and the beam energy of 6.5 GeV.

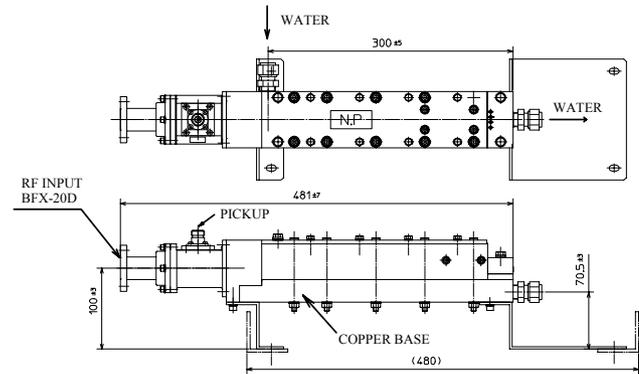


Figure 3: Drawing of the 3-kW broadband dummy load.

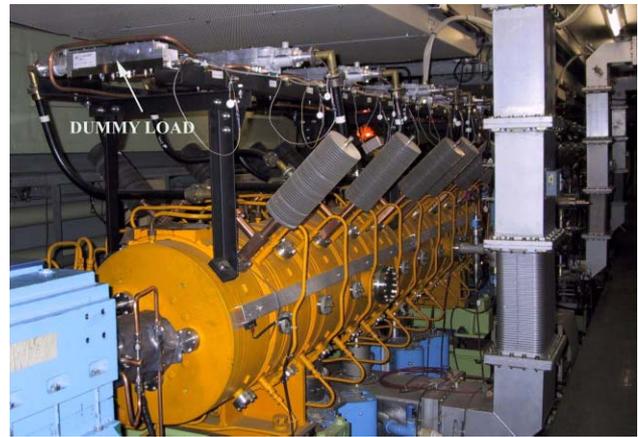


Figure 4: New higher-order-mode loads as installed on the top of the cavities.

EPICS-Based Control System

The control system for the rf system was fully upgraded to a new one which is based on the Experimental Physics and Industrial Control System (EPICS) [6]. Figure 5 shows an outline of the new control system. Most of the rf equipments are controlled by an I/O Controller (IOC) through original CAMAC interfaces. Some of the instruments, such as a master oscillator and data loggers, are controlled by another IOC through GPIB interfaces. Operator-interface (OPI) programs run on the workstations. We developed both an EPICS database and OPI programs. There were about 600 incoming signals from the equipments, and about 600 outputs to them. We then defined about 1200 database records which correspond to these signals. Some sequence controls were realized using record links and state programs for the EPICS sequencer. The OPI programs were developed using both a SAD/Tkinter script language and the Python/Tkinter language.

Using this system, we can control all parameters of the rf system, such as the rf voltage, the phases, and the cooling water temperatures. It also allows us to condition the cavities automatically before storage-ring operations.

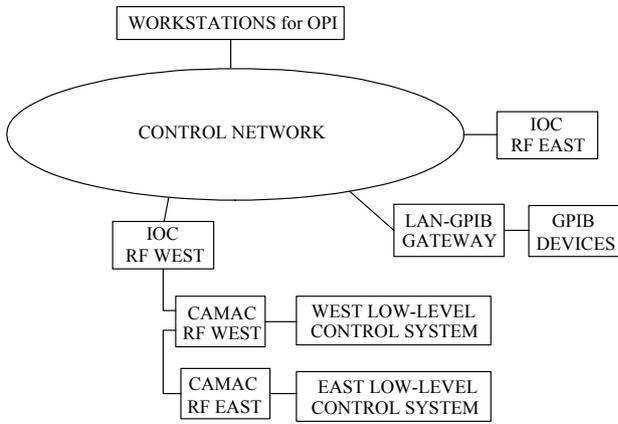


Figure 5: New control system for the rf system.

COMMISSIONING AND OPERATIONS

The PF-AR was recommissioned smoothly in January, 2002. During a half year after the commissioning, the maximum beam current was limited to about 40 mA due to some collective effects. We could then gradually increase the beam currents to about 60 mA. This was achieved by raising the injection energy from 2.5 GeV to 3 GeV, and by investigating optimum conditions for beam injection. The PF-AR is currently operated with the maximum currents of 50-60 mA with single bunch.

Figure 6 shows one of the control panels, indicating typical rf parameters during operations. It shows such parameters as the output power from the klystron (P_k), the drive power for the klystron (P_d), the cavity voltage (V_c), the cathode voltage (V_k), the beam current of the klystron (I_b), the voltage and the current of the klystron anode (V_a and I_a), the voltage and the current of the klystron heater (V_h and I_h), and so forth. Because an equal rf-power is fed to each cavity, the east klystron provides about a half power of the west one. In a case of Fig. 6, the output powers from the east and the west klystrons were about 350 kW and 710 kW, respectively, under the beam current of 57 mA. Because there is some margin in the rf power, we continue to make efforts for increasing the beam current to the target value of 70 mA.

CONCLUSION

During the upgrading project of the PF-AR, we carried out some improvements in the rf system. The improved rf system was commissioned very smoothly, and it has been working very well for more than one year. The stored current was gradually increased from 40 mA (before upgrade) to about 60 mA under routine single-bunch operations.

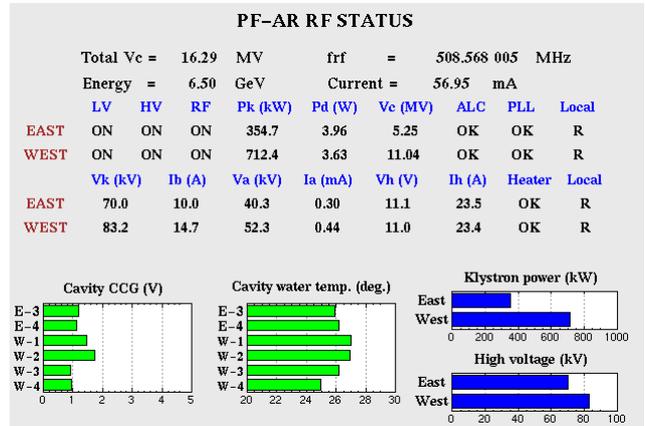


Figure 6: One of the control panels showing typical rf parameters under operation.

ACKNOWLEDGMENTS

We would like to thank Mr. T. Sato and Mr. H. Matsui for designing our temperature stabilization system for the cooling water. We also thank Mr. S. Tsuruoka and other engineers of Nihon Koshuha Co., Ltd., for developing the 3-kW broadband dummy load. We express our gratitude to Dr. N. Akasaka for providing his software for our purpose, and for his useful advices. We also thank Mr. J. Odagiri for his help in our developing control software.

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