ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-THPS23

DESIGN AND FABRICATION OF THE AUTOMATION SYSTEM IN TLS BL07A END STATION

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Abstract

The TLS beamline 07A (BL07A) end station was established to facilitate multiple uses with various modes. The mode switching capability was manually realized in the previous operation design, and it took considerable time to reinstall and realign dozens of devices as part of the mode switching process. Occasionally, urgent sample tests jump into the experimental schedule and take much time to reconfigure the system if different methods are used. Thus, an automated process system design was proposed to reduce the time wasted in switching modes. This design includes different types of experimental device transformations and high-speed gas exchange. The automation process is now conducted. The operating time of the experimental equipment transformation is efficiently reduced from a couple of hours to two minutes, and the amount of required manpower is decreased as well. Moreover, the duration of the execution time of the gas exchange process is also reduced dramatically from 100 to five minutes.

INTRODUTION

When promoting the application of synchrotron radiation in industry, the ease of operation and efficient experiments are often crucial factors. BL07A is an experimental station primarily designed to meet industrial needs, and in the past, the system couldn't handle urgent order demands. Different tasks typically require the conversion of different experimental equipment, and different samples may require adjustments to gas proportions. In the past, reinstalling and adjusting experimental facilities and changing gases required a significant amount of time and manpower. Therefore, improvements for the BL07A experimental station include the following four aspects:

1. Providing high-speed switching for different experiments to reduce manual operation time. Common experimental projects at BL07A are categorized into three different experimental natures: X-ray Absorption Spectroscopy (XAS), X-ray diffraction (XRD), and powder X-ray diffraction. Different experiments require different experimental equipment. BL07A's automation adopts multiple self-designed motor platforms to switch experimental equipment. The motor platforms have a good repeatability during the switching process, reducing the time required for traditional handling, assembly, and positioning.
2. Developing an automatic gas replacement system with a running time of less than five minutes. Users can quickly decide different gas proportions according to experimental requirements for different experimental modes and sample needs.
3. Adding sample switching equipment to continuously switch multiple sets of samples, replacing manual sample changes and improving experimental efficiency.
4. The automated system should be operable in the SPEC software. Originally, different devices at BL07A were controlled or had measurement data read through the SPEC software. In this automation project, equipment is controlled using the EPICS system running in the TPS accelerator, enhancing reliability. The control-side SPEC software can employ process to control various EPICS subsystems, reducing the difficulty of user adaptation.

THE MECHANISM OF THE AUTOMATION SYSTEM

The BL07A experimental station primarily offers three different types of experimental methods, including XAS, powder XRD, and XRD, catering to various experiments for the industry and academia. However, different types of experiments require distinct equipment. Therefore, the manager and users often spend several hours installing bulky and expensive equipment on the experimental platform, and each switch requires recalibration and realignment. Consequently, after the design of an automated system, the repeatability of positions can be ensured through the control system, eliminating the need for repositioning. This results in a significant reduction in the switching time for each experiment, without requiring manual intervention.

According to the three different experimental requirements of the BL07A experimental station, the mechanical design needs to facilitate the transition of three different experimental setups at the same beamline. The design concept involves the shared use of a 2.7-meter-long vacuum tube, Io chamber, and attenuator for all three experiments. At the rear end of the shared equipment, a movable adjustment platform is designed, as shown in Fig. 1. Experimental setups for XAS and XRD are installed on this movable platform. When users need to conduct XAS experiments, they can move the platform (X-direction) to allow the radiation path to pass through the sample stage. The photon energy is then measured by LYTLE or SDD detectors, and the It chamber, standard sample stage, and Ir chamber are used to calibrate the light source parameters during the experiment.

If users want to perform powder XRD experiments, they can move the platform to make the powder XRD experimental devices on the beam axis. Then, the MARIP equipment is moved upstream (Y-direction), allowing users to conduct powder diffraction experiments. The final XRD

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experiment shares the same optical path as the powder XRD experiment, with only the measurement equipment being different. However, it is necessary to move the MARIP equipment downstream in the Y-direction to prevent collisions during the operation of the XRD measurement equipment.

