UPGRADE OF A PRECISE TEMPERATURE REGULATION SYSTEM FOR THE INJECTOR AT SACLA

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Abstract

A precise temperature regulation system for an injector at SACLA is being upgraded. Although an existing temperature control system has been able to regulate an RF cavity temperature within 0.08 K, it has become clear that even a tiny fluctuation in a cooling water temperature, such as 0.1 K, for the RF cavities of an injector significantly influenced lasing stability. This temperature stability is limited by a PLC temperature measurement module, which has non-negligible temperature drift. In addition, it has been found that an ON-OFF alternatively heating method with a pulse width modulation signal generated a laser intensity variation having a high correlation with this modulation frequency. This variation is considered to be caused by a tiny-pulsed temperature variation due to the heater power switching, or small magnetic field leakage from heater current. Therefore, the temperature controller module was replaced by a more precise one with an extremely high temperature resolution of 0.001 K and an excellent stability of 0.01 K. We will also apply continuous level control of a heater with a DC power supply. Prior to full-scale introduction of this new scheme to the injector, we have introduced only a new temperature measurement and control module to the RF cavities in the injector, as a preliminary test, and estimated performance. As a result, the cavity temperature fluctuation could be drastically improved to 0.01 K (p-p).

INTRODUCTION

Following about one year of beam commissioning, public use at SACLA (SPring-8 Angstrom Compact Free Electron Laser) finally started on March 7th, 2012. To realize stable user operation, it is necessary to keep laser intensity and position as stable as possible over long periods. In particular, as extremely high stability of accelerator components is indispensable in the injector section [1], a low level RF (LLRF) feedback control over RF phase and RF amplitude is applied to pickup signal from RF cavities. We also established a precise temperature regulation system (PTRS) that is able to regulate a temperature within 0.08 K at each RF cavity. [2] [3]

However, during the beam commissioning, it has become clear that even a tiny fluctuation in cooling water temperature, such as 0.1 K, for the RF cavities of the injector significantly influenced the stability of laser intensity. [4] [5] This temperature stability is limited by a PLC temperature measurement module, which has non-negligible temperature drift. In addition, it was found that a frequency of an ON-OFF alternatively heating method with a pulse width modulation (PWM) signal had a high correlation with that of a position variation in an electron beam synchronized with a laser intensity variation. This is probably due to a tiny-pulsed temperature variation by the heater power switching, or small magnetic field leakage from heater current. Therefore, the present temperature measurement module was replaced with a more precise one having an extremely high temperature resolution, which is mentioned in the succeeding sections. In addition, continuous level control of a heater with a DC power supply, which we also argue in the next, is employed.

PRECISE TEMPERATURE-REGULATION SYSTEM

Technical Issues of the Existing System

Figure 1 shows a schematic layout of the injector at SACLA. At first, an electron beam emitted from a 500 keV thermionic gun is sliced to be 1 ns/1 A by a chopper. After the bunch compression (by velocity bunching) and beam acceleration with 238MHz/Sub-harmonic buncher (SHB), 476MHz/Booster and two L-band (1428MHz) alternating-periodic accelerating structures (APS), and a bunch compressor chicane, an 30 MeV electron beam with a bunch length of 3 ps is generated. L-band and C-band (5712MHz) correction cavities are installed in order to linearize the curvature of an energy chirp.

A cooling water system, which comprises a primary chilled water system of 12 °C supplied by a turbo refrigerator and a secondary circulating pure water system

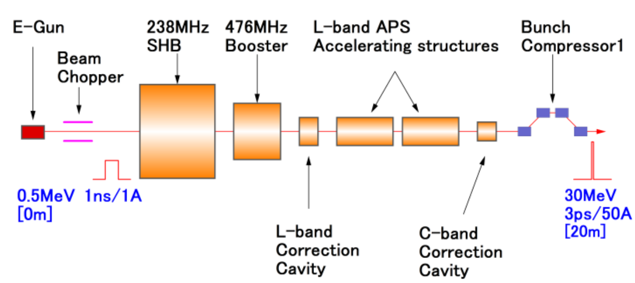

Figure 1: Schematic layout of an injector at SACLA.

