THE DEVELOPMENT OF CONTROL SYSTEM FOR 9 MeV CYCLOTRON*

Y.S. Lee, J.K. Park, Y.H. Yeon, S.H. Lee, S.H. Song, H.S. Kim, S.H. Kim, S.Y. Jung, S.W. Shin, J.C. Lee, H.W. Kim, J.S. Chai,#
College of Information & Communuication Engineering / WCU Department of Energy Science
Sungkyunkwan University,Korea
K. H. Park, PAL, POSTECH, Pohang, Korea

Abstract

The Sungkyunkwan University has developed the 9 MeV cyclotron for producing radio isotopes. In order to operate the cyclotron stably, all sub-systems in the cyclotron are controlled and monitored consistently. Each sub-system includes its own control devices, which are developed based on PLC or DSP chip and the sub control modules interface with main control system in real time. For the main control system, we choose the Compact-RIO platform from NI (National Instrument) to take into account for a fast latency and a robust control. The main control system has high-performance processor running hard real-time OS so that the system can control the cyclotron in a fast and an exact manner. In addition, the system can be remotely accessed over the network to monitor the status of cyclotron easily. The configuration of the control system for 9 MeV cyclotron and performance test result will be presented in this paper.

OVERVIEW OF THE 9 MeV CYCLOTRON

The cyclotron accelerates the negative hydrogen particle to produce radioisotopes, and a couple of sub-systems make the particle acceleration possible. The cyclotron consists of magnet system, RF system, ion source system, vacuum system, and cooling system. The detail configuration of cyclotron is demonstrated in Fig. 1.

In order to accelerate the particle stably, it is necessary for the environment to maintain the constant temperature and humidity, fundamentally. In addition, the degree of vacuum inside cyclotron should be under 1 x 10^{-6} mbar. A double-stage high-vacuum system has been installed to improve the vacuum state as the time to reach the vacuum level. The cyclotron includes a panning ion gauge (PIG) type ion source for generating negative hydrogen from plasma by the use of arc power supply outside of cyclotron. The electromagnet field made by both RF system and magnet system accelerates the negative hydrogen for the desired energy level. The RF system is composed of two parts which are RF resonator and RF amplifier. The RF amplifier provides the high power RF signals to RF cavity to increase the dee voltage up to 40kV for electric field inside the cyclotron. The electric field is regulated by RF tuner. The average magnetic field is 1.36T generated by about 138A coil current from magnet power supply (MPS) [1].

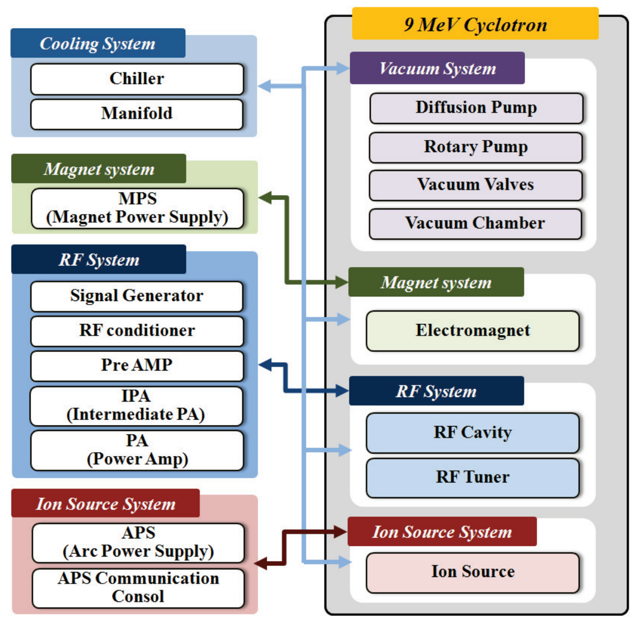

Figure 1: Configuration of 9 MeV cyclotron.