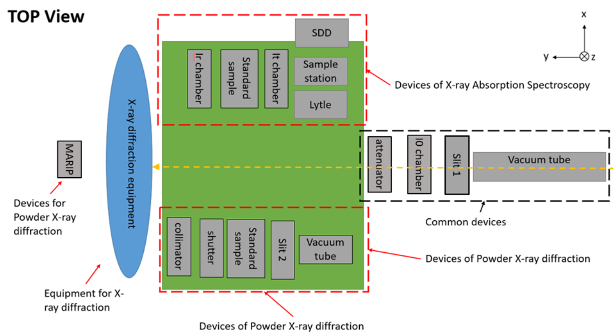

Figure 1: Illustration of the devices in BL07A.

Figure 2 illustrates the mechanical design architecture of the automation system. The movable adjustment platform (X1 motor stage) in the automation equipment is driven by a five-phase stepper motor and positioned by an optical scale. It is primarily used for switching between XAS and XRD experimental setups. In XRD experiments, to minimize light loss, the vacuum tube needs to be installed in the XRD optical path, bringing the XRD collimator as close as possible to the experimental sample. However, during the switch between XRD and XAS, the collimator may interfere with the XRD measurement equipment. Therefore, a compressible vacuum bellows tube is used instead of the vacuum tube, and the XRD experimental components are mounted on the Y1 motor stage. When switching between XRD and XAS systems, the XRD components need to be moved upstream first to avoid interference.

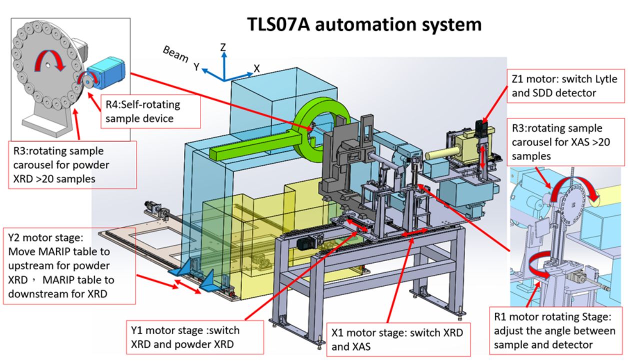

Figure 2: Mechanism design of automation system.

The Y2 moto stage is used to switch between the MARIP detector and XRD measurement equipment during powder XRD experiments. For uniform measurement of sample structures, the R4 electric spin sample stage in Fig. 2 is employed, allowing the setting of spin sample speed. The R3 electric rotary sample stage can accommodate 20 sets of samples and enables the switching of required measurement samples using a rotating disk mechanism. For XAS users, the Z1 motor stage can be used to select either LYTLE or SDD detectors. The R2 electric rotary disk can accommodate up to 20 sets of XAS samples, and the R1 rotary stage allows users to adjust the XAS sample and the incident angle of the light source according to experimental needs.

THE ELECTROMECHANICAL CONTROL SYSTEM

Figure 3 illustrates the structure of the automated electrical control system in BL07A [1]. The crucial aspect of this electromechanical control system is the control of the positions of mechanical components. In the XAS, powder XRD, and XRD systems of BL07A, all movements of automated platforms and sample stages are driven by stepper motors as the actuators for mechanical components. Depending on the specific requirements of each platform, optical scales or motor encoders are used to read the positions or angles of these mechanical components. BL07A utilizes motion controllers from Galil to control the motors, and the positioning signals from optical scales or motor encoders are decoded by the motion controllers and fed back to the control system (EPICS Server), achieving precise control of the positions of the motorized platforms. variable communication rules

The control system of BL07A adopts the EPICS Server system as an intermediary. Considering that the existing experiment software is SPEC, which can communicate with the process variables (PV) of the EPICS Server, and the Australian Synchrotron has encapsulated the driver interface of Galil motor controllers into modules within EPICS, installing the Galil motor controller module and related accessories allows the configuration of EPICS parameters based on the chosen motors and screws. This setup provides process variables to users. Ultimately, communication with the industrial computer is achieved through Ethernet interfaces to complete the motor control.

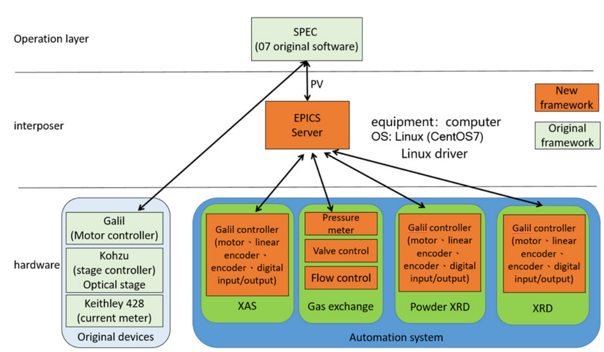

Figure 3: The frame of automation control system.

