STATUS OF A PRECISE TEMPERATURE-REGULATION SYSTEM FOR THE C-BAND ACCELERATOR AT XFEL/SPRING-8

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Abstract

This paper describes the present status of a precise temperature-regulation system for the C-band accelerator at XFEL (X-ray Free Electron Laser)/SPring-8. It is essential to maintain a constant temperature of an rf cavity for stable lasing. We therefore installed a heater-assembly unit into a cooling water circuit of each rf cavity. By controlling the heater power, the temperature of the cavity can be stabilized. We constructed a prototype of this system at the SCSS (SPring-8 Compact SASE Source) test accelerator to check its feasibility for the XFEL. The prototype significantly contributes to a stable supply of SASE to users. For the XFEL, we simplified this system in consideration of cost and controllability. For example, to make one regulation system simultaneously controlling two C-band accelerating structures was tried. Keeping a temperature variation as tight as ±0.02 K at any operational mode could be achieved by this system. The preliminary test results of the system are also reported in this paper.

INTRODUCTION

At the XFEL/SPring-8 project, the installation and alignment of components is actively underway with the aim of commencing rf cavity aging this autumn as scheduled. To realize stable lasing at the XFEL, it is essential to precisely control an rf phase in acceleration cavities installed in the injection and main accelerating areas. In particular, the allowable rf phase jitter of the C-band accelerator is as little as ±0.5 degree. Since this jitter results from the cavity deformation caused by the heat dissipation of the rf power, a temperature variation of 1 K corresponds to a resonant frequency variation of -97 kHz and an average phase shift of -5 degree. Consequently, the required temperature stability should be set at ±0.1 K. To meet this specification, we introduced a precise temperature-regulation system [1], which has significantly contributed to the stable supply of SASE for users at the SCSS test accelerator [2]. This temperature-regulation system employs a two-stage feedback control, which consists of electric heaters and a remote flow-rate control valve on the secondary side in addition to a primary temperature-controlled chiller system. Although the temperature-regulation system for the XFEL basically follows the same concept as the existing one, we attempted to improve controllability and reduce cost by simplifying the system and downsizing devices so as to deal with a large number of 64 C-band accelerating units while maintaining high performance. In this paper, we present the modifications, details of the control system, and some test results conducted at a pilot test bench for the C-band accelerating unit.

Since this modified system is applied to other rf cavities in the injection area and in-vacuum undulators to stabilize the magnetic flux density of permanent magnets, the total number of units will reach 82. For some rf cavities in the rf off-crest acceleration for bunch compression, a stricter temperature stability of ±0.02 K would be particularly required.

MODIFICATIONS

Reduction of Number of feedback Loops

At the SCSS test accelerator, each feedback loop was equipped with each C-band accelerating structure. However, almost all of the structures could be manufactured with a high dimensional accuracy greater than expected, to within the resonant frequency variation of 100 kHz. Consequently, we decided to control two structures by one feedback loop simultaneously.

Removal of Some Equipment

Although a pulse width modulator was employed to get a fast response for heater power control in the previous design, we confirmed that such a fast response is not necessary due to the large heat capacity. As a result, the modulator was taken out and the heater output power is directly controlled by a PLC (Programmable Logic Controller).

We also removed a remote-operated feed-water control valve, because the required temperature stability could be achieved with only the heater at a specific flow rate.

Improvement of Maintainability

The system has a function that the PID (Proportional-Integral-Derivative) parameters can be tuned and updated by remote control so that all components, which are deployed along the XFEL machine with 700m, can be operated from the central control room of SPring-8. In addition, software management becomes better by using the same PLC program for all the temperature controller for the XFEL.

PRECISE TEMPERATURE-REGULATION SYSTEM

Fig. 1 shows a schematic drawing of the precise temperature-regulation system for one of the C-band accelerating units. In the temperature-regulation system, two feedback loops are present, each of which controls two accelerating structures and SLED, respectively. Each

feedback loop is composed of rod electric heaters inserted into the cooling water pipe, two different mineral insulated RTDs (Resistance Temperature Detectors, Pt100, three-conductor type) with an absolute accuracy of ±0.02 K, and a Karman vortex flow meter, all of which are installed in the linac tunnel, as shown in Fig. 2. The typical heater power for the structures and SLED are 13 kW and 8 kW, respectively. The RTDs, whose sheath diameter is 1 mm, are embedded in the structures and SLED at a depth of 10 mm from their surfaces. The other RTDs, which have a 4.8-mm-diameter sheath, are used for measuring cooling water temperature.

