# PRECISE TEMPERATURE REGULATION SYSTEM FOR C-BAND ACCELERATING STRUCTURE

S. Takahashi, SPring-8/JASRI, Hyogo, 679-5198, Japan
T. Shintake, T. Saeki, K. Onoe, T. Inagaki, RIKEN, Hyogo, 679-5148, Japan

*Abstract*

±0.1ºC temperature regulation of the accelerating structure with/without RF-power is one of the most challenging parameters in SCSS (SPring-8 Compact SASE Source) project, which is aiming at constructing soft X-ray radiation facility based on the SASE-FEL [1]. Since the heat dissipation in the C-band accelerator is about ten times larger than the conventional S-band accelerators and it's level varies with different operational modes, an active control system is necessary. We designed the precise temperature regulation system for the C-band high-gradient accelerator, which monitors the structure temperature and provides feedback on the water temperature at inlet using an electric heater and a flow-rate control valve. For the demonstration of this scheme, we designed the prototype model, which is capable of handling 4 kW heat loss. It will be demonstrated at the high-gradient test using one accelerating structure from this April.

## INTRODUCTION

High-gradient C-band accelerator, as shown in Figure 1, is the key component for SCSS project. C-band has twice higher frequency of 5712 MHz than the conventional technology of S-band accelerator, which enables the total accelerator length to be about half. When RF-power is fed into an accelerating structure, the dimension of the structure is expanded because of heat dissipation, resulting in resonant frequency shift.

In case of the C-band accelerator, temperature variation of 1.0ºC corresponds to resonant frequency variation of about 100 kHz. It is required to keep the temperature variation as tight as ±0.1ºC by the specification of the C-band accelerator.

In the past technology, such a precise temperature regulation system was used to keep the water temperature being constant at the inlet of the structure. As for the C-band accelerator, since the heat dissipation is about ten times larger than the S-band accelerators and it's level varies from 0 to about 2 kW with different operational modes, in the traditional system the body temperature variation will exceed the allowed value. The target task is to maintain the body temperature of the structure to be constant by a feedback system. To realize this aim, we introduce a new configuration, which employs an electric heater and a flow-rate control valve in addition to the temperature-controlled cooling water system.

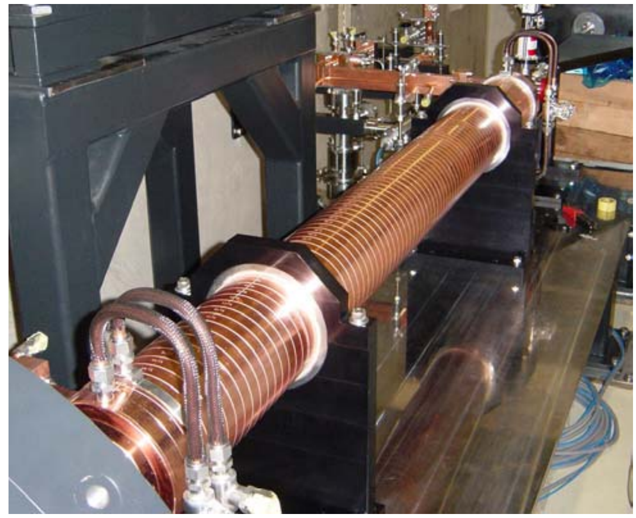

Figure 1: Photograph of the C-band accelerating structure. (1.8 m long)

## BASIC INVESTIGATION

The C-band accelerating structure is composed of 91 cells, made of OFHC (Oxygen Free High conductivity Copper), which are brazed in series. Figure 2 shows a one-fourth FEM (Finite Element Method) model and the cross-sectional view of a cell, whose thickness is about 20 mm. The resonance is tuned at 30.0ºC.

