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Development of an automatic prompt gamma-ray activation analysis system

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Abstract An automatic prompt gamma-ray activation analysis system was developed and installed at JRR-3M. This system is mainly composed of two personal computers, four programs, a vertical revolute joint robot, and data acquisition devices. The main control software, referred to as AutoPGA, was developed using LabVIEW 2011 and the program can control all functions of the analytical system. Up to 14 samples can be automatically measured by the system. Therefore, this system can not only dramatically increase the efficiency of routine measurements but also decrease the background level of gamma-rays for the analysis.

Keywords Prompt gamma-ray analysis · LabVIEW · Revolute joint robot · Automatic analysis · Sample exchanger

Introduction

Prompt gamma-ray analysis (PGA) using a neutron beam generated by a nuclear reactor is a convenient and nondestructive elemental analytical technique. In this analysis, gamma-rays emitted from target atoms are recorded within 10^{-14} s after the neutron capture reaction. PGA can be widely used in various science and technology fields, e.g., agriculture, earth and planetary science, material science, environmental science, and archeology [1–5], because the analytical methods have high sensitivity for certain specific light elements such as boron, hydrogen, and chlorine.

The PGA system at the Japan Research Reactor No. 3 Modified (JRR-3M) at the Japan Atomic Energy Agency (JAEA) was constructed in 1992 [6]. The system achieved a very low gamma-ray background level. However, the system was outdated because no improvements had been made since its construction. In addition, the PGA system was damaged by the Great East Japan Earthquake on March 11, 2011. In this study, an automatic system for PGA was developed in order to update the old analytical system and improve its measurement efficiency. The improvement was conducted from 2012 to 2013 after recovery efforts from the earthquake in 2011. A 3D image of the automatic PGA system is displayed in Fig. 1.

System outline

The new automatic PGA system is mainly composed of two computers (PC1 and PC2), four programs, a six-axis vertical revolute joint robot (Mitsubishi RV-3SD), and data acquisition devices (Fig. 2). The inside of the shielding body is not changed because the PGA is a highly sophisticated analysis system with very low background noise, and the installation of the device into the inside of the PGA would increase the background level. However, in this study, most of the devices and systems on the outside of the shielding body are completely improved. The core of the new system is an automatic sample exchanging and measurement system, and several automatic control functions have been integrated into the system. Each function is detailed in the following sections.

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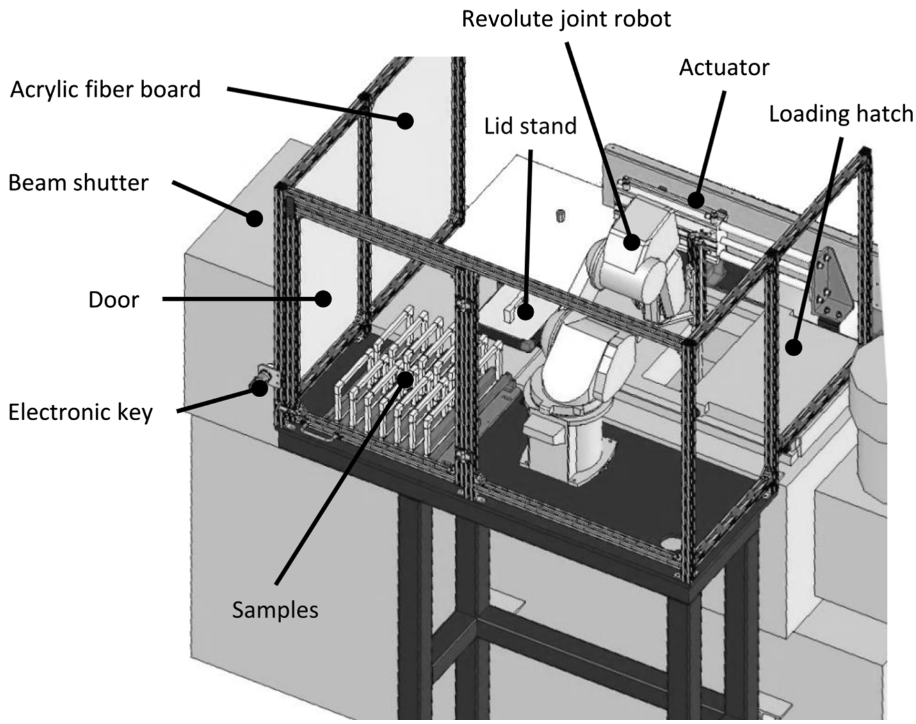

