ISBN: 978-3-95450-202-8 doi:10.18429/JACoW-HB2018-WEP2PO016

TEMPERATURE MEASUREMENT OF CLYOMODULES*

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Abstract

A quarter-wave resonator (QWR) and a half-wave resonator (HWR) cryomodules and the control systems such as programmable logic controller (PLC) are developed. Temperature sensors such as Cernox-1050 are calibrated and applied to the cryomodules. Preparation of vertical test is introduced. QWR and HWR cryomodules are fabricated and tested by using the developed PLC control system. The PLC rack and temperature monitors are shown and the human machine interfaces (HMI) screen is shown when the HWR cryomodules is tested at 2 K.

INTRODUCTION

Liquid helium and liquid nitrogen are commonly used as coolants for cryogenic systems and the effect of thermal radiation is important in design of cryogenic systems. Properties of superfluid helium fog were investigated [1-3] and n-dimensional blackbody radiation was studied [4]. The size effect of thermal radiation [5, 6] and the effective temperature of non-uniform temperature distribution were investigated [7, 8]. RAON accelerator system was designed [9] and superconducting radio frequency (SRF) test facility was constructed [10, 11]. The SRF test facility consists of cleanroom, cryogenic system, vertical test and horizontal test. Cavity processes and cavity assembles are performed in the cleanroom.

In this research we calibrate temperature sensors and apply them to cryomodules. Preparation of liquid helium and liquid nitrogen transfer lines, vertical test and horizontal test are introduced. PLC rack and HMI screen are shown to control and monitor the cryomodules.

TRANSFER LINES

Both liquid helium and liquid nitrogen transfer lines are needed to test QWR and HWR cryomodules in horizontal test facility. Figure 1 shows the fabrication process of liquid helium and liquid nitrogen transfer lines for cryomodules test from (a) through (f). The fabrication process consists of cutting, welding and leak test. About 20 turns of multi-layer foil insulation are used to cover the each of the transfer lines which includes the inlet and outlet of liquid nitrogen and liquid helium. Figure 1 (i) and (j) show the baking process by using heating wires for two days while pumping the vacuum area. Liquid nitrogen is used to cool down the thermal shield of cryomodules and lquid helium is used to cool down the helium reservoirs and cavities of cryomodules.

* This work was supported by the Rare Isotope Science Project of Institute for Basic Science funded by the Ministry of Science, ICT and Future Planning (MSIP) and by the National Research Foundation (NRF) of the Republic of Korea under Contract 2013M7A1A1075764.
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TEMPERATURE SENSOR

Temperature sensors such as Cernox-1050 are calibrated with physical property measurement system (PPMS) [12]. Figure 2 shows the resistance measurement as a function of temperature for five Cernox-1050 temperature sensors. The resistance of temperature sensors decreases as temperature increases because the sensors are semiconductor. The dependence of resistance on temperature can be explained well by Drude model [12].

Figure 1: Fabrication process of liquid helium and liquid nitrogen transfer lines for cryomodules test from (a) through (f).

The temperature sensors are calibrated from 1.9 K to 325 K. After calibration, the calibration data is saved as 340 files for each temperature sensors. The calibrated data of 340 files are uploaded to temperature monitors using Lake Shore Curve Handler. Figure 3 represents the locations of temperature sensors in the QWR cryomodule. The calibrated sensors are attached on cryomodules to monitor temperature.

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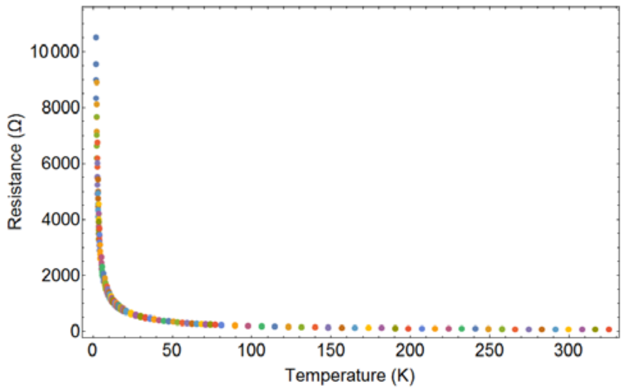

Figure 2: Resistance measurement as a function of temperature for temperature sensors.

