ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-THPO067

CONTROL SYSTEM AND EXPERIMENT FOR RAON HWR CRYOMODULES*

Heetae Kim†, Moo Sang Kim, Min Ki Lee, Yong Woo Jo, Jong Wan Choi, Youngkwon Kim, Juwan Kim, Sangbeen Lee, Yoochul Jung, Kitaek Son, Doyoon Lee, Ohryong Choi, Kyungtae Seol, Hyojae Jang and Hoechun Jung

Rare Isotope Science Project, Institute for Basic Science, Daejeon 34047, Republic of Korea

Abstract

A prototype of half-wave resonator (HWR) cryomodules is fabricated and tested. Cables and tray are installed for horizontal test. The design and the piping and instrumentation diagram (P&ID) of the HWR cryomodule are presented. The HWR cryomodule is tested with developed programmable logic controller (PLC) and experimental physics and industrial control system (EPICS) control systems. The heat loads of the HWR cryomodule for static and dynamic are measured.

INTRODUCTION

Cryogenic system is required to construct a linear accelerator when superconducting cavities are used to accelerate ion beams. The coolants of cryogenic systems are liquid helium, supercritical helium, liquid nitrogen, etc.

The Stefan-Boltzmann constant for n-dimensional blackbody radiation [1] and the size effect of thermal radiation were studied [2]. The effective temperature was investigated for non-uniform temperature distribution [3, 4]. RAON accelerator system was designed [5], QWR and HWR cryomodules were developed [6] and superconducting radio frequency (SRF) test facility was constructed [7]. The SRF test facility consists of cleanroom, cryogenic system, vertical test site and horizontal test site. Cavity processes and cavity assembles are performed in the cleanroom. Temperature measurement techniques was introduced for RAON cryomodules [8] and RF power couplers for half wave resonator (HWR) were designed [9]. In this research we design, fabricate and test a HWR cryomodule with developed PLC control system. Tray and cable information are shown for horizontal test. Design, feedthrough and radio frequency (RF) amplifier information are presented for the HWR cryomodule. The HWR cryomodule is tested, so static and the dynamic heat loads of the cryomodule are measured.

TRAY AND CABLE INSTALLATION

In order to perform the horizontal test, we develop the programmable logic controller (PLC) for cryomodules. To operate the PLC, tray and cables are installed in the horizontal test site. Figure 1 shows the pictures of tray and cables for the horizontal test. The PLC racks are located outside of the horizontal test bunker. All of the cables are connected with the PLC and the cables come to the local box as shown in Figure 1(c). Cables come out of the local box and are connected to the feedthroughs of cryomodules with connectors. The bunker consists of tray, local box, cables with connectors, compressed air distributors, RF power lines and helium transfer lines.

The cable of 1.5SQ is used for the power line of turbo pumps, dry pumps and heaters. Solenoid valves are used with 20AWG shielded pair cable. 22AWG shielded pair cable is used for gate valves, vacuum gauges, turbo pumps, dry pumps, control valves, temperature sensors and liquid helium level sensors. The connectors of 32 PIN are used for temperature sensors and the connectors of 10 PIN are used for heaters, pressure gauges and level sensors. Specific plastic connectors are used for pumps, display control units (DCUs), gate valves, vacuum valves, vacuum gauges, heaters, etc. The display control unit (DCU) is a universal operating unit for the monitoring and control the Pfeiffer turbo pumps.

Tray sizes are 300X100 (mm^2) and 500X100 (mm^2) which depend on the number of cables.

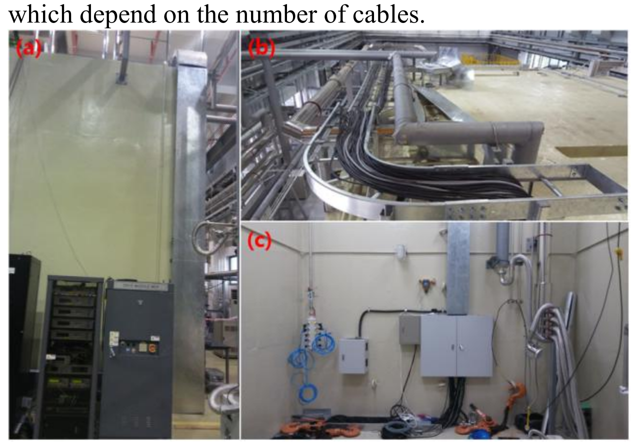

Figure 1: Pictures of tray and cables for horizontal test. (a) PLC rack and tray, (b) cables in tray on the roof of the horizontal test bunkers and (c) cables with connectors, tray, local box, compressed air distributors, RF power lines and helium transfer lines inside of the bunker.