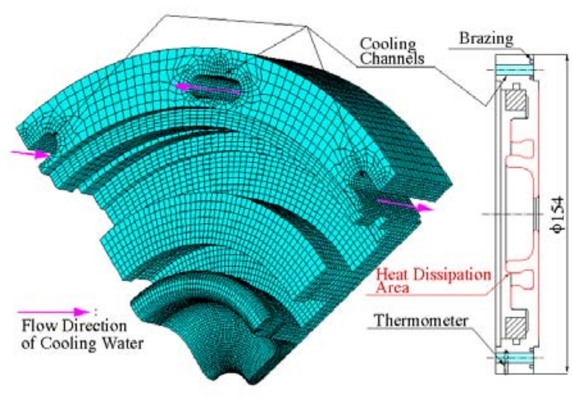


Figure 2: One-fourth FEM model and the cross-sectional view of a cell for the C-band accelerating structure.

The temperature of the cooling water increases along with passing through the structure. There are eight cooling channels in parallel, and the flow direction of each channel changes right and left alternately to compensate the temperature gradient in the water flow. Considering the performance of the structure, it is required that the temperature increase of the cooling water should be less than 1.0ºC. It means that the average cooling water temperature for eight channels at any cell is 0.5ºC higher than the cooling water temperature at the inlet. Table 1 shows the velocity, $\Delta T_1$, and $\Delta T_2$ for the various water flow-rates per channel, when the heat dissipation is the maximum of 2.0 kW. $\Delta T_1$ is the temperature difference of the cooling water between the inlet and the outlet of the structure. $\Delta T_2$ is the temperature difference between the cooling water and the copper body at the thermometer position. The flow rate of 4 l/min per one channel, namely the total flow rate of 32 l/min for 8 channels, are required to keep $\Delta T_1$ less than 1.0ºC at the operation of the maximum heat dissipation mode.

Table 1: $\Delta T_1$ (temperature difference of the cooling water between the inlet and the outlet of the structure) and $\Delta T_2$ (temperature difference between the cooling water and the copper body at the thermometer position) for various cooling water flow rates per channel when the heat dissipation is 2.0 kW. Velocity for each flow rate is also shown.

| Flow Rate (l/min) | Velocity (m/sec) | $\Delta T_1$ (ºC) | $\Delta T_2$ (ºC) |
|---|---|---|---|
| 2 | 0.48 | 1.80 | 1.33 |
| 3 | 0.72 | 1.20 | 0.99 |
| **4** | **0.96** | **0.90** | **0.80** |
| 5 | 1.20 | 0.72 | 0.68 |

To evaluate the detail temperature distribution in the accelerating structure body, we have to consider thermal resistances of heat transfer at the cooling water channels and heat conduction inside the structure body. We conducted thermal analysis on one-eighth part of the cell using a finite element analysis of ANSYS, where the heat dissipation is 21.4W (=2 kW in total for the structure) and the cooling water flow rate per channel is 4 l/min. Convection film coefficient of 5.4 kW/m$^2$/K are used based on their hydraulic diameters. The bulk temperature of the cooling water is 30ºC. In case of an acceleration gradient of 40 MV/m and a pulse-repetition rate of 60 pps, the heat flux distribution was calculated. All other surfaces are insulated.

Figure 3 shows the result of the steady state ANSYS solution. The temperature at the point, where the thermometer will be installed at depth of 10 mm from the outer surface in the center cell of the structure, is 30.8ºC. Then, the temperature difference between the cooling water and the structure body (=$\Delta T_2$) equals 0.8ºC. It means that if we want to keep the temperature at the thermometer to be 30.0ºC, the cooling water temperature should be about 28.8ºC (=30.0-$\Delta T_2$-$\Delta T_1$/2) at the entrance of the structure on this condition. For the different operational modes, the feedback system will automatically control this temperature.

According to the transient analysis, the time constant of the body temperature at the thermometer position is estimated to be 40 sec after the RF-power on and off.

