

CONSTRUCTION OF A TIMING AND LOW-LEVEL RF SYSTEM FOR XFEL/SPRING-8

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Abstract

The intensity of stable self-amplified spontaneous emission (SASE) generated by undulators is sensitive to the RF phase and amplitude of off-crest acceleration at injector cavities and 5712 MHz cavities before the bunch compressors (BCs). The demanded stabilities of the RF phase and amplitude for stable SASE generation are ± 50 fs (rms) for the phase and $\pm 0.01\%$ (rms) for the amplitude, respectively. We are constructing a low-level RF (LLRF) system to drive klystrons. To satisfy the demands, much attention has been paid to temperature stabilization for the system. A water-cooled 19-inch rack and a water-cooled cable duct are employed for almost all parts of the system. The temperature stability of the rack and the duct is expected to be within 0.4 K (p-p). The feasibility of the optical RF distribution system with the water-cooled duct was demonstrated using the SCSS test accelerator for the XFEL. A stable EUV laser intensity was observed at the test accelerator. Thus, the performance of the optical RF distribution system is sufficient for the XFEL.

INTRODUCTION

A 400-m-long 8 GeV electron linac is used in the X-ray free electron laser (XFEL) at SPring-8 [1]. To generate a SASE light in the X-ray wavelength region, the electron bunch has to have a very short bunch-length of 30 fs and a high peak current of 3 kA. A thermionic electron gun with a beam deflector produces a beam with a 1 ns bunch-length and a 1 A peak-current. The beam is compressed by a velocity-bunching method using 238, 476, and 1428 MHz cavities first. Then, three BCs are used to compress the bunch-length up to 400 times. We use 2856 and 5712 MHz cavities along the BCs. Because the beam is accelerated at an off-crest phase in these compression stages, the XFEL laser intensity is very sensitive to any change in the phase and amplitude of the RF field in the cavities. The tightest requested value is ± 50 fs (rms) for the phase and $\pm 0.01\%$ (rms) for the amplitude [2, 3].

To provide a stable laser, suppression of the temperature drift of the RF phase and amplitude is very important. One source of drift is the temperature coefficient of the LLRF modules. For example, the amplifier unit in an optical RF/trigger distributor module to distribute RF and trigger signals for LLRF modules in a 19-inch rack has a temperature coefficient of 182 fs/K. The other sources of drifts are the temperature coefficients of the optical path-length change of an optical fiber and the electric length change of a coaxial cable. A

phase-stabilized optical fiber (PSOF) was used to distribute timing and reference RF signals to all of the LLRF modules [4, 5]. The PSOF has a temperature coefficient of 2 ppm/K. Phase-stabilized coaxial cables were used between a cavity RF pickup and an IQ demodulator. This cable has a temperature coefficient of 5 ppm/K.

To satisfy the requested value of ± 50 fs for the phase stability, temperature changes have to be less than ± 0.27 K (rms) for the amplifier unit mentioned above, ± 0.01 K (rms) for the 1-km-long PSOF, and ± 0.1 K (rms) for the 20-m-long phase-stabilized coaxial cable. The ambient-temperature change of the klystron gallery is designed to be 4 K (p-p). Therefore, to efficiently suppress any influence of a temperature change, we decided to regulate the temperature of all LLRF modules, optical fibers, and coaxial cables. A water-cooled 19-inch rack used to install the LLRF modules was developed. In addition, a water-cooled cable duct to install the optical fiber cables and the coaxial cables was also developed. The temperature change in the racks and the ducts is kept within 0.4 K (p-p) depending on the temperature change of the cooled water from the facility.

In this paper, brief explanations of the timing and the LLRF system are described first. Then a water-cooled 19-inch rack and a water-cooled cable duct are explained in detail. Finally, the test result of operating the SCSS test accelerator using the PSOF installed in the water-cooled duct is presented.

LLRF SYSTEM

Figure 1 shows a schematic diagram of the LLRF system and the timing and reference RF signal distribution system. The systems comprising a master oscillator, a master trigger unit, an optical RF transmitter/receiver, a digital RF control system using an IQ modulator/demodulator, and a 500 W amplifier to drive the klystrons were newly developed to satisfy the very high stability of the RF signals. The figure also shows the section where the water-cooled rack and the water-cooled duct are used.