HWR CRYOMODULE

A prototype of a HWR cryomodule is designed. Figure 2 represents the design of the HWR cryomodule. The HWR cryomodule consists of two liquid helium reservoirs, two cavities, two couplers, two tuners, thermal shield, magnetic shield, etc. The operation frequency and temperature of the HWR cryomodule at RAON accelerator

* Work supported by 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. …
† kimht7@ibs.re.kr

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-THPO067

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

site are 162.5 MHz and 2.05 K, respectively. Temperature sensors such as Cernox-1050 are calibrated in the temperature range between 1.9 K and 325 K with physical property measurement system (PPMS) [8]. The calibration

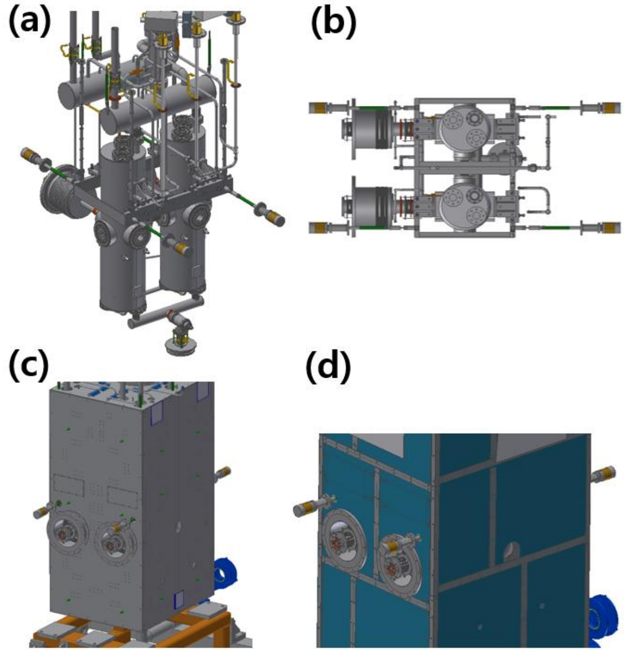

Figure 2: Design of a HWR cryomodule. (a) Liquid helium reservoirs, cavities and couplers, (b) top view of cavities, (c) thermal shield and (d) magnetic shield.

data which represents resistance as a function of temperature is saved as 340 files for each temperature sensor. The calibrated data of the 340 files are uploaded to Lake Shore Model 224 temperature monitors using Lake Shore Curve Handler. The calibrated cernox sensors and Pt100 temperature sensors are attached on the cryomodule to monitor temperature.

Feedthrough connectors of 32 Pin are used for temperature sensors and tuners. Feedthrough connectors of 10 Pin are used for liquid helium level monitors, heaters, pressure gauges and solenoid valves. Special connectors are used for cryogenic valves, turbo pumps, dry pumps, gate valves, vacuum valves and vacuum gauges.

HORIZONTAL TEST

The PLC program for HWR cryomodules are developed with compact logix PLC and studio 5000 software of rockwell automation. Allen bradley PLC controls pumps, heaters and valves. The PLC communicates with temperature monitors through Ethernet cable. The EPICS is developed from the PV lists of the PLC program. The PLC and EPICS control or monitor pumps, heaters, cryogenic valves, solenoid valves, liquid helium levels, temperature sensors, the vacuum pressures of cavity and vessel and the vapor pressures of helium reservoirs through switching hub.

The HWR cryomodule is installed at the bunker after the fabrication of the cryomodule and the cavities are assembled to the cryomodule in cleanroom with top-down assembly. Magnetic field strength inside of the cryomodule is measured to be below 15 mG. Figure 3 represents the HWR cryomodule installed in the horizontal test facility and the P&ID for the HWR cryomodule. The P&ID of the

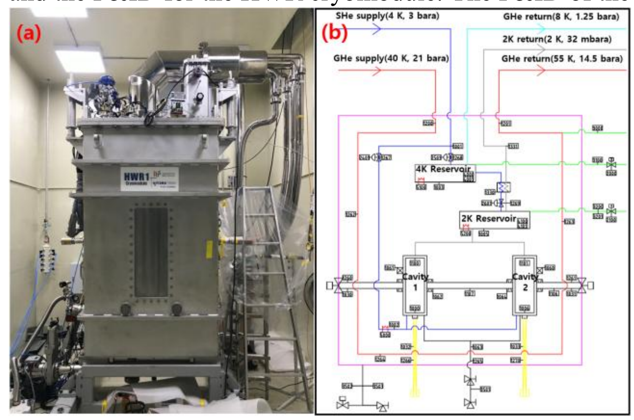

Figure 3: Picture of (a) the HWR cryomodule in horizontal test facility and (b) the P&ID for the HWR cryomodule.

