DESIGN AND UPGRADE OF THE SAFETY SYSTEM FOR THE SRF ELECTRONIC SYSTEM AT TAIWAN PHOTON SOURCE

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Abstract

This paper presents some new designs and upgrades of an SRF interlock and electronic system. Based on the experience from Taiwan Light Source (TLS) that uses one Cornell-type superconducting cavity made by ACCEL in the storage-ring RF system [1], in the new TPS SRF system [2] home-made LLRF and SRF electronics [3] are constructed for two KEKB-type superconducting cavities [4] that are installed in the storage ring of circumference 518 m. For reliable operation of the TPS SRF system, enhanced safety functions of the system were added to improve the original SRF system in TLS. The improved functions can provide both the operators and the RF systems with a safer environment and clearer messages for trouble-shooting and malfunction status indications.

INTRODUCTION

Two room-temperature Petra cavities were installed in the TPS storage ring by 2014 March 30. They attained the goal of stored beam current 100 mA as the first stage of machine commissioning. The reason for installing room-temperature Petra cavities was that the cryogenic system required by an SRF module was still under construction, and much outgassing from a beam chamber during initial vacuum cleaning with a small beam-current is unfavourable for an SRF module (the cryogenic pumping effect). The room-temperature Petra cavities were thus preferable at the initial stage of commissioning of the TPS storage ring.

The heat-loss test of the cryogenic system was then performed in the second stage. For acceptance of the cryogenic system (approximately 2014 April or May), two test dummy vessels in a loading area and the storage ring were installed. A spare cavity S0 (Cornell type) and a 500-L test dewar were used to store liquid helium for the cryogenic acceptance tests. At the same time, the electronic system was greatly modified for integration with the forthcoming SRF system installation. This arrangement helped the SRF system to operate fluently when both cryogenic and SRF systems were ready.

Third, after horizontal tests including CPL aging and a high-voltage test for the cavities of two sets in the SRF system, the preliminary system design goal, 500 mA, was attained with the advanced beam processing (vacuum cleaning) of the couplers of SRF modules.

Based on past experience with SRF modules in TLS, and manufacturing and acceptance tests at KEKB and MHI, much valuable experience and many test results were obtained in the NSRRC RF laboratory, but the environment on site differs from that in the laboratory; especially, two SRF systems are operated simultaneously. To fulfil the requirement of attaining 500 mA smoothly and safely, many essential functions, safety interlocks and operating sequences were thus added, described below.

ACCEPTANCE TEST ON A DUMMY LOAD FOR THE CRYOGENIC SYSTEM

Dummy Load Test

An SRF system requires supplies of liquid helium and nitrogen from a cryogenic system, but the cryogenic system could not ensure a sufficient supply of helium and nitrogen for the routine daily operation of SRF during the construction period (commissioning expected to end in 2015 March). Two testing dummy modules were thus used to perform the acceptance test.

The test on the cooling ability over the cryogenic pipes was performed first and was successful. After tests of leakage and heat loss of the cryogenic pipes, two dummy test loads were added with the originally installed valve box and the control system for formal commissioning of the cryogenic system.

The 500-L test dewar and the S0 SRF module, located inside the tunnel of the TPS storage ring and the loading area, respectively, served as dummy test loads for the cryogenic system, as shown in Fig. 1.

As the interfaces of this task differ from the KEK SRF modules, an additional electronic system was made and connected to an electronic rack to perform the test. After cooling of the dummy loads to 4.5 K with an appropriate level of helium, the cryogenic system was successfully commissioned with its specifications satisfying the heat loss on pipes and the cooling ability. The third stage of commissioning of the SRF system was thus initiated.

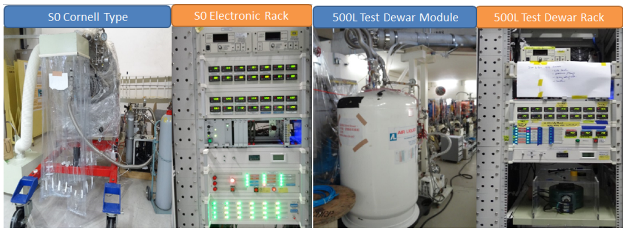

Figure 1: Test loads and home-made controller system.

Assembly of Safety Protection Components for the SRF Cryostat

The spring-relief valve and other protecting mechanisms that were installed can be activated if the stored liquid level or vessel pressure or temperature has reached its limit continuously over three minutes.

Difference between the Cryogenic Commissioned System and the Formal SRF Operating System

The 500-L test dewar provides no electronic liquid-level signal. Test probes were required; cryogenic sensor modules, PTCO, were mounted at various heights to measure the liquid level in the liquid-helium tank.

The hardware of S0 was the SRF module of Cornell design; the CLTS served as the cryogenic sensors.

The installation of the SRF electronic system was executed from 2015 April to July; several new functions were added, such as corrections to thermal temperature, modifications of the data-logging database and updates to the LLRF system. Although the electronic system could provide considerable protection, some improvements were still made, especially for personnel safety, such as X-radiation, cryogenic risk and SRF electronic fault detections. These are the main improved tasks for reliable and safe operation of the system.