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fed to each RF cavity, is prepared at SACLA. Temperature of the secondary cooling water fed to the cavities, is regulated at 26.5 ± 0.2 °C by controlling the flow rate of the heat exchanger system cooled by the primary water. The PTRS works by using the secondary circulating water system and electric heaters inserted into a cooling water pipe just prior to the cavities. In the PTRS, the temperatures of cooling water and cavities are measured using mineral insulated resistance temperature detectors (RTD), Pt100, three-wire and a PLC temperature measurement module (FA-M3, manufactured by Yokogawa Electric Co., Ltd. [6]). Temperature stabilization can be achieved by switching a heater power with a PWM signal based on the feedback control from a PLC temperature control module.

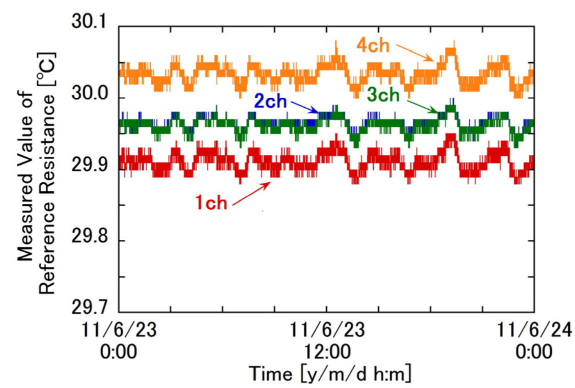
During the beam commissioning, a beam position variation resulted from the fluctuations of an RF phase and accelerating voltage of the L-band APS accelerating structure was observed. After the investigation, we found the reason of the fluctuation, as follows:

At the L-band APS accelerating unit, one klystron drives two APS accelerating structures. In order to adjust the resonant frequency of each APS cavities, the temperature of each accelerating structure is controlled by each PTRS, which has an independent fluctuation of 0.08 K caused by the PLC temperature measurement module. In other cavities like 238 MHz/SHB or 476 MHz/Booster, the LLRF feedback control compensates the variation of the RF field of the cavities caused by the temperature variation. But in the L-band APS accelerating unit, one LLRF cannot simultaneously compensate the two variations of the RF fields of both cavities. Actually the RF phase of the upstream accelerating structure is compensated by the LLRF feedback control, although the RF phase of the downstream accelerating structure varies without the correlation with the RF phase of the upstream one.

To investigate the causes, we attached a high-precision reference resistance (MAZ111R670V/111.670 ohm 1 ppm/K, manufactured by Alpha Electronics Co., Ltd.), which has an extremely small temperature coefficient, to each channel of four PLC temperature measurement modules. As each module has four channels, there were sixteen reference resistances, which were put in a constant-temperature bath at a time. As shown in Fig. 2 (a), one-day temperature trend graphs of four channels in one specific module, every channel in the module denoted the same trend of temperature variation. The fluctuating range for every channel was about 0.08 K (p-p) per a day with a cyclic period of several hours. On the other hand, Fig. 2 (b) shows those of four channels in different four modules (red, blue, green, yellow). There was no correlation among them and the maximum temperature fluctuating range was 0.08 K (p-p). Moreover, any of the four temperature trend lines was not correlated with both the inside temperature of the constant-temperature bath (purple) and the surface temperature of the modules (black) at all. Therefore, it turned out that the temperature drift of the PLC temperature measurement module restricts the temperature stability of the PTRS, and significantly influenced on the RF phase fluctuation of the L-band APS accelerating structure.

Another problem was a beam position variation with a frequency of 0.5 Hz, which synchronized with a laser intensity variation. From a frequency analysis of the beam position on a BPM located at the exit of BC1 while changing the control cycle of the PTRS for the injector from 0.5 Hz to 3 Hz at 0.5-Hz spacing, it was found that the position variation had a high correlation with the control cycle. This variation is considered to be caused by a tiny-pulsed temperature variation due to the heater power switching, or a small magnetic field leakage from the heater current. It suggests that continuous level control of a heater with a DC power supply should be replaced with the existing ON-OFF alternatively control with the PWM signal.

