DEVELOPMENT OF THE TPS VACUUM INTERLOCK AND MONITOR SYSTEMS

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Abstract

The vacuum interlock and monitor systems of Taiwan Photon Source are designed to maintain the ultra-high vacuum condition and to protect the vacuum devices. The pressure readings of ionization gauges are taken as the judgment logic to control the opening and closing of sector gate valves so as to protect the ultra-high vacuum condition. Monitors of the water-cooling system and the chamber temperature serve to protect vacuum devices from radiation hazards. The preparation, installation and status of the interlock and monitor systems are presented in this paper.

INTRODUCTION

Taiwan Photon Source (TPS) is a low-emittance 3-GeV synchrotron ring, in Taiwan, with the storage and booster rings in the same tunnel. The storage ring (circumference 518.4 m) is divided into 24 sections, including 24 bending and 24 straight sections [1]. The bending sections, which were prebaked to ultra-high vacuum in a laboratory, have been installed in the TPS tunnel during 2013 October to 2014 March; the straight sections, six of length 12 m and 18 of length 7 m are assembled continually, including injection and diagnostic sections, three PETRA cavities and five insertion devices in vacuum, and will be completed in phase I. Figure 1 shows the layout of the TPS vacuum system with the storage ring (SR), booster ring (BR) and control-instrument area (CIA).

The triangularly shaped vacuum chamber in a bending section was designed for localized pumping [2]. A crotch absorber located downstream intercepts more than 70 % of the synchrotron light from the bending magnet. Pumps near the crotch absorber in the antechamber increase the effective pumping speed and decrease the number of pumping ports on the axis so as to produce a smooth vacuum surface with small impedance. During machine commission, exhaust pumping systems with turbo-molecular pumps will be installed as shown in Figure 2 to increase the pumping performance.

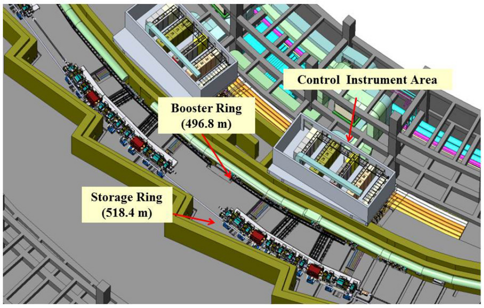

Figure 1: Layout of TPS vacuum system.

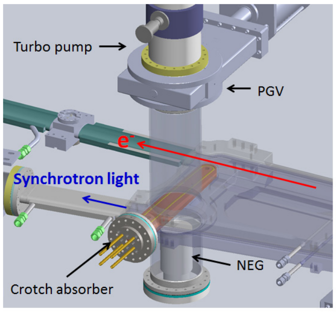

Figure 2: Schematic depiction downstream of the bending chamber with the exhaust pumping system

In the TPS vacuum system, a prototype safety interlock system was designed and tested for vacuum in 2010 [3]. The safety interlock system is based on the characteristics of vacuum devices, such as a gauge, ion pump and 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 programmable automation controller, (PAC, NI Compact-RIO) serves for the vacuum safety interlock, data acquisition and monitor systems. Between the PAC and the 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 meter for cooling water, or directly by the I/O terminals of the vacuum devices. The architecture of the control and communication relations is shown in Figure 3.

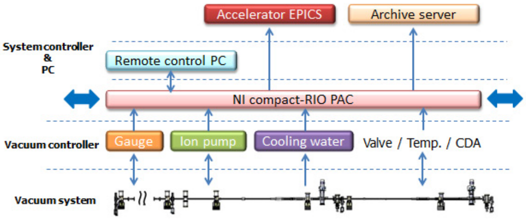

Figure 3: Architecture of the vacuum control and communication system.

