Development of Monitoring and Control Systems in Cavity Cooling System Test Loop for The Experimental Power Reactor

Arif Adtyas Budiman, Dedy Haryanto, Kussigit Santosa, Syaiful Bakhri

Centre for Nuclear Reactor Technology and Safety - National Nuclear Energy Agency of Indonesia, Building No. 80 PUSPIPTEK Area, Serpong, South Tangerang, 15310, Indonesia

email: arif-adtyas@batan.go.id

Abstract. The Experimental Power Reactor as a fourth type of reactor currently being developed in Indonesia is high temperature gas cooled reactor which has a passive cooling system. This passive cooling system uses the principle of natural circulation through changes in water density and called as reactor cavity cooling system. To study the reactor cavity cooling system, a test facility will be created at BATAN which is called the Cavity Cooling Test Loop. This test facility consists of mechanical systems, piping and instrumentation. The instrumentation are includes temperature measurement, flow rate, pressure and heating control. Measurement and control monitoring systems that are needed in order to get data effectively and efficiently have not been made. Therefore, in this study, LabVIEW was used to create monitoring and control programs. A program to monitor temperature, flow rate and pressure has been made with a measurement point of 60 thermocouples, 1 flowmeter, and 1 pressure sensor. The heaters control program is made for 10 units with control of each heater ranging from 200°C to 900°C. Simulation has been done to test the performance of the program using DAQ simulator. Based on the simulation results, the program can be applied to the test facility by paying attention to the input type in the DAQ module.

Keywords: RCCS-RDE, CCTL, Monitoring, Controlling, LabVIEW

1. Introduction

The research development of the High Temperature Gas Cooled Reactor (HTGR) are highly intense in many countries such as China, Japan, Germany, USA, and Indonesia. The benefit of the HTGR is not only produce a high amount of energy but also for the industrial application by its hot steam utilization. Nowadays, Indonesia through the National Nuclear Energy Agency was conducting the research of the high temperature gas cooled reactor in modular scale called as the Experimental Power Reactor or Reaktor Daya Eksperimental (RDE) with the HTR-10 as a reference. RDE used the pebble bed type of fuel to bring the inert coolant temperature rised up to 700 °C [1]. In order to maintain the heat transfer process, the additional cooling system is needed. This additional cooling system must capable to remove the decay heat around the reactor pressure vessel (RPV). So that, by the RDE’s
design, this additional safety feature is called the Reactor Cavity Cooling System (RCCS) and located between RPV and inner concrete.

The RCCS as a passive cooling system has a function to cooling the RPV and concrete which relies on the natural circulation phenomenon. A de-mineralized water will use as a primary coolant in the RCCS. The RCCS design consist of the heat removal section and support section. The heat removal section are located in the nuclear island (risers, annular tubes) and chimney (air cooler). The piping system and expansion tanks are the support section in order to maintain the sustainable of flow. In a natural circulation process, the flow will generated by changing the coolant density. When the heat was absorbed in the risers, the coolant density will decrease and begin the flow against the gravity force. Meanwhile, after heat was removed from the cooler, the coolant density will increase and follow the gravity force. In this case, there are no cooling pump existed. So that, it would be a solution for some accident scenario in loss of elctic power to cooling the RPV and inner concrete simultaneously.

According to support the RDE’s detail design, BATAN will be constructed the RCCS in scale of test facility. This facility is called the Cavity Cooling System Test Loop (CCTL). The CCTL’s design of height and heat removal capacity is appropriated as similar as the RCCS in full scale. It has 11 m on the total height with an air cooler, five risers, two manifolds as the annular tubes, a configuration of heat source as a RPV, an expansion tank, the piping sytem, and instrumentation. So, in general the composition of CCTL consists of mechanical aspects, piping and instrumentation. This paper will discuss specifically about the development of monitoring instrumentation, and control. Monitoring and control instrumentation play an important role in this matter. This control can be manual, semi-automatic, and fully automatic. There are many ways to make control both manually, semi-automatically and fully automatically, one of which uses LabVIEW as a programming tool.