WATER-COOLED 19-INCH RACK

Figure 2 shows a photograph of the water-cooled rack and the water-cooled duct installed in to the klystron gallery. A schematic top view of the racks is shown in Figure 3. We developed two types of racks. One is a side blow type for which circulating air generated with fans in the rack is fed into the side wall of installed modules; the

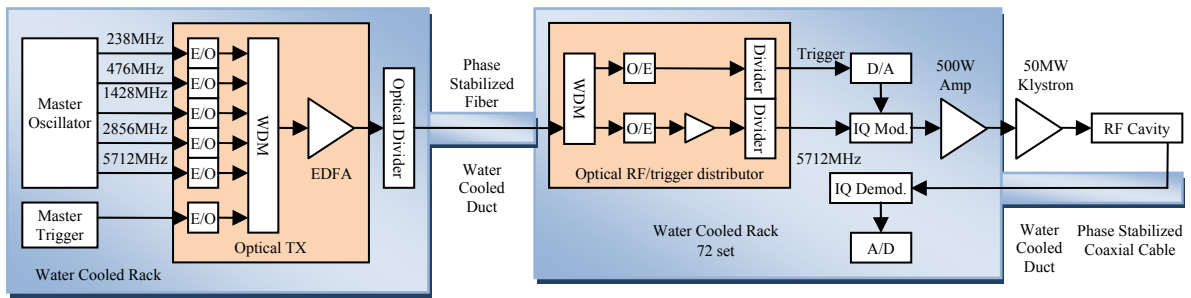


Figure 1: Schematic diagram of an LLRF system and the timing and reference RF signal distribution system.

other is a front blow type for which air is fed into the front panel of the modules. Both types have a heat exchanger in the left side of the rack, respectively. The difference between the two types is the position of the fans. The vibration of the RF cable generally deteriorates the phase stability of the RF signals. To prevent vibration of the cables in front of the LLRF modules by cooled air, the side blow type was prepared.

Another feature of the rack is a centralized water-cooled ultra low-noise DC voltage power supply. Removing voltage transformers and voltage regulation circuits in each module is realized by this configuration. Since most of the heat in the rack is generated with power supplies including transformers, this centralized power-supply configuration reduces the internal heat sources of the individual modules in the rack. Furthermore, since sufficient space for air flow in the modules is equipped by the configuration, the cooling efficiency of the rack is increased.

We measured the temperature stability inside the rack. Inside temperature variations per a 1 K outside temperature variation in the water-cooled rack was 0.11 K. The phase change of the amplifier unit mentioned in the introduction is expected to be 20 fs in this rack. This value satisfied the demanded value.

WATER-COOLED CABLE DUCT

The PSOF used to distribute timing and reference RF are installed in the dedicated water-cooled cable duct to moderate a change of the ambient temperature (Figure 2). The duct consists of double rectangular steel ducts, as shown in Figure 4 (a). Four copper water pipes are tightly attached on the side outer surface of the inner duct with a thermal compound. This inner duct makes an isothermal distribution plane. The fiber cables are covered with cushions in the inner duct to reduce the vibration caused by the cooled water.

A prototype water-cooled cable duct to confirm its temperature stability was built, and an experiment to check the feasibility of the duct was carried out. Figure 5 shows the measured inside temperature changes of the duct. The room temperature in the experiment was 29.08 ± 1.71 K (p-p), but the fiber temperature was controlled to within 26.21 ± 0.08 K (p-p) by cooled water with a temperature of 26.06 ± 0.12 K (p-p). The temperature time lag of the thermal insulation system of the duct was 45 minutes. Furthermore, the inside temperature

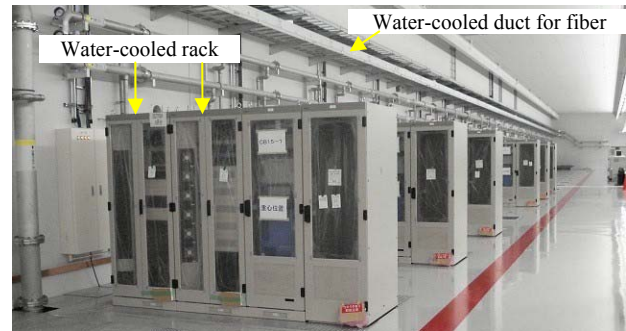


Figure 2: Water-cooled rack and water-cooled duct installed in the klystron gallery.

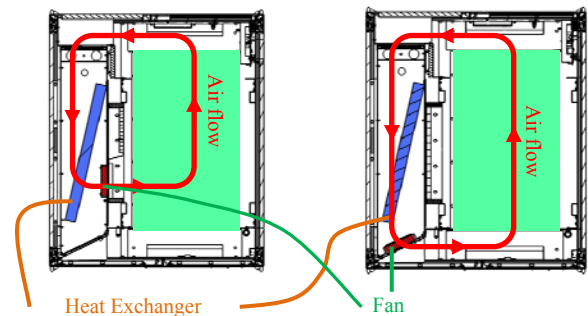


Figure 3: Schematic top view of the water-cooled racks. Side blow type (Left) and front blow type (Right).