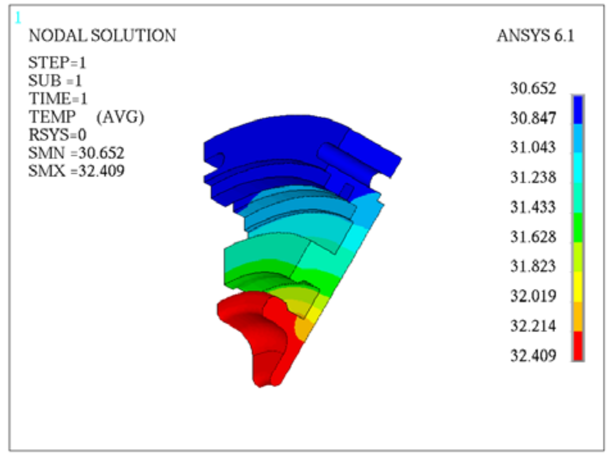


Figure 3: Temperature distribution of the center cell on condition that the heat dissipation is 21.4 W per cell, and the cooling water flow rate per channel is 4 l/min.

## DEMONSTRATION MODEL

Figure 4 shows the one unit of the C-band main linac, which consists of two 50 MW klystrons, their pulse modulators, one rf-pulse compressor, four accelerating structures, and associated waveguide system. The colored components, will be prepared at the high-gradient test for the demonstration of the acceleration gradient of 40 MV/m. The heat dissipation at the high-gradient test is twice larger than the nominal operational mode.

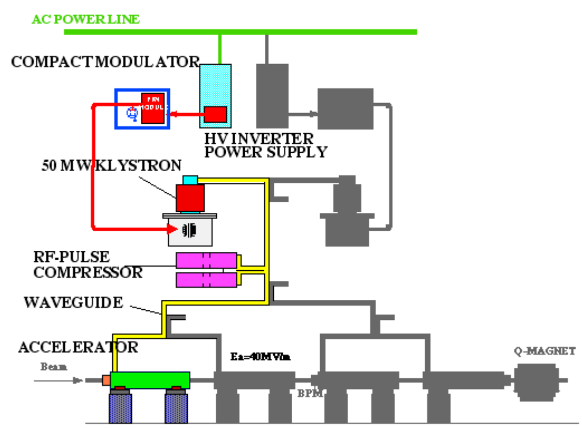


Figure 4: One unit of the C-band main linac. In the SCSS 1GeV machine, four units will be used. The colored components will be prepared at the high-gradient test.

### *Chiller System*

As shown in Figure 5, we prepared a chiller whose cooling and circulating ability are about 60 kW and 300 l/min, respectively. There are two refrigerators, basically operated in parallel. The main refrigerator (#2) has three capillary tubes with different conductance, where the coolant flow rate is controlled stepwise in 3 bit configuration, namely in 8 steps. In order to linearize the stepwise change, the supplemental refrigerator (#1) is prepared, which uses an inverter-controlled compressor. Using this technique, the cooling water temperature is stabilized below ±0.5ºC.

In order to prevent the copper body from corrosion, we design the cooling water system as a closed-loop circuit and prepared nitrogen gas tank to pressurize by 0.2 kgf/cm$^2$. The resistivity of circulating water will be kept at higher than 1MΩ•cm by a built-in ion-exchange resin.

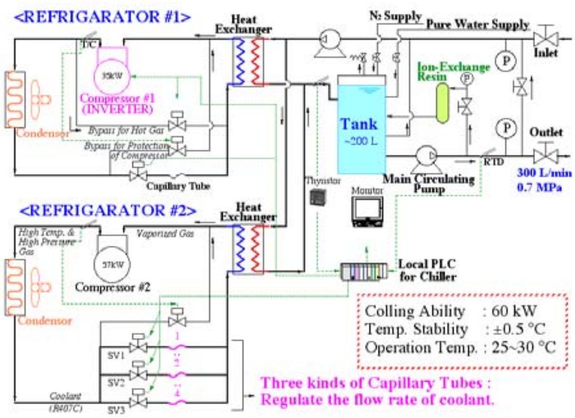


Figure 5: Detail configuration of the chiller system.