Fig. 1 Three-dimensional image of the automatic sample exchange system of PGA

Software

An integrated PGA control program (AutoPGA) was developed by the author using LabVIEW 2011. The program which runs on the windows operating system is designed to easily control all functions of the PGA system and has a user-friendly interface. Figure 3 shows the main screen of the program, which is composed of seven screens, including the main, neutron monitor, helium flow control, input/output signal, machine vision, logging and communication, and the error message screens. Switching between the screens is accomplished by selecting the appropriate tab. Users other than administrators generally open only the main screen, and end users of the PGA never use many of the functions included on the other screens.

Automatic analysis system

In the PGA system, 14 samples hung on the center of Teflon frames with Teflon strings that can be placed onto a sample stand. Each sample frame is selected and introduced into a Teflon sample box purged with helium gas using a revolute joint robot. Opening and closing of the loading hatch is enabled with compressed air and air bulbs that are controlled by a 24 V digital output signal using a digital output module (NI 9477). A physical interlock on the loading hatch that synchronizes with the neutron beam shutter is operated by a single-pole single-throw relay (NI 9481), and the relay can also control the opening and closing of the neutron beam shutter. Another interlock mechanism installed in the door is used to place the samples on the sample stand. When an electronic key is removed and the door is open, the servomechanism of the revolute joint robot is shut down and the alarm beeps. When the door is closed and the electronic key is connected, AutoPGA sends a robot controller (Mitsubishi CR1D-700) the reset signal using the NI 9477 and the alarm stops. Therefore, the user does not need to directly operate the reset switch of the robot controller.

The robot is controlled by the robot controller. A sequence program designed by the author and written in MELFA BASIC V is uploaded to the controller via a universal serial bus (USB) port. The AutoPGA program is installed in PC1 and controls the entire series of automatic analytical operations. The user inputs a user name and the number of samples on the basic screen and then clicks the start button. AutoPGA automatically starts the servomechanism of the robot and initiates the sequence program. It then closes the neutron beam shutter, releases the interlock, and opens the loading hatch. The robot begins operating, and the Teflon lid on the Teflon sample box is removed and placed on a lid stand. The robot selects the sample frame and introduces it into the sample box and then places the lid on the sample box. The loading hatch is closed, the neutron shutter is opened, and the measurement is begun. The sample exchange requires about 40 s.

