INTRODUCTION OF ACCELERATOR KNOW-HOWS TO KAGRA'S VACUUM SYSTEM

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Abstract

KAGRA is a large-scale cryogenic gravitational wave telescope in Japan. In March 2023, next collaborative observation on gravitational waves will start. The stable operation of pumps, gate valves and gauges in KAGRA vacuum system is critical, while there has been less effort to develop a remote monitoring system for them. We developed a small EPICS-based vacuum monitoring system for KAGRA as a prototype, which simulates the vacuum control system of J-PARC Main Ring.

The system consists of a micro-server, a MOXA serial device server, and a PLC controller with I/O modules. The micro-server works as an EPICS IOC. The MOXA connects a gauge (CC-10) and an ion pump (Digitel MPCq). The PLC I/O modules accept on/off/fault signals of a roots pump and a turbo molecular pump, and open/close signals of gate valves.

In February 2022, this vacuum monitoring system was installed and tested successfully in the KAGRA tunnel. During the FY2022, we proceed to increase the number of remote monitoring stations.

INTRODUCTION

The Kamioka Gravitational Wave Detector (KAGRA) is a large-scale cryogenic gravitational wave telescope of ICRR (Institute for Cosmic Ray Research of University of Tokyo). The KAGRA is located in Kamioka, Hida, Gifu Prefecture, Japan [1]. The early joint observation with GEO600 was carried out in April, 2020 [2]. The next is planned to be a collaborative observation between LIGO, VIRGO, and KAGRA, which is called "O4". It will start in March 2023.

Since 2020, there is an MOU between KEK (High Energy Accelerator Research Organization) 's accelerator division, NAOJ (National Astronomical Observatory of Japan), and ICRR, with which KEK is asked to provide suggestions on cryogenic, vacuum and control systems of KAGRA. Since 2021, the control staff of KEK/J-PARC visited KAGRA site, and discussed with the KAGRA staff about the control system of KAGRA.

As we all know, the stable operation of pumps, gate valves and gauges in KAGRA vacuum system is critical. However, there has been less effort to develop a remote monitoring system for them. In fact, there have been cases where a pump stopped without being aware of it. Toward the "O4", to develop a remote monitoring system of vacuum devices is very important.

Therefore, during the second half of FY2021, we (KEK) developed a prototype of vacuum monitoring system for KAGRA, which simulates the vacuum control system of accelerator facility J-PARC (Japan Proton Accelerator Research Complex) Main Ring.

DESIGN OF PROTOTYPE VACUUM MONITORING SYSTEM

Background

The digital control system of KAGRA was introduced from LIGO. The slow control part of the system is based on an open-source framework, EPICS (Experimental Physics and Industrial Control System) [3]. Thus, the KAGRA vacuum system is planned to use EPICS. However, KAGRA staff has less development experience of EPICS-based systems.

The control system of J-PARC Main Ring is EPICS-based, which was developed in 2006 [4] and has been running steadily ever since. To develop the KAGRA vacuum system faster, know-hows of the J-PARC control system are used.

Hardware

The goal of the KAGRA vacuum system is to monitor the status of pumps, gate valves, and gauges. To achieve these objectives, a commercial micro-server (Pinon Sabataro Type-P), which is a standard component of the J-PARC control [5], is introduced as an EPICS IOC (Input Output Controller). A MOXA serial device server (RS485-LAN converter) and a PLC controller (Yokogawa F3MA) are used to realize the communication between vacuum devices and the IOC. The structure of the system is shown in Fig. 1.

The gauge (CC-10 controller) has a RS485 serial interface. To monitor vacuum pressure in Torr, a MOXA server is used to convert the RS485 to LAN port, then connected to the KAGRA local network for data monitoring.

Vacuum devices with digital I/O only, such as Gate Valve (GV), Turbo Molecular Pump (TMP), and Roots Pump, are connected to a control box, which is designed for handling metal signal cables. Then a PLC controller accepts On/Off/Fault signals of a roots pump and a TMP, and Open/Close signals of gate valves. The PLC is also connected to the KAGRA local network.

