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VACUUM CONTROL SYSTEM FOR THE TAIWAN PHOTON SOURCE

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Abstract

The Taiwan Photon Source (TPS) is a 3 GeV storage ring. A NI C-RIO controller, basic to the real-time, EPICS program, is used and designed such as to maintain ultra-high vacuum conditions and protect vacuum components. Pressure readings from ionization gauges are taken as the logic signal to control sector gate valves to protect ultra-high vacuum condition. Monitoring of vacuum components, water-cooling systems and chamber temperatures serves to protect vacuum equipment from radiation power. The evolution and status of the control system is presented in this paper.

INTRODUCTION

Commissioning for the TPS, a low-emittance 3-GeV synchrotron ring, started in December 2014 and is now currently operated in top-up mode at 400mA for users. During past year's operation, the design goal of 500mA beam current was archived on December 2015. Until the last machine shut down in June 2018, a total beam dose of 3631 Ah was accumulated and the beam cleaning effect decreased to 1.43×10^{-11} Pa/mA. Table 1 lists some operational milestones of the TPS in past years.

Table 1: Milestones for the TPS Currently in Operation

Date	Milestone
2014.12	first beam stored
2015.03	100mA beam current archived
2015.12	500mA design goal archived
2016.09	open to user (300mA)
2016.11	1000 Ah beam dose accumulated
2017.11	400mA operational Beam Current

The TPS storage and booster rings are located in the same tunnel. The storage ring with a circumference of 518.4m, is divided into 24 sections, including 24 bending and 24 straight sections. Each section corresponds to one control instrument area (CIA). Figure 1 shows a schematic 3D drawing of the TPS vacuum system with the storage ring (SR), booster ring (BR) and control-instrument area (CIA). The vacuum component connection cable lengths between tunnel and CIA are 20 to 30 meter long.

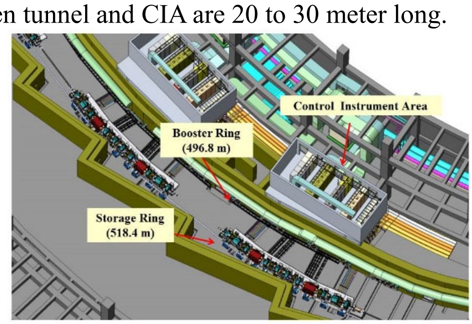

Figure 1: Schematic 3D drawing of the TPS vacuum system.

Figure 2 illustrates the layout for 1/24 of the TPS vacuum system, consisting each of a straight and a bending section with two sector gate valves (SGV), two pumping gate valves (PGV), two front-end valves (FEV), six metal angle valves (MGV), six ionization gauges (IG), ten non-evaporable getter (NEG) pumps, six sputtering ion pumps (IP), and eight turbo-molecular pumps (TMP). The vacuum chambers inside the cell contain two straight ducts S3, S4, and two bending chambers B1, B2; the S1 and S2 ducts are located at both ends of the cell isolated with two SGVs [1].

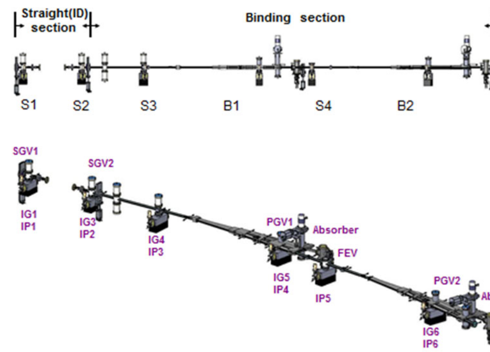

Figure 2: Layout of 1/24 vacuum section.

The mechanism of the vacuum control system is to maintain and protect ultra-high vacuum conditions by controlling and monitoring vacuum components as described above. The safety interlock system is based on the conditions in vacuum components, such as a gauge, ion pump or valve. The following sections describe the design concepts.

VACUUM CONTROL SYSTEM

TPS uses EPICS (Experimental Physics and Industrial Control System) to control and monitor the accelerator machine. EPICS can provide a standard client-server model for a distributed system. In the TPS vacuum control system, a Compact-RIO real-time controller from National Instrument® serves for the vacuum safety interlock, data acquisition and monitoring systems. Between the C-RIO and vacuum system, the interface of I/O communication is used by the I/O connect port of the vacuum controllers , such as vacuum gauges, pumps and meters for cooling water, or directly by the I/O terminals of the vacuum components. The architecture of the control and communications relations is shown in Fig. 3.