LabVIEW as a programming tool for instrumentation systems has been widely implemented. In his paper, Kussigit, et al., has made a monitoring and temperature control system on the FASSIP-02 strand. LabVIEW software is used as a monitoring and control center so that it can support the experimental activities very well [2]. Putra H. Et al., used LabVIEW as a PID control and monitoring tool using the reaction curve method on heating temperature settings. From the results of his research, using the PID tuning system in LabVIEW obtained significant data for heater controlling [3]. Another research using LabVIEW, Selim. A, et. Al., has developed a data acquisition system and calibrated electrometers for therapy dosimeters. From his research it was found that with the programs that have been made can minimize human error and improve the better statistics of calibration [4]. Previously, in research on the electrical and instrumentation systems of CCTL, Handono, et al. has drafted an instrumentation monitoring system with a total temperature measurement point of 25 thermocouples and 2 flowrate sensors for the loop, and 1 water level sensor in the expansion tank [5]. However, at this time a number of updates need to be added such as the addition of the number of measurement points and the heating control system because temperature monitoring at various docking points, flow rates, and absolute pressure are the main focus in the experimental activities. The component that can be controlled in CCTL are the heaters. There are 10 heating points with each heater having a power of 15 kW which is arranged vertically along the RPV. With a total power of 150 kW, a powerful instrumentation system is needed to be able to operate CCTL properly. Therefore, it is needed to develop a monitoring and heater control system for the CCTL by using LabVIEW as the main tool and DAQ simulator as programming support. The objectives of this research is to build a capable virtual instrumentation for the CCTL with data acquisition system and heater control.

2. Methodology

2.1. Cavity Cooling Test Loop (CCTL)

Nowadays, BATAN has successfully built two passive cooling system test facility called FASSIP-01 and FASSIP-02 which involves conduction and convection processes to deliver heat from heaters. Unlike the two, CCTL is a testing facility that is being developed by BATAN to study natural
circulation phenomena generated by heat radiation from RPV. In theory, the heat radiation received by riser pipes at a certain temperature will change the density of the water inside so that the density value decreases and build the flow through the place that has a lower temperature [6].

When the CCTL operates, there will be 3 types of heat transfer that occur, it begins with the radiation from RPV to the environment which resulting in changes in the density of air in the cavity and water in the riser pipes, then heat conduction occurs simultaneously with a hotter surface to the fluid in contact. In order to support these three heat transfer processes so that they can be observed perfectly, the CCTL geometry has been designed. CCTL consists of a heating unit in the form of RPV, a heat receiving unit in the form of a riser pipe filled with de-mineralized water as a hot carrier fluid, a heat exchanger unit (no blower), a pressure regulating unit in the form of an expansion tank, and an instrumentation unit in the form of data acquisition and heater control programs. In general, CCTL construction can be seen in Figure 1.
In Figure 1, the height of RPV is equal to the height of the riser pipes which is 9.0 m. The bottom manifold and top manifold are functioned as flow dividers and collectors respectively. On the cooler, there is a ducting which serves to air temperature in it so that hot air can be more optimal to move up. The position of the expansion tank is installed after the cooler with a purpose not only to maintain the stability of the operating pressure, but also as not to block the convection heat transfer process carried from the flow collector.

2.2. CCTL’s Instrumentation

The CCTL instrumentation system consists of several thermocouple sensor, a flowmeter and a pressure transducer that is attached to CCTL, while the Solid-State Relay (SSR) is installed in the heater settings network. This instrumentation system is described in Figure 2 regarding block CCTL diagrams.

![Figure 2. Block Diagram of the CCTL.](image)

Figure 2. Block Diagram of the CCTL.

Based on the block diagram in Figure 2, a chassis NI cDAQ™ 9178 is used as signal manager to the other modules such as NI 9213, NI 9203, and NI 9476 which are used for temperatures, currents and digital I/O signals, respectively. The display of the NI cDAQ™ 9178 , NI 9213, NI 9203, and NI 9476 module are shown in Figure 3, 4, 5, and 6 respectively.