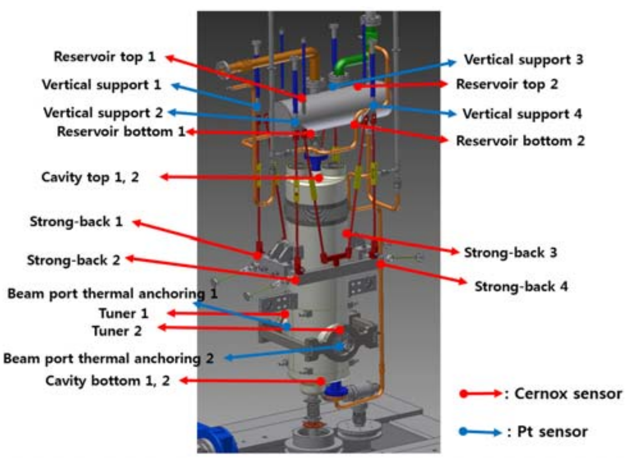

Figure 3: Locations of temperature sensors in a QWR cryomodule.

PREPARATION FOR VERTICAL TEST

The superconducting cavity made of Nb was performed with Buffered Chemical Polishing (BCP), High Pressure Rinsing (HPR), and High Temperature Heat Treatment, and then the cavity is assembled inside the cleanroom of class 10 of SRF test facility. Figure 4 shows the resistivity measurement of Nb as a function of temperature. The resistivity of Nb is measured with PPMS. The resistivity of Nb decreases as temperature decreases, which is a characteristic of conductors. The Nb also shows first-order phase transition at 9.3 K in Fig. 4. The Nb is also known as type-II superconductor.

The vertical test, the performance test of the superconducting cavity, is performed at vertical test site in SRF test facility. The superconducting cavities passed the performance test are assembled to cryomodules. Figure 5 represents the preparation of the vertical test for a cavity in cleanroom, two cavities prepared for cryostat installation and the top view of the cryostat. The superconducting cavities which are assembled in cleanroom and are passed leak test, are installed in the cryostat's top flange and then are moved to the vertical test site. After that, it is ready to do the vertical test. An ion pump is turned on to maintain the vacuum of cavities and the supply and recovery pipes of liquid helium and liquid nitrogen are connected to the cryostat. Connect the purging pipe for the helium zone of the cryostat, high frequency signal cables, temperature sensor cables and pressure sensor cables, and then check the operation of all the sensors. Finally, the cooling preparation for the vertical test is ready once the cryostat is purged with helium gas.

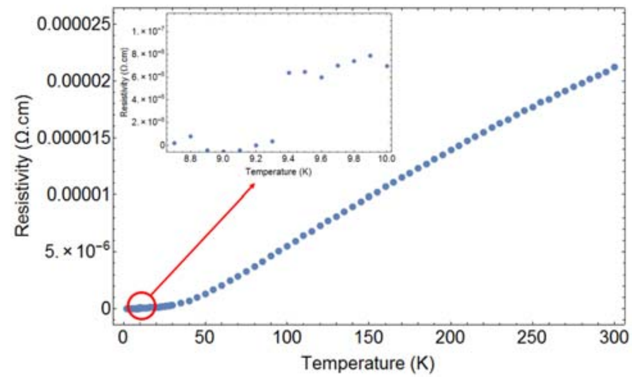

Figure 4: Resistivity of Nb as a function of temperature.

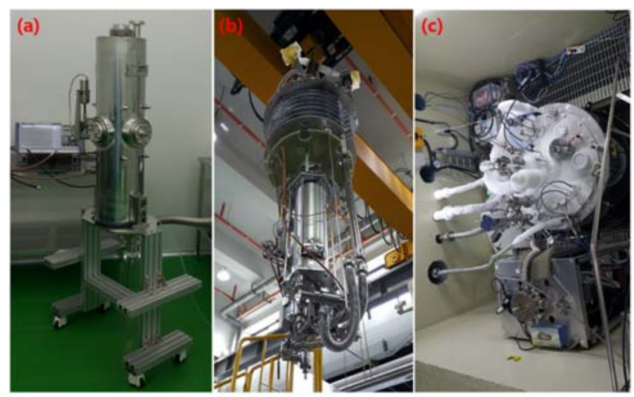

Figure 5: Preparation of vertical test for (a) a cavity in cleanroom, (b) two cavities prepared for cryostat installation and (c) the top view of a cryostat.

The performance test of superconducting cavities begins once the temperature of cavities becomes 4.3 K by circulating the cryostat with liquid nitrogen and liquid helium. Conditioning is performed in order to make the maximum electric field by changing the frequency and power in which a variable coupler is used for the superconducting cavity. After finishing conditioning, the figure of merit of cavity which includes Q factor, frequency change with respect to pressure (df/dp), etc., are measured through Voltage Controlled Oscillator Phase Locked Loop (VCO PLL). The Q factor is measured by using the input and output power of the cavity. The efficiency of the cavity increases as the value of the Q factor increases because stored energy in cavity is high compared with energy loss in cavity. The cavity becomes more stable as the value of df/dp representing the frequency change with respect to external pressure becomes lower.