In the electrical control hardware, a multi-axis motion controller can output pulse signals to stepper motor drivers to control the motion of the motors. BL07A utilizes a multi-axis motion controller card (Galil DMC-4080), which can simultaneously control eight of motor drivers and relative encoders. This is particularly convenient for scenarios requiring control of multiple-axis motors. Additionally, the controller provides sixteen digital output and input channels, as well as eight 12-bit analogy input channels,

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facilitating the use of digital output/input signals by electromechanical control personnel for controlling solenoid valves or reading the signals of limit switches.

When conducting experiments using XAS or XRD, the gas proportions inside the Io, Ir, or It chambers need to be adjusted according to the different types of samples. When there is a need to readjust the gas inside the chambers due to a sample change, the BL07A automated ventilation system uses electromagnetic valve switches before the pump to extract the original gas in the chambers. After achieving the desired vacuum state inside the chambers (confirmed by the pressure gauge), the system uses a flow meter to reintroduce the required gas proportions. The control system of the gas replacement system is illustrated in Fig. 4. The electromagnetic valves are controlled through the digital output of the Galil controller, establishing EPICS server PV control switches. The pressure gauge uses the Modbus/RS485 interface to read the chamber pressure, which is then transmitted to the Galil controller, establishing EPICS server PV. As for the flow meter, there is no readily available module to utilize. Therefore, EPICS support software components for the flow meter have been developed, ensuring that all devices in the automation system support the EPICS architecture. Users can control the newly added automation hardware through PVs, write functions for different operational features, and allow experimental users and managers to directly design experimental processes without considering hardware control issues. This enables the rapid development of the BL 07A automation system, achieving the expected results of automated experiments in a short period.

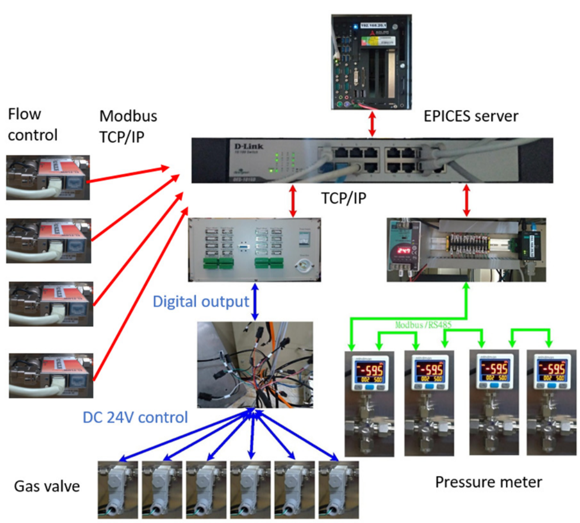

Figure 4: The control frame of gas replacement system.

SUMMARY

In industrial promotion, the issue of delivery time is frequently encountered, and the speed of experiments often plays a significant role in the success of promotion. Therefore, the industrial promotion team aims to upgrade the existing TLS BL 07A experimental station by introducing automation to increase experiment speed, reduce labor, and minimize experiment time wastage. With the collaboration of precision mechanical engineering team, the industrial promotion team, and colleagues, four automation specifications were collectively achieved: 1. rapid switching between different experiment modes to reduce manual operation time. The experiment mode change was reduced from the original 1 hour to 2 minutes. 2. Addition of an automatic gas replacement system, with replacement time reduced from the original 1.5 hours to five minutes. 3. Installation of a sample replacement system capable of conducting more than 20 samples, allowing for continuous long-term experiments. 4. Establishment of an EPICS server control system, enabling the operation of automation commands and the creation of action programs within the original SPEC experiment software without affecting its original functions. TLS BL 07A automation control system not only meets the requirements of these four automation specifications but also introduces additional features such as switching functions for multiple measurement devices and sample rotation for improved uniform results in experiments. The increased efficiency in laboratory utilization has received positive feedback from experiment users.

REFERENCES

[1] Huai-San Wang, “Design and Implementation of the Automatic Control System at TLS 07A1 End station”, Rep. NSRRC-internal-2022.