(a)



(b)

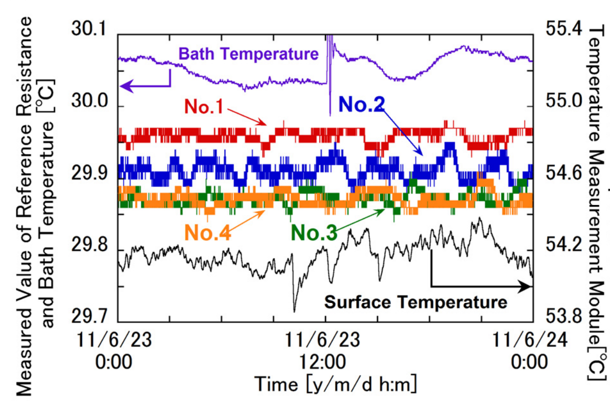


Figure 2: Fluctuation of measured values by PLC temperature measurement modules with high-precision reference resistances. (a) Temperature trend graphs of four channels in one specific module. Red line, blue line, green line and yellow line show each of 1ch, 2ch 3ch and 4ch, respectively. (b) Temperature trend graphs of four channels in different modules. Red line, blue line, green line and yellow line show each module of 1, 2, 3, and 4, respectively. Purple and black lines show inside temperature of the constant-temperature bath and surface temperature of the modules, respectively.

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Upgrading

A new instrument with a high resolution of 0.001 K, REX-F9000 manufactured by RKC INSTRUMENT INC., [7] was adopted in place of PLC temperature measurement module. It also has a temperature control function for two independent systems. Temperature stability was evaluated with a high-precise reference resistance (MAZ110R894V/110.894 ohm) by the same procedure as the above mentioned. Figure 3 shows two-day trends of measured values of the reference resistance (red) and the ambient temperature (blue). The new module performed well with a measurement accuracy of 0.004 K (p-p) and 0.0010 K (standard deviation) even under the circumstances that the ambient temperature varied within about 1 °C.

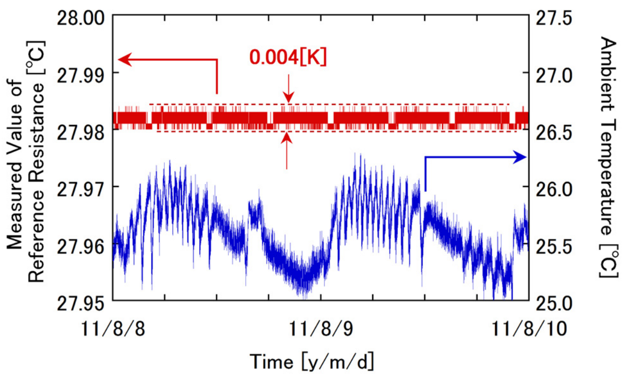


Figure 3: Trend graphs of measured values by using a new temperature measurement and control module with a high precise reference resistance (red) and the ambient temperature (blue).

A schematic drawing of a new upgraded temperature regulation system for the L-band APS accelerating structure, as an example, is shown in Fig.4. As mentioned above, there are two feedback loops in this system, each of which controls the upstream and the downstream accelerating structure, respectively. In each loop, a controlled object is the cooling water temperature at the inlet of each accelerating structure, which is measured by

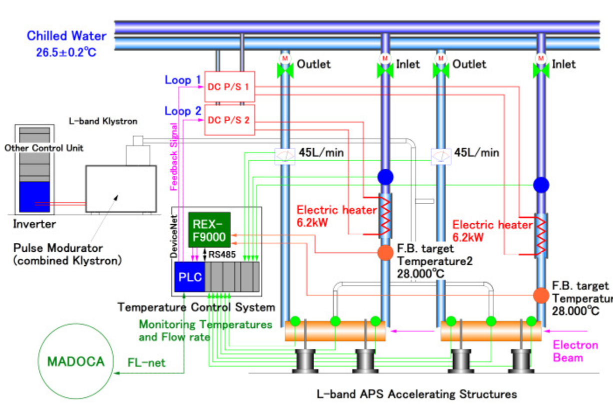


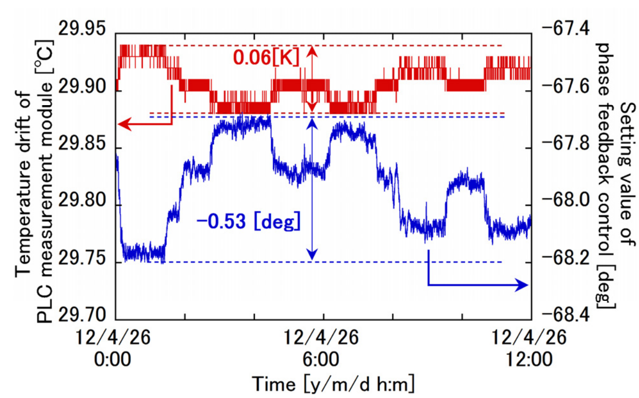
Figure 4: Schematic drawing of the precise temperature-regulation system for one L-band accelerating unit.