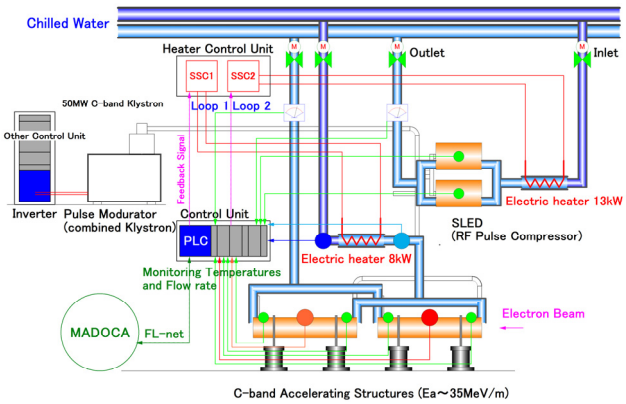

Figure 1: Schematic drawing of the precise temperature-regulation system for one C-band accelerating unit.

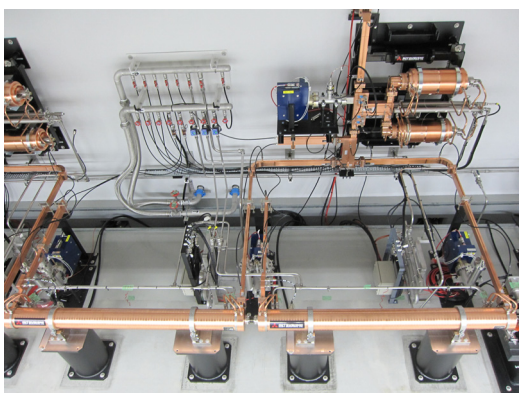

Figure 2: Precise temperature-regulation system and one C-band Accelerating unit in the linac tunnel.

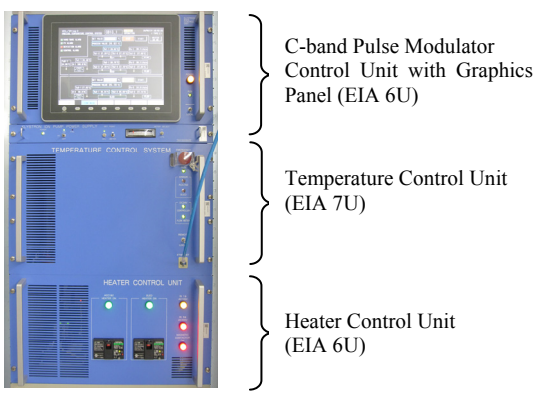

Figure 3: Control units for the precise temperature-regulation system in the klystron gallery.

A control circuit is mounted within a rack in the klystron gallery, as shown in Fig. 3. It is divided into two units, namely a temperature-control unit and a heater-control unit. The latter unit switches the heater power (ON/OFF operation) using SSC (Solid State Contactor) with AC zero-cross control based on the feedback control signal from the PLC (FA-M3, Yokogawa Electric Co., Ltd. [3]).

Control Circuit

The temperature-control unit using the PLC measures the individual temperatures and the cooling water flow rate, and sends the PID feedback control signal to the heater-control unit.

The performances of the temperature monitoring module and the temperature-control/PID module of the PLC are as follows: Input resolution and accuracy of temperature module are ±0.2°C and 0.02°C, and the sampling and output cycle of control data are 200 ms/sample and 500 ms/loop. When local operation is required, a GUI (Graphical User Interface) is available on a common graphics panel linked to a C-band klystron modulator in the rack. Fig. 4 shows an example of the GUI operation window.

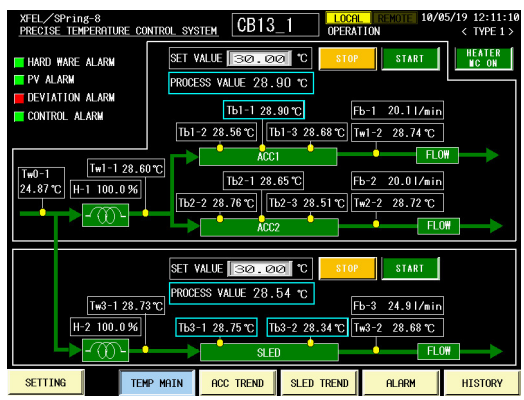

Figure 4: GUI on the local graphics panel.

In this window, we can start/stop the temperature regulation, set the target temperature, and check all measured data, including alarm information. By moving to other graphic layers, auto-tuning, logging, and setting the calibration values of the RTDs are all possible. The auto-tuning is a function with which the PLC automatically measures the characteristics of the temperature feedback control loop by using the limit cycle methods, and obtains the optimal PID parameters.

As the PLC communicates with the host link via FL-net, all the systems are controlled and monitored with the MADOCA framework of the SPring-8 control system [4].

PERFORMANCE

A performance evaluation test was conducted for the temperature-regulation system at the C-band accelerating

unit pilot test bench under the nominal operation (that is, repetition rate of 60 pps, rf pulse width of 2.5 μs, and an accelerating gradient of 35.2 MV/m).