![Figure 3. Chassing NI cDAQ™ 9178](image)

Figure 3. Chassing NI cDAQ™ 9178

A chassis NI cDAQ™ 9178 as shown in Figure 3 has 8 slot module with voltage input in range of 9 to 30 VDC [7]. Based on the initial design of the CCTL instrumentation shows that a number of thermocouples are needs to be added in order to optimize the experimental activity, so that by using the chassis NI cDAQTM 9178 can actualize some additional thermocouples. The reading of the thermocouple which is through its voltage signals will be processed by a NI 9213 module which has 16 thermocouple channels, an internal autozero channel, and an internal cold-junction compensation.
channel is shown in Figure 4 [8]. There are 60 thermocouples that will be installed in CCTL so that it requires 4 units of NI 9213 modules. In order to read the flow rate and absolute pressure, the NI 9203 Module which has 8 analog input channels and the input current reading range is 0 to 20 mA (unipolar) and ±20 mA in bipolar condition is used for receiving the current signals [9]. The current values will be read by the module and translated by the program in LabVIEW. In this case, the analog input will be translated to the absolute pressure and flowrate. To generate the sourcing signal, the NI 9476 module which has 32 sourcing output channels and an output voltage of 36 V is used in a certain condition [10]. This module will be used to deactivate the SSR, so it will be turn-off the heater.

![Figure 4. Thermocouple Module](image)

![Figure 5. Current Module](image)

![Figure 6. Digital I/O (Sourcing Output) Module](image)
2.3. LabVIEW Software

The use of National Instruments hardware will involve the LabVIEW software as a programming tool. LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) Programming is use a graphical codes with visual displays to conduct a program [11]. The LabVIEW interface is shown in Figure 7.

![Figure 7. LabVIEW Interface; A. Block Diagram Panel, B. Front Panel](image)

In Figure 7, the front panel function is to place the visual functions such as graphics, buttons, or images. Meanwhile the block diagram function is to build the wiring program. By considering the limitation in this study i.e. a development design, so that the program will be created and simulated first in order to test its reliability. To simulate the data acquisition function using the NI modules, an additional program called Simulated NI-DAQmx should be activated through the configuration of the devices is shown in Figure 8.

![Figure 8. Choosing Simulation Device in NI-MAX](image)

This simulation feature can be downloaded through the http://www.ni.com website. Please noted that to choose the right configuration that matches computer specifications. In Figure 8, it is clear that the functions of the NI modules that will be used in CCTL can already be used through the Simulated NI-
DAQmx Device or Modular Instrument. The modules are configured to the DAQ simulator was obtained as shown in Figure 9.

![Activated Modules in Simulated NI-DAQmx](image)

**Figure 9. Activated Modules in Simulated NI-DAQmx**

In Figure 9 it is clear that the number of thermocouple modules are used as 4 units, a unit of the current module and a unit of digital output module. After the modules was initiated, a heater monitoring and control program was created. In general, the flow chart of this study as follow as the Figure 10.

![Flowchart Study](image)

**Figure 10. Flowchart Study**

3. Result and Discussion

A monitoring and heating control program for CCTL and testing has been made. The monitoring program consist of 60 points measurement of temperature, a point measurement of absolute pressure, and a point measurement of flowrate. The monitoring program is shown in Figure 11.
Based on Figure 11, the DAQ Assistant function is configured. The thermocouple configuration uses a K-type thermocouple with a read data sample per second. The thermocouple configuration is shown in Figure 12.

It can be seen from Figure 12 that there are 8 configurable types of thermocouple. The K-type thermocouple that will used in the CCTL instrumentation design have a measuring range up to 1200°C, so that it is suitable to build a heater control program with the temperature threshold up to 900°C. According to Hangbin. Z, et. al., the axial temperature from the RPV surface has a pattern with the maximum temperature was on the middle-near the outlet [12], so that it is needed to build a heater control configuration. The heater control configuration is shown in Figure 13.
In Figure 13, there are 10 heater controls program in order to manage the heater temperatures. It has 10 temperature variation for every heater control program by using case structure from 200°C to 900°C. The value of 2°C has been inserted as a tolerance to the SSR while deactivating the heater. The controlled temperature was created in order to check the heater controls program. An indicator will give information to users with continuous blinking before reach the temperature threshold and means that the heater is ON. The front panel of the CCTL monitoring and controlling as shown in Figure 14.

It can be seen from Figure 14, that there are 9 thermocouples for every riser tube. The massive number for the riser tube is meaning for the detail experimental activity because it has a function as a flow generator. In the right side, the heater monitoring in form of graph is used to know the present temperature while reaching their threshold. The heater controls position is on the right-bottom corner and has a configurable temperature threshold control.
In case of natural circulation, a fluid dynamic must be examined carefully. Therefore, all risers profile will give more description about its fluid dynamic when the CCTL is operating. The interface can be seen in Figure 15.