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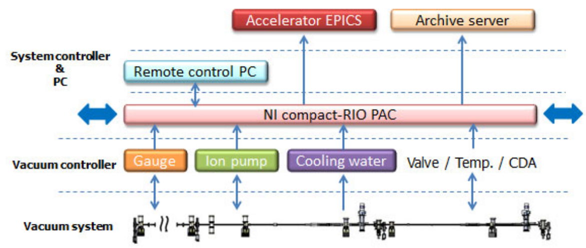

Figure 3: Architecture of the vacuum control and communications system.

Since the vacuum system of the storage ring is divided into 24 sections, with 24 C-RIO controllers distributed into 24 CIA associated with 24 vacuum sections. Each C-RIO collects all signals from one section, including about 48 analogue input signals, 96 digital input signals and 64 digital output signals. Among the analogue signals, the vacuum gauge and pump pressure readings are taken as the basic logic signal for the safety interlock system. The RTD temperature sensor readings serve to monitor the cooling water and vacuum components without special cooling system such as valves, bellows and BPM blocks. Digital input and output signals provide the status , set-point, logic trigger and remote control of the vacuum components [2]. A model of the 9074 C-RIO controller with three analogue input modules, three digital input and two digital output modules installed in CIA is shown in Fig. 4.

Figure 4: A model of the C-RIO controller with modules.

In addition to the storage ring, vacuum signals of the booster ring (BR), the transfer lines between linac and booster ring (LTB) and between booster ring and storage ring (BTS) are connected to adjacent C-RIO controllers, depending on the location, for safety interlock, data acquisition and monitors. Figure 5 shows the number of I/O ports for each vacuum subsystem.

Sub-system	AI		DI	DO
	reading	RTD	status / trigger	control
LTB	3	N/A	22	13
BR	108	N/A	264	192
BTS	6	N/A	32	27
SR	144	360	1152	1008
UTILITY	168	168	480	N/A

Figure 5: I/O ports for the vacuum subsystem.

SAFETY INTERLOCK SYSTEM

The protection of the ultra-high vacuum condition and of vacuum components is the main concern for the safety interlock system. Before the vacuum control system is designed, the properties of the vacuum components must be considered, especially the safety interlock system. Some considerations follow.

(1) Vacuum-gauge protection: In the storage ring of the TPS, an ionization gauge was chosen and taken as the source for a logical signal. During machine operation, the readings of a vacuum gauge may increase to more than 10^{-6} Pa. To avoid vacuum gauges operating in conditions of poor vacuum for an extended period, which would decrease their lifetime, a self-protection mode is set. In this mode, vacuum gauges become automatically switched off when the vacuum pressure increases suddenly to more than 1×10^{-3} Pa, but can be switched on only manually after the pressure recovers.

(2) Ion-pump protection: Similar to the vacuum gauges, ion pumps are switched on only when the local pressure is less than 1×10^{-4} Pa according to the logical output signal of the vacuum gauges. A protection mode of an ion-pump controller is concurrently selected. In this mode, the controller limits the output current and switches off the high voltage when the output current reaches or exceeds a threshold current by more than 0.2 s.

(3) Isolation valve: The mechanism of the safety interlock system is set to control the opening and closing of the sector gate valves (SGV) to isolate a vacuum system with poor pressure. When the pressure increases to more than 1×10^{-4} Pa, which is the trigger output of the vacuum gauges at either end of the valve, the SGV closes to protect the vacuum at the other side. Two properties of the SGV must be considered here: the pressure of compressed air and the closing time. The pressure of compressed air for normal operation is 4~8 bar (4.08~8.16 kg/cm^2). A trigger point of 5 kg/cm^2 for the compressed air is therefore set as the interlock trigger signal for the utility system. The closing interval of the SGV is 4 s, based on sufficient pressure and rate of flow of compressed air to fill the cylinder. To ensure normal operation of the SGVs, independent air piping for each SGV is necessary. If one air pipe supplies more than one SGV, the closing time of the SGVs is delayed, thus affecting the performance of the SGVs.