Table 1: Specification of Primary Control Parameters

System	Parameter	Specification
Magnet	Coil current	138A (±10ppm)
RF	Frequency	83.2 MHz
	RF mode	CW / Pulse
Ion source	H_2 gas flow rate	0 ~ 10 SCCM
	Arc current	0 ~ 2 A
	Arc voltage	0 ~ 2 kV
Vacuum	Degree of vacuum	1 x 10^{-6} mbar
Cooling	Water Temp.	< 20 ℃
	Water Resistivity	> 10 MΩ

*Work supported by Nuclear R&D program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (2012-0925001)
#jschai@skku.edu

ISBN 978-3-95450-128-1

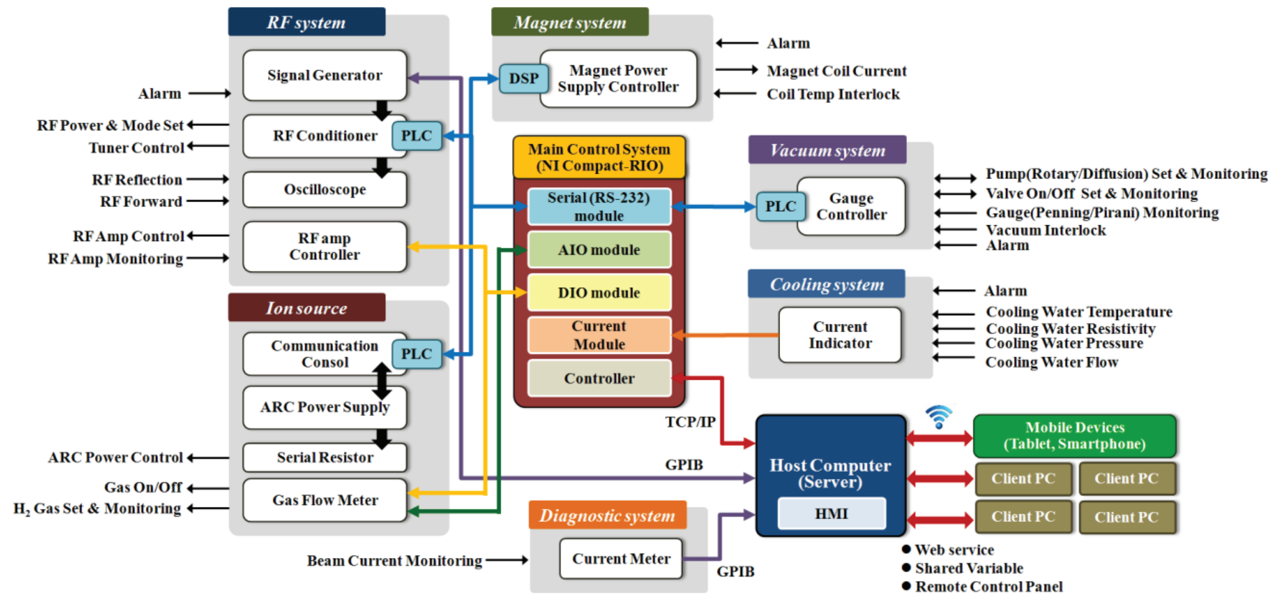

Figure 2: Architecture of 9 MeV cyclotron control system.

CONTROL SYSTEM DESIGN

The control system accesses the each sub-system, and monitors the status of each device. In addition, the control system should set the proper parameters depending on the monitoring data from sub-systems, and prevent from the emergency situation occurred during the operation sequence of cyclotron. Therefore, we have carried out a requirement analysis starting from the system specification, and then designed the control system considering capability, expandability and accessibility to achieve high reliability and safety for the system [2].

The architecture of the control system consists of three parts; a host computer, main control system and local control systems. The main control system gathers the status signals from local control systems and supervises the whole cyclotron, comprehensively. Many parameters handled at main control system are shared with the host computer, so an operator can control the cyclotron through the host computer. All of local control systems have self interlock functions and protect itself from the unexpected damage [3]. The primary specification of control parameters are shown in Table 1.

Magnet System Control

Magnet system is in charge of beam focusing and acceleration, and the MPS provides the current to electromagnet of cyclotron. The MPS includes control module based on DSP controller, so that it can make the stability of provided coil current maintain below 10ppm by using PI control. In addition, DSP controller can interface with main control system by serial communication (RS-232). Therefore, the main control system can access the magnet system and share the information about operation such like current value, interlock signals (over current, over heat etc.).

RF System Control

The RF amplifier consists of pre amp, intermediate power amplifier (IPA), power amplifier (PA) and programmable logic controller (PLC). The PLC can fulfil the sequence control with in/out signals for operation of RF amplifier. In addition, the PLC provides the data of RF amplifier to main control system by 24 V digital signals (DIO). Therefore, the main control system can monitor the status of RF amplifier related to overload or interlock, and control the operation of RF amplifier.