Fig. 5 shows the results of temperature stability with or without a first-order lag filter, whose time constant is 5 s. Because the filter was able to decrease the noise content significantly, all subsequent tests were performed with the filter.

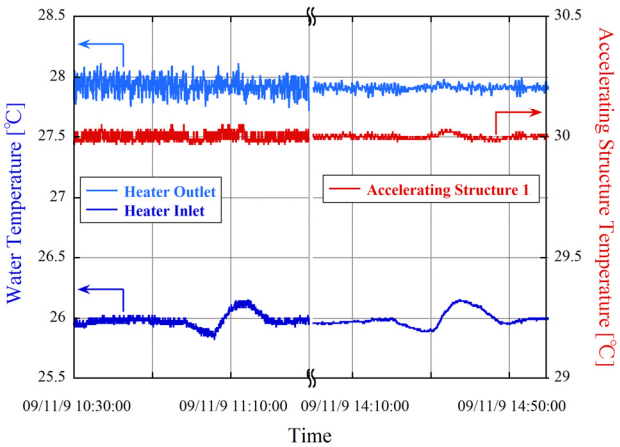

Figure 5: Trend graphs of temperature at the heater inlet (dark blue), the heater outlet (light blue), and the accelerating structure 1 (red). Left half of the graph shows results obtained without the filter, and the right half shows results obtained with it. (Feedback control using the temperature of the accelerating structure 1 alone.)

Fig. 6 shows the results of the case in which the feedback target is the average temperature of the two accelerating structures. The target temperature was 30.00°C, at which the resonant frequency was 5712 MHz. The dark blue line, indicating a water temperature upstream of the heaters, corresponds to a chiller discharge temperature. Deliberately giving it a fluctuation of ±0.1 K, which is equivalent to the target performance of the chiller, the short-term stability of the target temperature

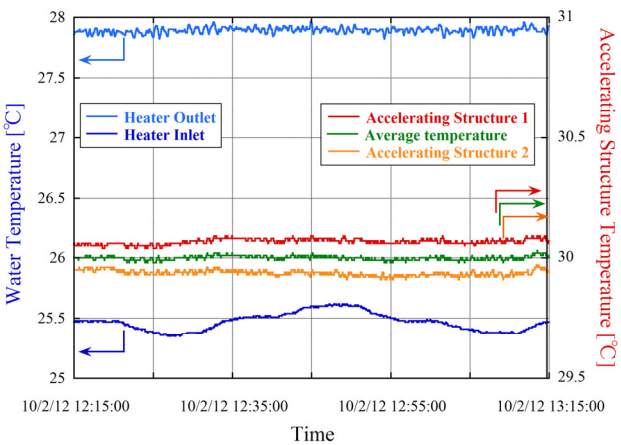

Figure 6: Trend graphs of the temperature. (Feedback control using the average temperature of the accelerating structures.)

was 0.05 K (p-p). Although the average temperature was constant, moderate drift was observed in the temperature of each structure independently.

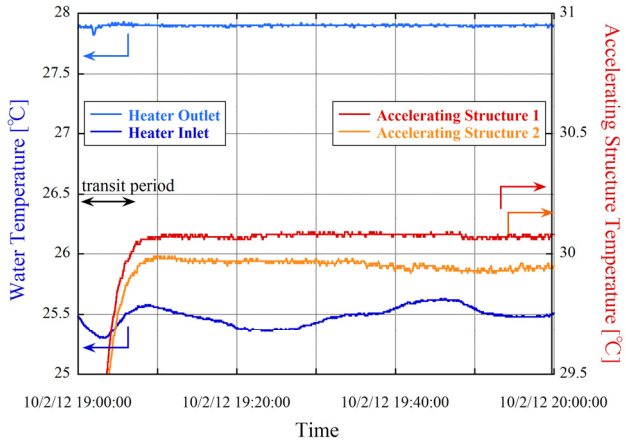

Figure 7: Trend graphs of temperature. (Feedback control using the inlet water temperature of the accelerating structures.)

We attempted to change the feedback control target to the water temperature downstream of the heaters, namely the entrance of the structures. As shown in Fig.7, the fluctuations of the target and the structures' temperatures were 0.04 K and 0.07 K (p-p), respectively.

SUMMARY

The development of a precise temperature-regulation system for the XFEL/SPring-8 project is nearing completion and improvements are made to the existing system at the SCSS test accelerator in terms of cost and maintainability. Thus far, the temperature of the C-band accelerating structure can be stabilized within ±0.03 K on the practical operational conditions. We will optimize the system upon commissioning by tuning PID parameters and varying a feedback control target to confirm temperature and rf phase stability of the structure.

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