HWR cryomodule is for RAON linear accelerator site. The prototype of the HWR cryomodule is tested at SRF test facility, so liquid nitrogen is used instead of helium gas and liquid helium is used instead of supercritical helium. The cables from the local box in the bunker are connected to the feedthroughs and special plastic connectors of the cryomodule. Compressed air pressure which keeps up to 7 bars in the bunker are needed to control gate valves, vacuum valves and cryogenic valves. The gate valves and vacuum valves work around 7 bars and the cryogenic valves work around 4 bars. Cylindrical type of compressed nitrogen gas is used to control vacuum valves when the compressed air pressure is lower than about 6 bars. Vacuum valves are not closed completely when the compressed air pressure is lower than the recommended pressure. The helium transfer line adaptor of the HWR cryomodule is connected with transfer lines which include helium inlet, helium outlet, nitrogen inlet, nitrogen outlet and 2K outlet.

The solid state power amplifier (SSPA) for the HWR cryomodule and the connection of a coaxial line to a power coupler are shown in Figure 4. The solid state power amplifier (SSPA) has the drive frequency of 162.5 MHz, continuous-wave (CW) operating mode and the maximum power of 7 kW. The efficiency of the SSPA is higher than 50%. Radio frequency (RF) power is transferred to the power coupler of the HWR cavity through the coaxial line. The power coupler can be biased up to 1 KV.

The cavities and vessel of the cryomodule are evacuated by using dry pumps and turbo pumps. Leak test is performed for cavity, vessel, helium transfer lines and thermal shield lines in the cryomodule. To do leak test for the helium transfer line, the helium leak rate is monitored from the vessel while helium gas is supplied to the helium transfer lines while three cryogenic valves are opened. To do leak test for the thermal shield, the helium leak rate is monitored from the vessel while helium gas is supplied to the thermal shield transfer lines.

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-THPO067

Coupler radio frequency (RF) conditioning is performed for about 8 hours with 400 V DC bias at room temperature. In order to cool down the cryomodule, liquid nitrogen is supplied to the thermal shield and then liquid helium is supplied to the helium reservoirs. The initial liquid helium path to cool down the cryomodule is from helium inlet to 4 K reservoir, 2 K reservoir and then helium outlet. By

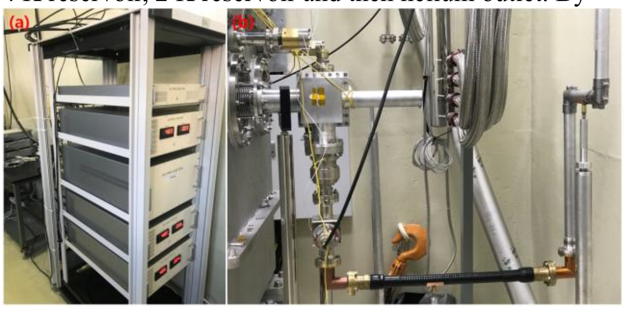

Figure 4: RF test of a HWR cryomodule. (a) SSPA and (b) the connection of a coaxial line to a power coupler in the cryomodule.

opening fast cooldown cryogenic valve, we can supply liquid helium to the bottom of cavities and then the liquid helium goes to 2 K reservoir, after that, the liquid helium goes out to 2 K outlet. Best superconducting niobium cavity requires the clean surface which does not have damages, dust particles and hydrides. Chemical etching and high pressure rising are performed for the cavities before cavities are installed to the cryomodule. Fast

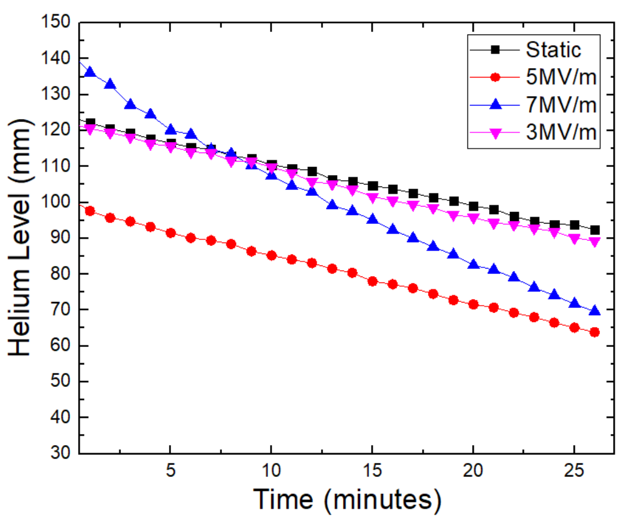

Figure 5: Static and dynamic heat load measurement for a HWR cryomodule at 2.1 K. The static heat load is 6.6 W. The total heat loads for 3 MV/m, 5 MV/m and 7 MV/m are 7.0 W, 8.7 W and 14.5 W, respectively.

cooldown is known to help to prevent Q disease coming from hydrides formation, so we perform fast cooldown. We supply liquid helium with high flow rate to cavities when the temperature of the cavities is decreased from 150 K to 50 K. The fast cooldown time is below 40 minutes in the temperature range between 150 K and 50 K. Cavity RF conditioning is performed for about 24 hours at 4.3 K once liquid helium level is increased at two helium reservoirs.