The RF system also includes a RF conditioner to generate RF signal which is delivered to RF pre amp. The RF conditioner has internal oscillator, so that it can generate 83.2MHz RF signal by itself. It is also possible to receive the RF reference signal from external RF oscillator. The PLC inside RF conditioner controls the RF power, RF mode (CW/Pulse), and RF duty (when the RF mode is pulse type). In addition, the RF conditioner can control the motor of RF tuner to regulate the resonant frequency of RF cavity. The main control system can access the RF conditioner by serial communication (RS-232) and share the data.

Ion Source System Control

For the stable generation of negative hydrogen plasma, the ion source system needs hydrogen gas and high voltage at least 2 kV. Therefore, we adopted the gas flow meter for control the gas quantity constantly, and ARC power supply to provide high voltage/current to ion source. In case of gas flow meter, it is handled by 0~5V analogue signal (AIO) for monitoring and setting the gas quantity, and 24 V digital signal (DIO) for ON/OFF control. In case of ARC power supply, it includes the PLC, so that it can perform the control task and status monitoring by serial communication (RS-232).

Vacuum System Control

The developed cyclotron has initial vacuum state (about 1X10^{-2} mbar) by using rotary pump, and then makes the high vacuum state (about 1X10^{-6} mbar) by using diffusion pump. There are many valves such like roughing valve, fore-line valve, and main valve, between each vacuum pump and chamber. The vacuum system includes the gauge controller and PLC which receives the monitoring signal of vacuum status from gauge controller. The PLC also controls the vacuum pumps and valves, simultaneously. The vacuum system also interfaces with main control system by serial communication (RS-232) and it is handled by main control system to control and monitor the vacuum system.

Cooling & Beam Diagnostic System Control

The cooling system is a basis system with vacuum system for beam acceleration of cyclotron. The important parameters of cooling system are water temperature, resistivity, pressure, and flow. Therefore, the parameters are monitored in real time and consistently. The main control system monitor the status of cooling system by analogue signals (4~20 mA) about cooling water.

There is a beam dump inside cyclotron to diagnose the beam generation, and the beam current is monitored by current meter. The main control system accesses the current meter with GPIB interface.

IMPLEMENTATION

We implement the control system by using Compact-RIO (from National instrument) as hardware platform and LABVIEW as software to take into account the performance, development time and convenience in use. The control system of 9 MeV cyclotron is depicted in Fig. 3.

Figure 3: 9 MeV cyclotron control system.

Hardware Platform Implementation

As mentioned above, we adopted the Compact-RIO (NI-9082) which is running by real-time operating system and has high performance as main control system. In addition, the platform is a modular type so, it is flexible. In order to interact with local control system, we also use NI modules such as NI-9269 (AO module), NI-9239 (AI module), NI-9375 (DIO module), and NI-9870 (serial communication module) which are execute the control function for the relevant devices as programmed [4].

Software Design

The control system software is classified into two programs; One is the program for main control system (real-time target), and the other is the program for host PC. The program for main control system is deployed to Compact-RIO, and then performs control & data acquisition about operation of sub-systems. The data gathered by real-time target is exchanged with host computer program via TCP/IP protocol. The practical control tasks are performed at real time target, so we minimize the graphical part of the program for real-time target to reduce CPU possession and memory consumption. The program for host computer includes the human machine interface (HMI) and the operator can control the cyclotron by this program.

Remote Control

As shown in Fig. 2, the control system can be accessed remotely by the network clients via TCP/IP protocol. There are two ways for remote controls and signal monitors in the control system. Using the web browsing program, the one of the clients fully use the main control user interfaces provided by the host machine at a time. On the other hand, limited access for the system can be allowed to concurrent hand-held devices such as tablets and smart phones. In this manner, the host machine deploys the pre-defined network-shared variables and web services and then the mobile clients access them through the platform-dependent applications.

CONCLUSION

The 9 MeV cyclotron has a number of sub-systems and almost sub-systems include control module. The local control system and sub-systems exchange the data of status with main control system. The main control system is implemented based on NI Compact-RIO which has high performance and multiple job capability itself, so that the control system can perform the tasks for control and monitor the cyclotron with high reliability. The main control system communicates with host computer, and it is possible to control remotely via TCP/IP protocol.

REFERENCES

[1] Lee, Byeong-No, et al., "Design study of a 9 MeV compact cyclotron system for PET." *Journal of the Korean Physical Society* 62.11 (2013): 1595-1599.

[2] Jacky, Jonathan, et al., "Control system specification for a cyclotron and neutron therapy facility." *IEEE Particle Accelerator Conference*. 1991.

[3] Pohang Light Source Technical Design Report. (2010).

[4] http://www.ni.com

ISBN 978-3-95450-128-1