As the vacuum system of the storage ring is divided into 24 sections, there are 24 PAC distributed into 24 CIA associated with 24 vacuum sections. Each PAC is in charge of all signals from one section, including 48

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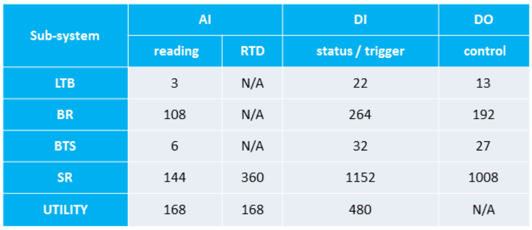
analogue input signals, 96 digital input signals and 64 digital output signals, roughly. In the analogue signals, the pressure readings of the vacuum gauge and pump are taken as the basic logic judgement of the safety interlock system; the readings of the RTD temperature sensor serve to monitor the cooling water and vacuum devices with no cooling system such as valves, bellows and BPM blocks. Digital input and output signals provide a status display, set-point, logic trigger and remote control of the vacuum devices. Besides the storage ring, vacuum signals of the booster ring, the transfer line from the linac to the booster ring (LTB, linac to booster ring) and the transfer line from the booster ring to the storage ring (BTS, booster to storage ring) are connected to adjacent PAC, depending on the location, for safety interlock and monitors. Figure 4 shows the I/O number of 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 4: I/O number of the vacuum subsystem.

PROPERTIES OF VACUUM DEVICES

Before the vacuum control system is designed, the properties of the vacuum devices must be considered, especially for the safety interlock system. Some considerations follow.

(1) Vacuum-gauge protection. In the storage ring of TPS, an ionization gauge was chosen and taken as the logic judgment. During the machine commission, 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 that would decrease their lifetime, a self-protection mode is set. In this mode, vacuum gauges become switched off automatically when the vacuum pressure increases suddenly to more than 1×10^{-3} Pa, but are switched on only manually when the pressure decreases.

(2) Ion-pump protection. According to a similar mechanism of the vacuum gauge, the ion pump becomes switched on only when the local pressure is less than 1×10^{-4} Pa according to the logic output of the vacuum gauges. A protection mode of an ion-pump controller was concurrently selected; in this mode, the controller limits the output current and switches off the high voltage when the output current attains a threshold current for 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 of the trigger output of vacuum gauges at either end of the valve, the SGV closes to protect the vacuum at the other end. Two properties of 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 5 kg/cm^2 of compressed air is hence set as the interlock trigger judgement of the utility system. The closing interval of the SGV is 4 s, based on a sufficient pressure and rate of flow of compressed air to fill the cylinder. To ensure the normal operation of SGV, independent air piping for each SGV is necessary. If one air pipe supplies more than one SGV, the closing time of SGV becomes delayed, then affects the performance of the SGV.

(4) Exhaust pumping system. During the machine commission, the exhaust pumping system, with a turbo-molecular pump, fore-line pump unit and an uninterruptable power supply (UPS), is designed to be installed downstream of the bending chamber to evacuate the gas load from the crotch absorbers irradiated with synchrotron light. For the safety interlock issue, the pumping gate valve (PGV) was designed to be installed before the turbo-molecular pump shown in Figure 2; all signals of the pumping system were used for the self-protection system. When a failure message of the pumping system occurs, the PGV becomes closed immediately to avoid a pressure backstream from the pumping system. The diaphragm type of fore-line pumping unit is chosen because of the smaller rate of increase of pressure when its power is interrupted. Figure 5 shows one inspection graph in which the signal of pressure of the pumping unit of the diaphragm fore-line increases when power is interrupted at *t*=0. The pressure is less than 1×10^{-3} torr until 180 s. This mechanism not only protects the turbo-molecular pump by preventing inrushing air at a great speed of rotation, but also provides a buffer period for the closing of the PGV.

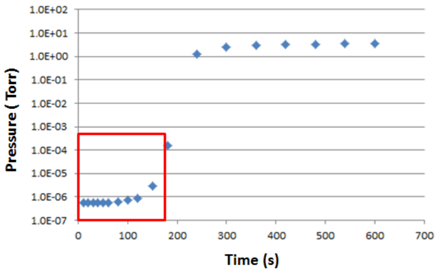


Figure 5: Pressure curves of the diaphragm fore-line unit pump when power is interrupted at *t*=0.