LOGIC DESIGN

Figure 6 shows the logic diagram of the SGV control mechanism, which complies with the principle of manual on and fail-safety. When the pressure on both sides of an SGV is satisfactory, the SGV can be controlled and switched off automatically as soon as the interlock at either end is triggered. All three gauges are installed between two SGVs. If any two gauges are over the set point or

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malfunctioning, the logic trigger becomes active and the SGVs are then closed. Two front- ends (FE) associated with this vacuum system additionally ensure the completeness of the safety interlock system. Besides, considering the vacuum pressure, the emergency trip for neighbouring valves is added to the interlock system to decrease the risk of a spread of poor vacuum. When any neighbouring valve is out of control or malfunctions, the emergency trip signal becomes active and the SGVs close to prevent the spread of poor vacuum.

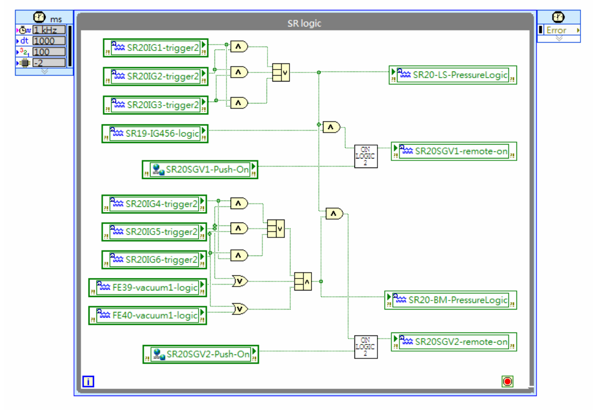

Figure 6: Diagram of the SGV logic control system.

Besides the basic protection of ultra-high vacuum condition, another issue is about vacuum component protection from synchrotron radiation power. The open signal of an SGV and normal status of the cooling water are summed and sent to the machine protection system (MPS) to make sure the vacuum system is ready for machine operation.

During the past years of operation, the interlock logic was optimized. The biggest difference was to avoid a machine trip by a single signal source. Several times during machine operation, false FE vacuum signals caused interrupts from faulty evaluation of signals from FEs and BLs. A vacuum signal in the storage ring adjacent to the FE system was added and a trip signal is given only when these two signals fault simultaneously. The temperature interlock system was also corrected. Countdown and reset functions were added to avoid a trip signal being sent by the signal from a damaged temperature sensor [3].

MONITOR SYSTEM

NI Labview is a system engineering software, which offers a graphical programming approach that visualizes the application. The graphical interface is flexible and easy to use. Web publishing functions in Labview are widely used in the TPS vacuum monitoring system, which transfer Labview front panel pages to web pages easily. Figure 7 displays one example for the monitoring page of the vacuum status, which includes machine operation conditions and insertion devices status acessed from the TPS EPICS IO server and vacuum pressure signal binding from 24 C-RIO controllers. It is easy to be viewed by vacuum group staff on PC or cell phone.

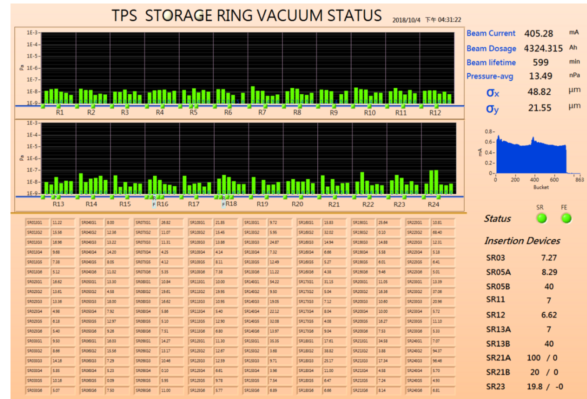

Figure 7: Vacuum monitoring page of the TPS storage ring.

One fake event occurred originating from the Front End (FE) interlock system, which also uses a C-RIO 9074 controller [4]. The reason for the event was not clear, but experience indicates that it was easy occured after long time operation without rebooting or execution of the distributed system manager (DSM) function of Labview. The CRIO 9074 VxWorks OS controllers were replaced to Linux OS versions, since the C-RIO 903X Linux OS controller exhibits a more stable performance, the CPU loading is five times lower than for the 9074 VxWorks.

CONCLUSIONS

The design of the TPS vacuum control system is described above. The vacuum pressure protection function and component protection logics worked well during the past years of operation. All vacuum signals, including vacuum pressure, status of vacuum devices, temperature distribution were displayed on web pages which is easy to monitor. More applications like LINE Notify instant message sending function will be developed in the future.

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