REX-F9000 with a four-wire RTD. Temperatures of the other cooling water and body of the accelerating structure are measured in the same way as before. Solid State Contactors for heater switching in the existing system is replaced by water-cooled DC power source of 7 kVA (200 V/35 A) for the continuous level control of a DC heater. Proportional-integral-derivative (PID) feedback control process is running on a REX-F9000, and then a result of the data processing is transferred to a PLC communication module. The DC power supply is monitored and operated by a PLC CPU module which communicates with a host link via DeviceNet. The flow rate of cooling water for each accelerating structure is 45 L/min, which is monitored by a Karman vortex flow meter.

PERFORMANCE EVALUATION

Prior to full-scale introduction of the new scheme, we initially installed only REX-F9000 to the injector at SACLA to evaluate the performance. We attached a high-

(a)



(b)

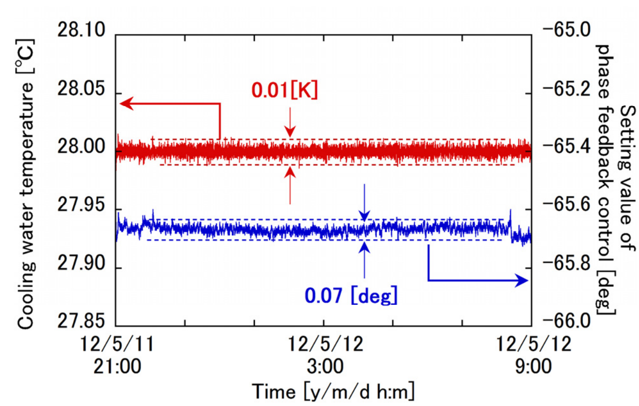


Figure 5: Comparison of the temperature regulation performance between feedback control with the PLC and that with REX-F9000. (a) Trend graphs of temperature drift (red) and a setting value of phase feedback control (blue) for 238MHz SHB. (Feedback control with the PLC). (b) Trend graphs of cooling water temperature (red) and a setting value of phase feedback control (blue) for 238MHz SHB. (Feedback control with REX-F9000).

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precision reference resistance to the idle channel of the temperature measurement module and measured a temperature drift. Figures 5 (a) and (b) show a two-day trend of temperature (red) and a setting value of the phase feedback control for 238MHz SHB (blue), using the existing system with the PLC and the new system with REX-F9000, respectively. The inherent temperature drift of the temperature measurement module changed the real temperature of cavity. Although the temperature drift makes a resonant frequency shift, it is supposed to be compensated by the LLRF feedback control, as shown in Fig. 5(a). We measured a relationship between a temperature change and an RF cavity phase. As a result, a sensitivity coefficient of 12.3 degree/K was obtained. When computed from this measured conversion factor, the setting value shift of -0.53 degree (see blue line in Fig.5 (a)) corresponds to a temperature change of 0.043 K. In other words, the temperature change, which actually occurred, is 0.043 K, which nearly equals to a temperature drift of 0.06 K (see red line in Fig.5 (b)). As shown in Fig. 5(b), after the introduction of REX-F9000 to the injector, the RF cavity temperature fluctuation could be drastically improved from 0.08 K (p-p) to 0.01 K (p-p). Accordingly, the setting value of the phase feedback control also decreased from -0.53 degree to 0.07 degree (see blue line in Fig.5 (b)).

CONCLUSIONS

Although an existing temperature control system has been able to regulate a cavity temperature within 0.08 K, it has become clear that a PLC temperature measurement module is short of our demanded high temperature stability due to its own temperature drift. In addition, it was found that laser intensity variation has a high correlation with a frequency of ON-OFF alternatively heating control. Therefore, we decided to introduce a new scheme mainly composed of a new temperature measurement and control module with a high temperature resolution of 0.001 K and an excellent stability of 0.01 K. According to a preliminary verification test with introduction of only REX-F9000 to the injector, the RF cavity temperature fluctuation could be drastically improved from 0.08 K (p-p) to 0.01 K (p-p). Accordingly, the controlled phase shift drastically decreased from 0.53 degree to 0.07 degree. In this August, we will introduce the new scheme of the temperature regulation system with the continuous level control of a heater with a DC power supply so that laser intensity is expected to be more stabilized.

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