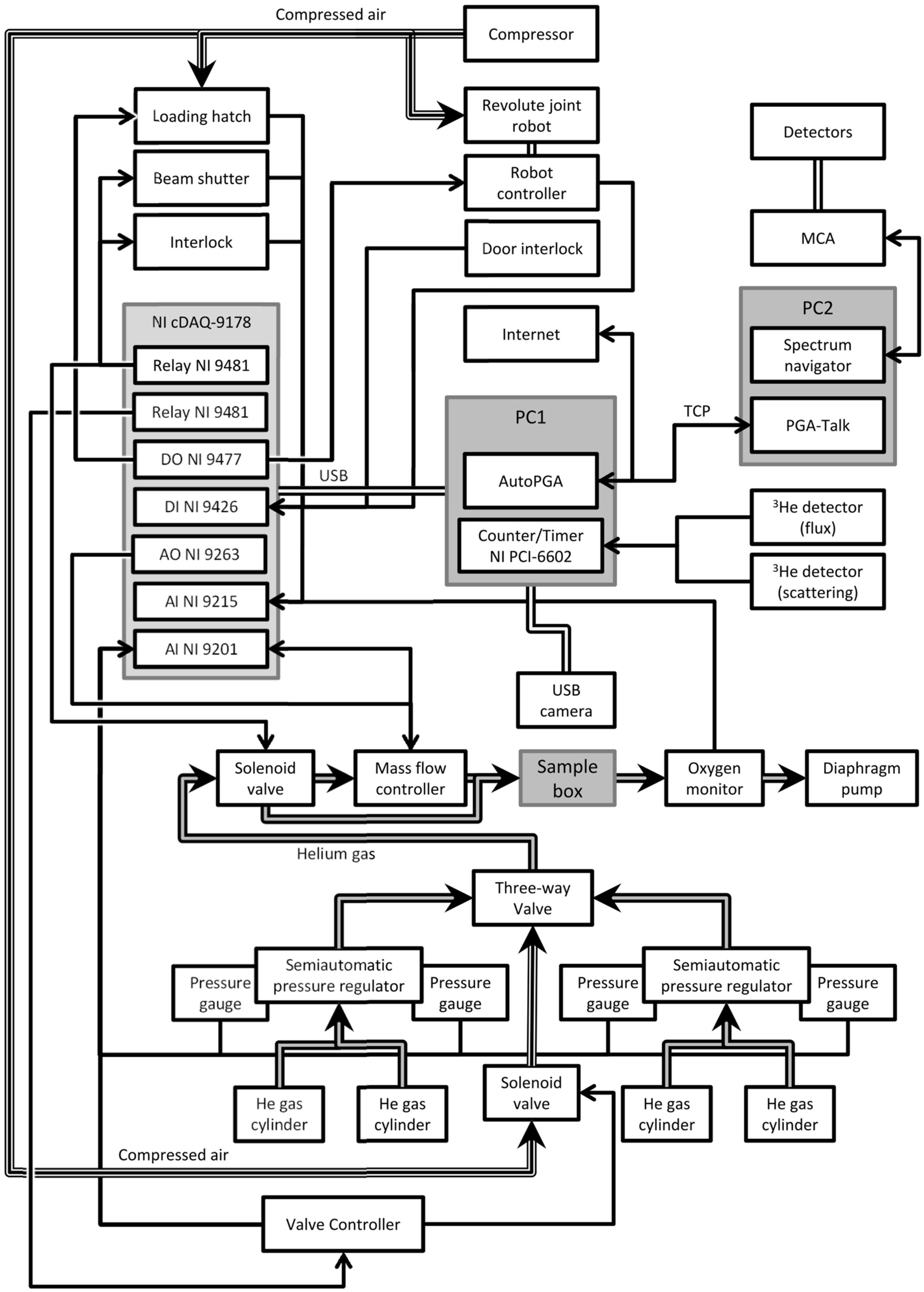

Fig. 2 Schema of the automatic PGA system

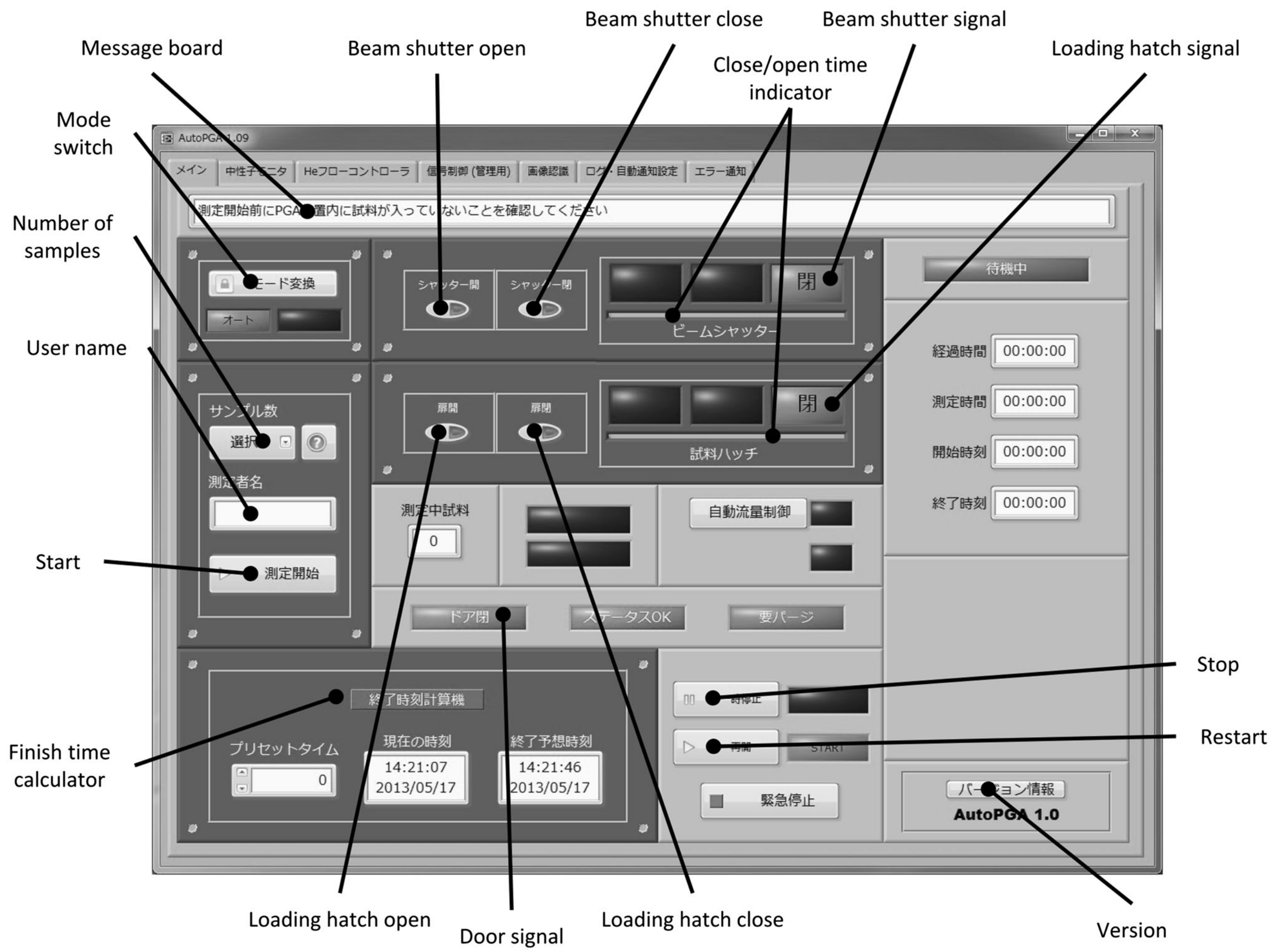

Fig. 3 Screenshot of the main panel of version 1.05 of the AutoPGA program. Only a Japanese version is operating at the present stage (April 2014); an English version is under construction

An existing measurement program (SEIKO EG and G Spectrum Navigator) is installed in PC2 and is used for the gamma-ray measurements. In the automatic analysis, a batch processing mode is utilized that calls a communication program (PGA-Talk created by the author) after each measurement. PGA-Talk, also designed using LabVIEW, sends a signal to PC1 via transmission control protocol (TCP), and AutoPGA recognizes the completion of the gamma-ray recording and begins to exchange the sample. When the sample exchange is complete, AutoPGA sends a signal to PC2 via TCP and PGA-Talk is automatically shut down. Spectrum Navigator then begins the measurement of the next sample. Upon completing the measurement of the last sample, AutoPGA sends an end signal to the robot controller, and the robot removes the last sample from the sample box. The loading hatch and neutron beam shutter are closed, an end message appears on a popup window, and a voice message is played to inform the user of the end of the measurement.

The AutoPGA program installed in PC1 communicates with the robot controller using 24 V digital output/input modules (NI 9477 and NI 9426) installed in NI cDAQ-9178. AutoPGA sends a set of digital signals, including the sample number expressed as 4-bit data, the start signal, the last sample signal, and the robot control signals. Therefore, AutoPGA can control all functions of the revolute joint robot using a digital signal output when the channel 5 signal that is used to acquire the operational authority of the robot controller is on. However, a user cannot control the robot in the user mode instead of the administrator mode.

Users can manually measure their samples when the AutoPGA analysis mode is switched to the manual mode. The neutron beam shutter and the loading hatch can be opened and closed by four switches of the AutoPGA program. The users can exchange the samples by hand when the loading hatch is opened.