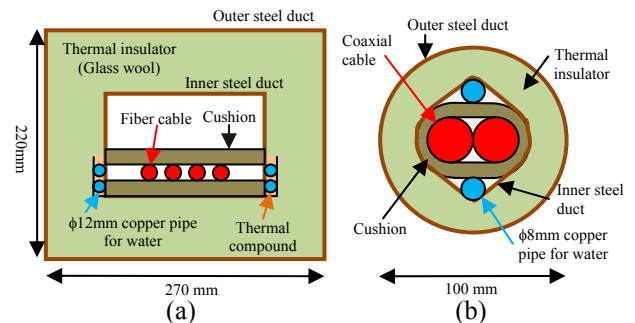


Figure 4: Cross-section view of the water-cooled duct for the fiber and coaxial cable.

variations per a 1 K outside temperature variation in the water-cooled duct for a long time was 0.07 K.

A water-cooled duct to stabilize the temperature of coaxial cables from a cavity RF pickup to the IQ demodulator is also employed. The basic idea of the structure of the duct is the same as that of the rectangular steel duct for the fiber, as shown in Figure 4 (b). It has

double metal planes, and a soft copper sheet is used for the inner metal plane to fit the arbitrary shape of the coaxial cable.

The temperature stability of the rack and the cable duct during 60 hours was measured in the test operation with an actual XFEL condition at the klystron gallery, as shown in Figure 6. The temperature change of the coaxial cable inside the duct was 0.33 K (p-p), and the temperature change of the water-cooled rack was 0.24 K (p-p), while the fluctuation of the klystron gallery temperature was 0.76 K (p-p). These values satisfied our design value.

OPERATION OF THE SCSS TEST ACCELERATOR WITH A WATER-COOLED FIBER DUCT

A 5712 MHz RF signal as a time reference RF is now distributed by a 10 W amplifier and phase-stabilized 15D coaxial cables for driving individual instruments, such as a klystron as a high-power RF source at the SCSS test accelerator [6].

To check the feasibility of our developed optical fiber system to transmit a time reference RF signal, a prototype optical fiber system using the PSOF, which was installed into the water-cooled duct, was built in parallel with the present coaxial cable system. The temperature of the fiber was kept to within 26.62 ± 0.06 K (rms) by the duct. The intensity of a EUV laser was compared between the coaxial-cable case and the optical-fiber cable case. From the result shown in Figure 7, the intensity fluctuations of the EUV laser for 20 minutes were 5.86 ± 0.66 (Arbitrary unit) in the coaxial-cable case and 6.20 ± 0.66 in the optical-fiber cable case, respectively. A significant difference was not observed between both cases. Thus, we confirmed that the RF signal transmitted through the water-cooled optical fiber system had sufficient performance to guarantee stable EUV laser generation at the SCSS test accelerator.

CONCLUSION

The accuracies requested for the RF signal of XFEL/SPring-8 is 50 fs in a phase and 0.01% in amplitude under the most severe case. To satisfy these severe requested values, all of the LLRF system and the reference RF distribution system were newly developed. We also developed a water-cooled 19-inch rack and a water-cooled cable duct to reduce the RF phase and the amplitude drifts dependent on the temperature. The inside temperature variations per a 1 K outside temperature variation were 0.11 K for the water-cooled rack and 0.07 K for the water-cooled duct, respectively. These values satisfy our demand.

All C-band LLRF systems, a part of the injector LLRF systems, and the optical fiber for the reference RF distribution, have already been installed in the klystron gallery. The cabling between a cavity and a LLRF system is now ongoing. Commissioning will be started on October 2010, and the first light is planned for March, 2011.

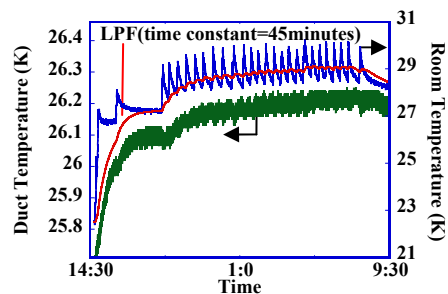


Figure 5: Measured temperature of the prototype water-cooled duct.

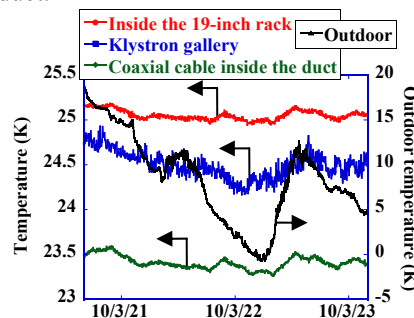


Figure 6: Temperatures of the rack and the coaxial cable duct during 60 hours at the klystron gallery.

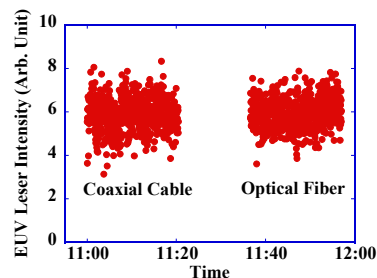


Figure 7: Comparison of the EUV laser intensity between the coaxial cable case and the fiber cable case.

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