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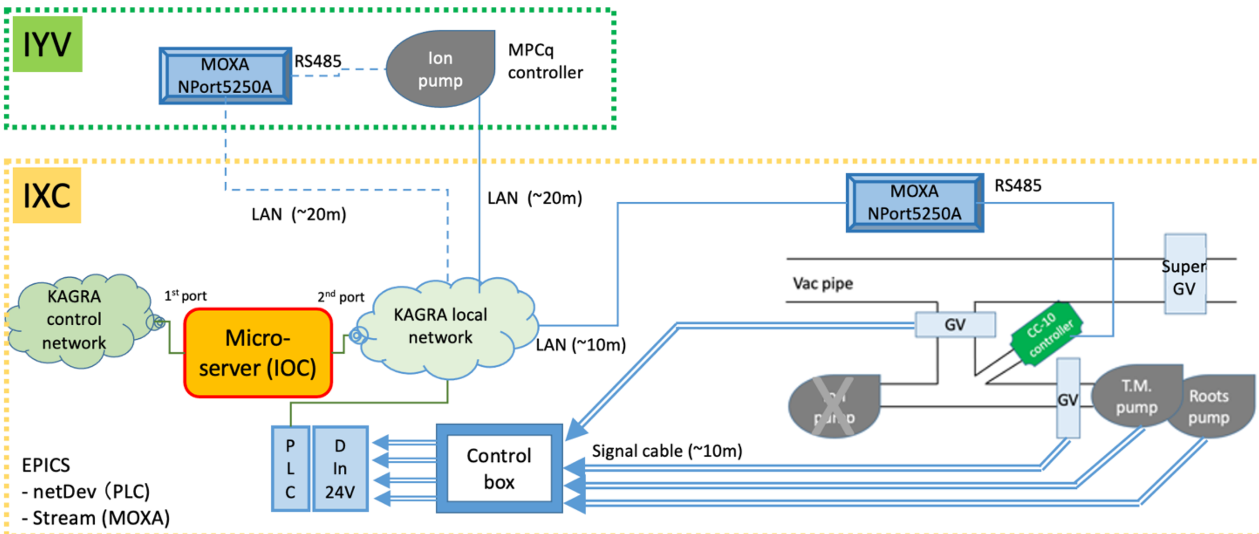

Figure 1: The structure of prototype monitoring system of KAGRA.

In addition, an ion pump (MPCq controller) has both a RS485 port and an ethernet port. To realize ion pump monitoring, a MOXA server can be used as the CC-10, but direct ethernet connection to the KAGRA local network is also possible.

The micro-server has two ethernet ports. One of the ports is connected to the KAGRA control network. Another port is connected to the KAGRA local network for data collection and for system development and test.

Software

The basic environment of EPICS is imported from the J-PARC control system. The operating system of a micro-server is CentOS 7. An EPICS IOC is running on it.

Some EPICS modules are used for realizing the communication between devices and a micro-server. For example, EPICS StreamDevice [6] is used for serial communication with MOXA servers; netDev [7, 8] is used for PLC-EPICS communication. Within the PLC, Ladder program is embedded to realize monitoring functions of pumps and gate valves.

DEMONSTRATION

Hardware – Real Implementation

A prototype of KAGRA vacuum monitoring system was developed. The real implementation is shown in Fig. 2 and Fig. 3.

As in Fig. 2, the CC-10 controller is connected to the MOXA server by a RS485 cable, then connected to the KAGRA local network. About the ion pump controller (MPCq controller), we tested the communication between the controller and IOC with a MOXA server (through RS485) or without MOXA server (through network), both were successful. We finally decided to connect the controller to the KAGRA local network directly.

Figure 3 shows a PLC controller, a control box, and a micro-server (Saba-taro server). The PLC controller includes a D-in module, a D-out module, an ADC module, and a ladder CPU module. The digital signals of gate valves and pumps are transferred to the PLC I/O modules through the control box, then monitored by Saba-taro server through the KAGRA local network.

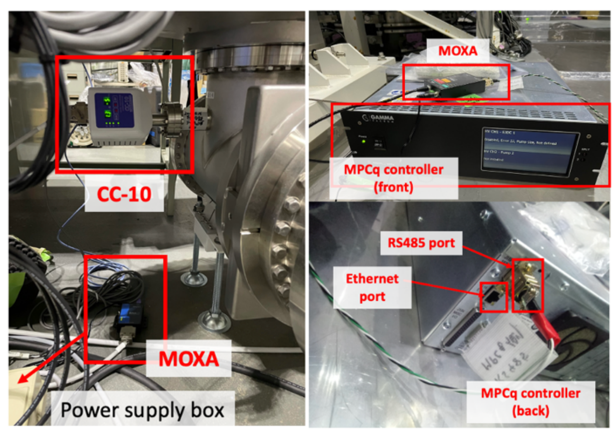

Figure 2: Real implementation of a CC-10 controller, a MOXA server (left), and an ion pump controller (MPCq controller) (right).