Helium flow control and neutron recording systems

With the older system, during the measurements, the Teflon sample box was purged with helium gas but the mass flow of helium was manually controlled. In this study, an automatic mass flow control system was developed and integrated into the AutoPGA program. Helium gas flows into the sample box through a tube connected to a joint, and the small amount of air in the box is aspirated using a small diaphragm pump through another tube. An oxygen monitor (JKO-O2LJD2) is installed upstream of the pump, and the oxygen pressure of the air in the box can be recorded by the monitor. AutoPGA reads the partial pressure of oxygen via the analog voltage input (NI 9215) and automatically controls the mass flow controller (Azbil MQV0010) via the analog voltage output (NI 9263). The mass flow is also recorded by an analog voltage input module (NI9201). When the loading hatch is opened, the flow volume becomes 0 and then the box is rapidly purged when the hatch is closed. The partial pressure of oxygen and the settings for the flow volume and current flow volume are always displayed on a screen of the AutoPGA program. The mass flow of helium is controlled in the range from 0 to 10 l/min using three parameters, such as the minimum flow, upper threshold, and lower threshold. If the oxygen pressure is higher than the upper threshold, the mass flow is set at a maximum of 10 l/min. On the other hand, if the oxygen pressure is lower than the lower threshold, the mass flow is set at a minimum. The helium mass flow continuously changes between the upper and lower thresholds. This system efficiently reduces the helium consumption and contributes to a decrease in the background noise level for the gamma-ray analysis.

The user can skip the automatic mass flow control system and manually control the mass flow using a pressure regulator. When the user exits the AutoPGA program, the switch of a solenoid valve installed upstream of the mass flow controller is automatically turned off and the helium gas flows into the by-pass tube. When the user opens the AutoPGA program, the switch of the solenoid valve is automatically turned on.

Two neutron helium-3 detectors are installed in the PGA; one is for the neutron flux and the other is for the neutron scattering. Prior to this study, the neutron flux and neutron scattering were recorded using a printer for thermal paper and a pen recorder, respectively. This old system was updated in this study using a counter/timer (NI PCI-6602) installed in the PCI bus of PC1. The neutron flux data is continuously recorded and automatically saved in an Excel file every day by the AutoPGA. The neutron scattering is also monitored and the data is used to check the degree of purging of the helium gas in the sample box.

It is important to monitor the flux of the neutron beam in order to be able to evaluate the operation of the nuclear reactor and the accuracy of the measurements. Previously, the flux of the neutron beam was checked every morning before the start of operations, but the shifting of the neutron flux during the day could not be recorded. The new system can continually record the state of the neutron beam and the measurements, resulting in improved accuracy when rapid change of neutron flux occurs. In the daily flux monitoring, about 2.5 % fluctuation of neutron flux was observed in an operation cycle (26 days). If the same fluctuation occurs hourly, the accuracy of the measurement may improve by 2.5 %.

Logging, internet, and error functions

All events occurring in the system, such as the start of the analysis, the exchange of samples, the end of the analysis, and error warnings, are logged on a panel of the AutoPGA program. Users can easily confirm the operational situation using the time series log. The log information is automatically sent to the administrator by e-mail via the internet. In addition, the same information is automatically posted to twitter, and therefore, all users can remotely know the condition of the PGA.

Machine vision

AutoPGA provide imaging-based automatic inspection which is used to achieve higher fault tolerance of robot operation. The image is acquired by the USB camera on the loading hatch. When the Teflon lid is at a normal position, the machine vision inspection system can detect two horizontal edge lines of the handle of the lid. On the other hand, when the Teflon lid is not at a normal position, the machine vision system cannot detect horizontal edge lines and the robot stops. Similarly, the sample frame in the sample box can be detected by the system as two edge lines inclined by 45 degrees.

Conclusion

An archaic PGA system installed in the JRR-3M of the JAEA was completely improved and a new automatic PGA system was developed using a revolute joint robot. The main AutoPGA program developed using LabVIEW controls the entire analysis system automatically. The advantages of the new PGA system are as follows:

(1) The automatic sample exchange system using the revolute joint robot dramatically improves the efficiency of the measurement and liberates the user

from hard work late at night. In particular, the system is effective for the measurement of a large number of homogeneous samples.

(2) Because most of the analysis operations other than the placement of the samples is automated and the status of the PGA can be checked remotely by e-mail, twitter, and a web camera, the radiation exposure of the users can be decreased compared with the old system. When 14 samples are measured, the exposure becomes 2/15 by simple calculation.

(3) The new PGA system can record the flux of the neutron beam and the neutron scattering at any time. Because the PGA is located at the end of the T1 neutron beam line and is in the only position where white light neutrons can be investigated in the JRR-3 guide hall, the sequential data for the neutron flux is useful not only for improving the accuracy of the measurements but also for evaluating the operation of the nuclear reactor.

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