## *Temperature Regulation System*

Figure 6 shows a cooling water circuit for the one accelerating structure. The cooling water is supplied to the structure after heated by an electric heater, which is installed near the structure. The fundamental role of the heater is to compensate the heat dissipation of the structure and also the temperature fluctuation from the chiller, so that the structure temperature will be kept at 30.0±0.1ºC at any operational mode even if the RF-power is off. Because the heater power directly feeds into the accelerating structure, its temperature will quickly respond. Since the total cooling water circuit is a large system, if we provide the same feedback on the chiller system, it will have very long response time and should be of no practical use.

In order to save the electric consumption power on the heater, we prepared a control valve in front of the heater. When the RF power is off, the valve will be closed down to about 25%, and the water temperature will be raised up to 30.0ºC by low heating power.

We adopted PLC (Programmable Logic Controller) for the main control. A mineral insulated resistance thermometer (Pt100Ω, four-conductor type), whose sheathe diameter is 0.8 mm, is used for the measurement of the target temperature. PLC is monitoring the target temperature, and providing feedback on both the heater power and the control valve opening to regulate the water temperature at the inlet of the structure. The heater power is controlled using a solid-state relay, which adopts zero cross type thyristor control, to decrease noise generation. The control valve is driven by DC motor with a position sensor. To avoid frequent movement of the valve and increase life, the valve opening is controlled by averaging history including a hysteresis margin.

Figure 7 shows an example of the monitoring touch panel, on which we can control all of the feedback parameters.

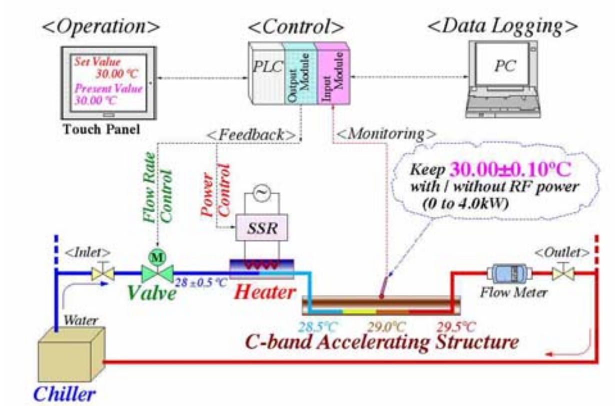


Figure 6: Cooling water circuit for the one accelerating structure and the feedback system.

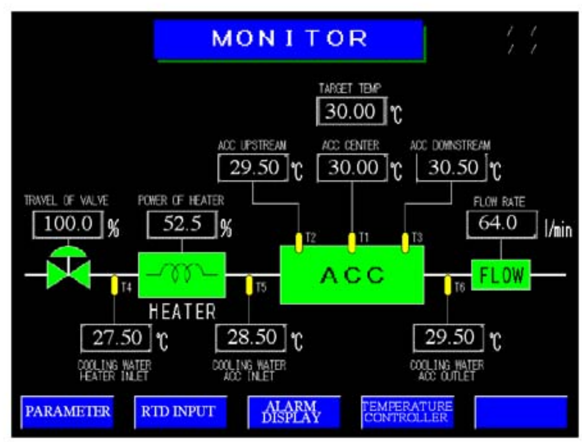


Figure 7: Monitor display of the control touch panel.

# FUTURE R&D PLAN

The main components for the high-gradient test have already been installed. We confirmed that the temperature variation of the chiller could be kept as tight as about ±0.2ºC at RF-power off condition.

We are planning the following R&D items:

- Operation test at the high-gradient test, including the comparison with predicted data from our analysis
- System design and cost down for 1 GeV SCSS machine, where 16 accelerating structures should be prepared
- Engineering design check for mass production.

# REFERENCES

[1] T. Shintake, "Status of SCSS project", in this proceeding.