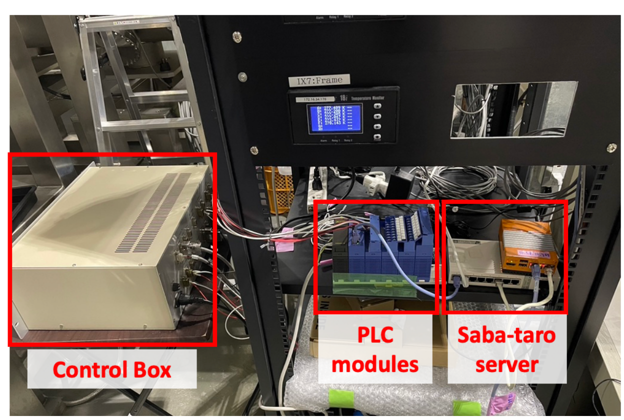

Figure 3: Real implementation of a PLC controller, a micro-server, and a control box in KAGRA.

System Test in KAGRA

In February 2022, the prototype system was installed and tested in the KAGRA tunnel. Firstly, we opened and closed the gate valves. Figure 4 shows the GUI of system, monitoring changes in the gate valves status (Open/Close) and pressure values. Secondly, remote monitoring of pump status (On/Off/Fault of a roots pump and a TMP) was confirmed. The "ON" indications are found in Fig. 4. The remote monitoring of an ion pump (by a MPCq controller) was also confirmed in May 2022.

These results show that the remote monitoring of all the vacuum devices in real time has been achieved successfully.

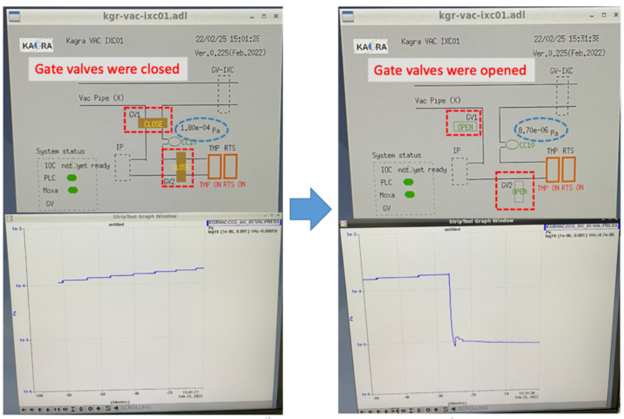

Figure 4: The upper picture shows the GUI of the prototype system. The lower picture shows the pressure change caused by the opening gate valves. The trend graph is by an EPICS tool, StripTool.

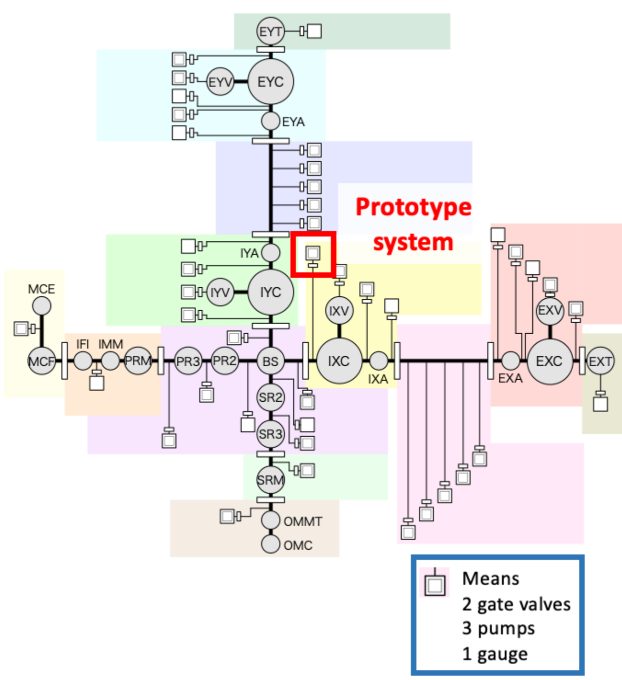

Figure 5: Figure of vacuum system for KAGRA.

FUTURE PLAN

At present, the prototype system realizes the monitoring of 2 gate valves, 3 types of pumps, and 1 gauge. The whole of the vacuum system in KAGRA is shown in Fig. 5. The prototype system covers only one of forty points.

In the fiscal year 2022, we would like to extend the prototype, and install a greater number of monitoring points before the start of "O4".

CONCLUSION

The prototype of KAGRA vacuum monitoring system was developed and demonstrated toward "O4". The prototype system is an EPICS-based system. It consists of a micro-server, a MOXA server, and a PLC controller. In February, 2022, the remote monitoring of 2 valves (Open/Close), 3 types of pumps (Run/Fault/Stop), and 1 gauge (pressure in Torr) have been realized in KAGRA successfully. In the fiscal year 2022, we would like to install a greater number of monitoring points before "O4".

ACKNOWLEDGEMENTS

We express our best thanks to J-PARC MR staff members and company (KIS) members for their encouragement and suggestions during system development.

Special thanks go to Mr. Yoshihiro Sato for cablings of serial lines for ion pumps and gauges.

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