LOGIC DESIGN

The protection of the vacuum and the vacuum devices is the main issue of the safety interlock system. Figure 6 shows the logic diagram of one SGV control system, which complies with the principle of manual on and fail-safety. When the pressure on both sides of the 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 SGV. If any two gauges are over the setting or malfunctioning, the logic trigger outputs; SGV are then closed. Two front-end (FE) vacuum systems associated with this vacuum system additionally ensure the completeness of the safety interlock system. Besides the consideration of pressure in the vacuum system, the emergency trip of 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 triggered; the SGV then becomes closed to prevent the spread of the poor vacuum in advance.

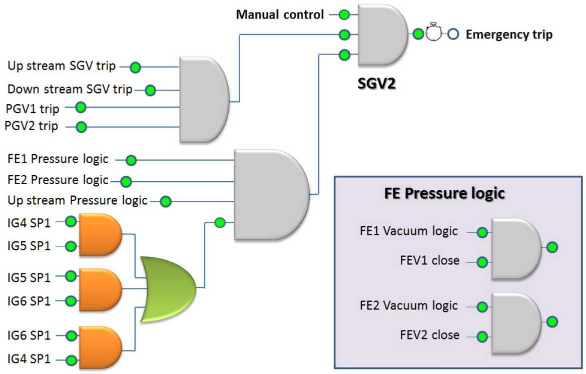


Figure 6: Diagram of the SGV logic control system.

As the exhaust pumping system is installed, the logic control system for PGV is designed and shown in Figure 7. The mechanism for the time delay serves to provide a buffer period for the judgement of the UPS signals to avoid a transient blackout or a sudden fluctuation of the line power system. The emergency trip of a PGV is interlocked with the neighbouring vacuum system to prevent the spread of a poor vacuum from the backsteam of the exhaust pumping system.

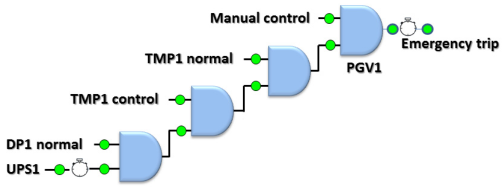


Figure 7: Logic control system of the exhaust pumping system.

For the protection of vacuum devices, the protection of a front-end valve (FEV) and a monitor of the water-cooling system are included. Of 48 beam lines in TPS, only seven are ready in phase I. The FEV is the isolation interface between the storage ring and the FE vacuum system. A photon stopper with a cooling channel is designed and installed upstream of the FEV to avoid the FEV becoming irradiated directly with synchrotron light. The logic-control system including a photon stopper, flow rate of cooling water and a FEV is shown in Figure 8. The opening status of the FEV is a key factor to control the photon stopper. When a FEV is in an open status, a photon absorber can be opened to allow synchrotron light to pass. If a FEV is not in an open status, the opening of the FEV is inhibited. The vacuum status behind the FEV requires also an interlock to prevent erroneous human operation, especially when only seven FE are ready in phase I. Flow rate 12 L/min of cooling water is designed for the photon stopper to remove the heat load from the synchrotron light, and set-point output 3L/min is set for the interlock system.

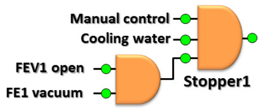


Figure 8: Logic control system of the photon stopper.

Apart from the above vacuum system and vacuum devices, other devices are also of concern, such as the cooling system of the crotch absorber, the system to monitor the temperature of the vacuum chamber, etc. The mechanism of a countdown or a beam trip for the safety interlock system will be used to ensure the normal operation of the entire vacuum system.

CONCLUSIONS

The design concept of the TPS vacuum interlock system is described above. The assembly of the vacuum system will be completed in the next several months. All vacuum-related systems including vacuum devices, utility system, signal transmission, interface communication and the safety interlock system are tested and optimized continually so that normal operation is expected and working well during machine commission.

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