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CONTROL SYSTEM FOR HORIZONTAL TEST

After finishing vertical test, the cavities are assemble to cryomodule in cleanroom. Figure 6 represents the QWR and HWR cryomodules. The QWR cryomodule is installed for a linear accelerator demonstration after horizontal test and the HWR cryomodule is under horizontal test by connecting the HWR cryomodule with transfer lines and by using PLC.

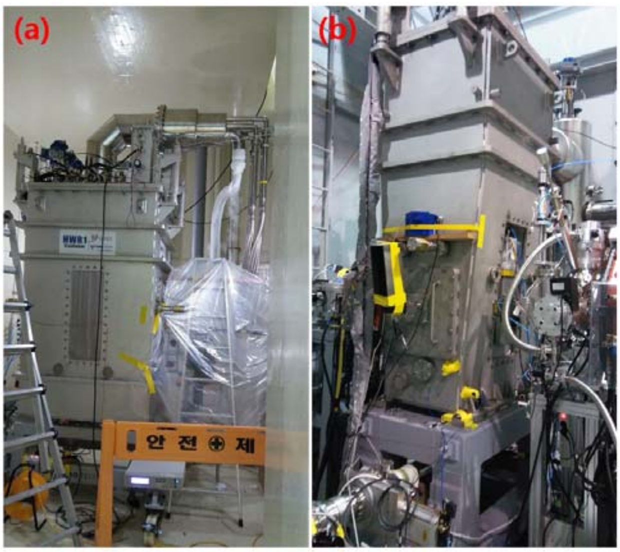

Figure 6: Cryomodules for (a) HWR and (b) QWR.

Figure 7: Control system of cryomodules for (a) PLC rack and (b) temperature monitors.

Compact Logix PLC and Studio 5000 software of Rockwell Automation is used to develop the PLC program for HWR cryomodules. Allen bradley PLC controls pumps, heaters and valves. The PLC communicates with temperature monitors through ethernet cable. PLC and EPICS control and monitor pumps, heaters, valves and temperature sensors through switching hub. Figure 7 shows the PLC rack and temperature monitors for cryomodules. The PLC are designed to control QWR and HWR cryomodules.

PLC human machine interface (HMI) screen for HWR cryomodules is shown in Fig. 8. It consists of 4 K helium reservoir, 2 K helium reservoir, two cavities, etc. Temperatures in many locations are monitored in the HMI screen. Vacuum pressures of cavity and vessel and vapor pressures of helium reservoirs are also monitored in the HMI screen. The drive frequency for the HWR cryomodule is 162.5 MHz and the cavities are operated at 2 K.

Temperature of cavity can be measured well by using the vapor pressure of liquid helium when the temperature is especially below 4.3 K. The temperature measurement of Cernox sensor depends on the contact between cavity jacket and sensor.

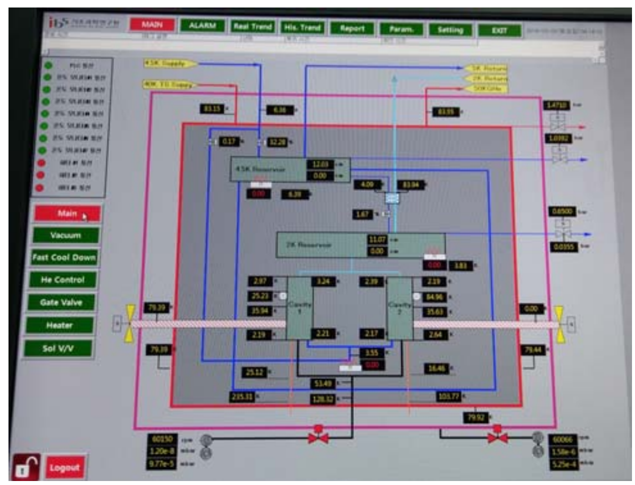

Figure 8: HMI screen for HWR cryomodules.

SUMMARY

We have developed QWR and HWR cryomodules and tested the cryomodules with PLC. Temperature sensors are calibrated by using PPMS and applied to the cryomodules. QWR and HWR cryomodules are fabricated and tested by using developed control systems such as PLC. The PLC rack and temperature monitors are shown and the HMI screen is shown when the HWR cryomodule is tested at 2 K.

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