![Figure 15. Riser Profiles Interface](image)

In order to verify the program reliability, a program reliability testing has been done by manual heating control. Monitoring program testing is done by random simulation using DAQ simulator. Test results using simulations are shown in Figure 16.

![Figure 16. Result of Data Recorded in lvm](image)

According to Figure 16, it is shows that the data was recorded every second and gives the string for date and time. At this time, the data acquisition program was successfully created and verified by simulation. In case of the real condition, it could be more attention to connect the sensors to the modules to avoid
the miss signal to be read. By this study, the program would be contributing to the experimental research by using CCTL.

4. Conclusion

According to the result, the monitoring and heater control was successfully created by using LabVIEW software. The temperature monitoring program has 60 measurement points which are consist of 10 points measurement for heaters, 45 for the riser tubes, 3 for piping system, 1 for the expansion tank, and 1 for the environmental temperature. Meanwhile the flowrate and pressure monitoring has used 1 sensor for each. In another program, the heater control program was created with 10 type of program in order to give more changes variation in temperature distribution along the RPV. Therefore, this study will useful for the CCTL’s Instrumentation design.

5. Acknowledgements

The authors wish to thanks the research funded by DIPA of The Centre for Nuclear Reactor Technology and Safety, National Nuclear Energy Agency of Indonesia and research grant from The Higher Education of the Republic of Indonesia by FLAGSHIP Program in 2018.

6. References

[1] M. Subekti, S. Bakhri, and G. R. Sunaryo, “The Simulator Development for RDE Reactor The Simulator Development for RDE Reactor,” 2018.
[2] BBPTP, “Prosiding SEMINAR NASIONAL,” 2017.
[3] P. Hindarpratama, M. H. M. Sc, and A. Sudarmaji, “Rancang Bangun Ruang Uji Temperatur Terkendali Berbasis Mikrokontroller untuk Alat Penjejak Kurva Tertutup Histeresis Elektrik.”
[4] S. Aydin and E. Kam, “Developing of an automation for therapy dosimetry systems by using labview software,” Results Phys., vol. 9, pp. 1007–1015, 2018.
[5] H. Khairul, S. Edy, S. G. Rinai, K. Kiswanta, and S. Sudarno, “Electrical and Instrumentation Design of Cavity Cooling Test Loop of Reaktor Daya Eksperimental ( RDE ),” 2018.
[6] M. Juarsa, A. R. Antariksawan, M. H. Kusuma, D. Haryanto, and N. Putra, “Estimation of natural circulation flow based on temperature in the FASSIP-02 large-scale test loop facility,” IOP Conf. Ser. Earth Environ. Sci., vol. 105, no. 1, 2018.
[7] N. Instruments, “Datasheet NI cDAQTM 9178,” 2018. [Online]. Available: http://www.ni.com/pdf/manuals/374046a.pdf. [Accessed: 25-Oct-2018].
[8] N. Instruments, “Datasheet NI 9213,” 2018. [Online]. Available: http://www.ni.com/pdf/manuals/378021a_02.pdf. [Accessed: 25-Oct-2018].
[9] N. Instruments, “Datasheet NI 9203,” 2018. [Online]. Available: http://www.ni.com/pdf/manuals/374070a_02.pdf. [Accessed: 25-Oct-2018].
[10] N. Instruments, “Datasheet NI 9476,” 2018. [Online]. Available: http://www.ni.com/pdf/manuals/373964c_02.pdf. [Accessed: 25-Oct-2018].
[11] N. A. W. Agus Nur Rachman, “PENGEMBANGAN SISTEM INSTRUMENTASI THERMOBATH DAN AKUISISI DATA TERMOKOPEL TIPE K,” vol. 20, no. 1, pp. 31–39.
[12] H. Zhao, Y. Dong, Y. Zheng, T. Ma, and X. Chen, “Numerical simulation on heat transfer process in the reactor cavity of modular high temperature gas-cooled reactor,” Appl. Therm. Eng., vol. 125, pp. 1015–1024, 2017.