After finishing RF conditioning for two cavities, the cryomodule is cooled down to 2.1 K. In order to measure dynamic heat loads, we let the level of 4 K reservoir and 2 K reservoirs rise while RF power is supplied to one of the cavities. The cryogenic valve for the 2 K reservoir is closed and the liquid helium level of the 2 K reservoir is decreased as times goes. Here, the liquid helium level of the 2 K reservoir is measured as a function of time. The temperature of the cavity is kept by controlling the valve of 2 K pumps. The temperature of the cavity corresponds to the vapor pressure of 2 K reservoir. The dynamic heat loads are measured by considering the evaporation rate of the liquid helium in 2 K reservoir. The static heat load is measured without RF power. Figure 5 shows the static and dynamic heat load measurement for the HWR cryomodule at 2.1 K. The measurement time for each experiment is about 30 minutes. The static heat load is 6.6 W. The total heat loads for 3 MV/m, 5 MV/m and 7 MV/m are 7.0 W, 8.7 W and 14.5 W, respectively.

After finishing experiment, warm-up process is started. We close the valve of 2 K pump and stop liquid helium and liquid nitrogen supply. Pumps to make 2 K are stopped. During warm-up process, the liquid helium in reservoirs and cavities evaporates rapidly above 4.5 K. Therefore, we make the evaporated helium go out to either helium outlet or 2 K outlet while the cryogenic valves are opened.

SUMMARY

We have designed, fabricated and tested the prototype of the HWR cryomodule. Tray and cables are installed for horizontal test. The 3D drawing and P&ID of the HWR cryomodule are shown and the utility information for the horizontal test at the bunker is also shown. Feedthrough information are shown for temperature sensors, tuners, level monitors, heaters, pressure gauges and solenoid valves. The PLC and EPICS for the cryomodule are developed to operate the cryomodule. The experimental procedure for the horizontal test is introduced. The static and dynamic heat loads of the HWR cryomodule are measured.

REFERENCES

[1] P.T. Landsberg and A. De Vos, "The Stefan-Boltzmann constant in n-dimensional space", *Journal of Physics A: Mathematical and General*, vol. 22, p.1073, 1989.

[2] Soon-Jae Yu, Suk Joo Youn, and Heetae Kim, "Size effect of thermal radiation", *Physica B*, vol. 405, p.638, 2010.

[3] Heetae Kim, Myung-Soo Han, David Perello, and Minhee Yun, "Effective temperature of thermal radiation from non-uniform temperature distributions and nanoparticles", *Infrared Physics & Technology*, vol. 60, p. 7, 2013.

[4] Heetae Kim, Chang-Soo Park, and Myung-Soo Han, "Effective temperature of two-dimensional material for non-uniform temperature distribution", *Optics Communications*, vol. 325, p. 68, 2014.

[5] D. Jeon *et al.*, "Design of the RAON accelerator systems", *Journal of the Korean Physical Society*, vol. 65, p. 1010, 2014.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-194-6 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2018-THPO067

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2018). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

[6] Woo Kang Kim, Heetae Kim, Hyung Jin Kim, Youngkwon Kim, Min Ki Lee, and Gunn-Tae Park, "Design and Assembly of the QWR and the HWR Cryomodules", *Journal of the Korean Physical Society*, vol. 67, p. 1287, 2015.

[7] Wookang Kim, Mijoung Joung, Yoochul Jung, Heetae Kim, Jongwon Kim, Youngkwon Kim, and Ilkyoung Shin, "Fabrication and Low Temperature Test Plan for Rare Isotope Science Project", in *Proc. LINAC'16*, East Lansing, MI, USA, Sep. 2016, pp. 585-587, doi:10.18429/JACoW-LINAC16- TUPLR072

[8] Heetae Kim, Yoochul Jung, Yong Woo Jo, Min Ki Lee, Jong Wan Choi, Youngkwon Kim, Juwan Kim, Won-Gi Paeng, Moo Sang Kim, Hoechun Jung, and Young Kwan Kwon, "Temperature Measurement Techniques for RAON Cryomodule", *Applied Science and Convergence Technology*, vol. 27, p. 30, 2018.

[9] Sangbeen Lee, Eun-San Kim, and Ilkyoung Shin, "Design of RF Power Coupler for RISP Half Wave Resonator", in *Proc. IPAC'16*, Busan, Korea, May 2016, pp. 2208-2210, doi:10.18429/JACoW-IPAC2016- WEPMB041