INTEGRATION AND UPGRADE FOR THE SAFETY INTERLOCK

Safety Protection for Liquid Helium

On 2015 Aug 24, an incident occurred involving the leakage of liquid helium at a coupler tower on SRF module No.2. An abnormal event of this kind happened for the first time in NSRRC since the commissioning of SRF modules in the laboratory and on site. According to the historical records, KEKB would close the valve of LHe at a coupler tower manually during a long shutdown. If the supply of LHe continued when there was no RF power on the coupler, the remaining cold gaseous helium flowing through the HEX line would decrease the temperature and shrink the rubber O-ring within the coupler tower. A shrunken O-ring cannot retain effective sealing at the coupler tower between the LHe vessel and outside; the cold helium gas would then leak through this point and finally cause ice freezing and continuous leakage of gaseous helium, as shown in Fig. 2.

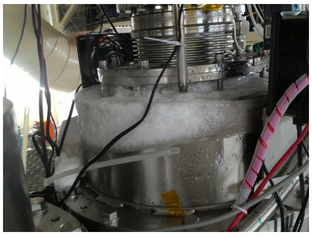

Figure 2: Ice-frozen status at the coupler of KEKB-SRF module No. 2 during leakage of cold helium.

Modifications after the Incident

After the SRF module warmed to room temperature (300 K), the helium leakage was tested. All M12 bolts around the coupler tower were refastened from 15 N m to 16 N m. If the rubber O-ring was frozen to become broken, a refastening of the bolts would not stop the helium leak. We were fortunate that the helium leakge terminated after refastening and recooling the SRF module.

To avoid a recurrence of such an accident, a PLC controller is used with a well programmed secure procedure to prevent the coupler temperature from being too low when the RF is switched off. A new rapidly responding bypass mechanism was built to adjust the LHe pressure during a long maintenance period. This function is not controlled with the PLC and can be operated only manually by authorized personnel from the cryogenic group to ensure that the system can recover to its normal status after releasing this function. The state of the machine flow to prevent a helium leak at a coupler tower is shown in Fig. 3.

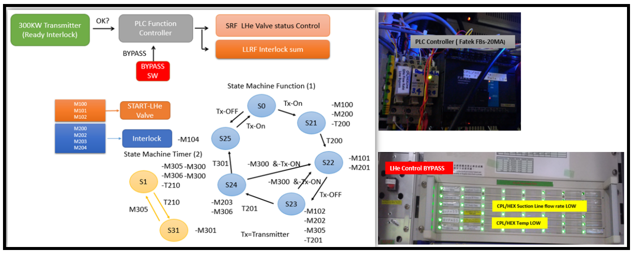

Figure 3: PLC Protection states to prevent helium leakage.

Detailed PLC Operating Sequence

(1) The RF transmitter (300 kW) turns on with valve (GHe) opening and simultaneous interlock. After 5 min, the interlock is released.

(2) If the RF transmitter is shut down from an ON status; the valve would remain open for 5 min.

(3) If the RF transmitter recovers within 10 min, the valve can be opened without pre-flow of helium gas for 5 min (ignore step (1)).

(4) The rate of gaseous He flowing through the coupler can be tested or calibrated on switching to the 'bypass' valve. This bypass is not controlled with the PLC or interlock of the transmitter, and can be operated manually. The default rate of flow of gaseous helium is 8 SLPM.

(5) The interlock sum of the HEX line temperature the low (cold gas outlet line at the coupler) gas flow controller is set on the LLRF interlock sum. During a long shutdown, the interlock sum has a latch status and would not trigger an alarm call.

ACCESSORY VACUUM MONITORING SYSTEM

As a superconducting cavity must be operated under ultra-high vacuum, the pressure of the vacuum chamber next to the SRF module is important. To prevent vacuum pollution to the SRF cavity, there are rapidly responding interlock-sum (using comparators, clk-1 ns 5 ns), slowly responding interlock-sum (using a relay, 100 ms) and dual-level PLC protection logics for a vacuum monitor. The logic diagram is described as follows.

The pressure of the cavity is read from an SRF electronic rack. Both rapid and slow interlock modules would activate a protection mechanism to turn off the RF power to the SRF cavity immediately if a vacuum incident occurs. Moreover, a gate valve is controlled with a PLC module; as the gate vales are pneumatic type, a relay-type controller can be used because of its slow response, as shown in Fig. 4 and 5.

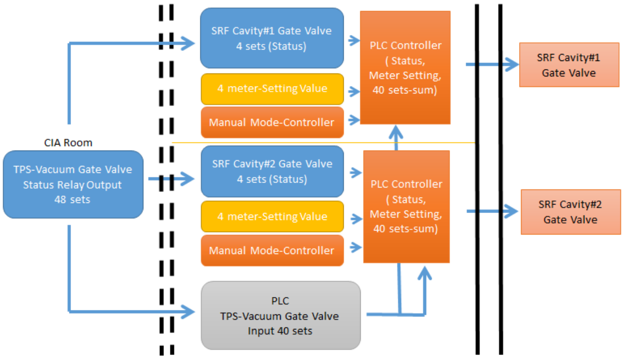

Figure 4: Vacuum status monitor and gate-valve control-system diagram.

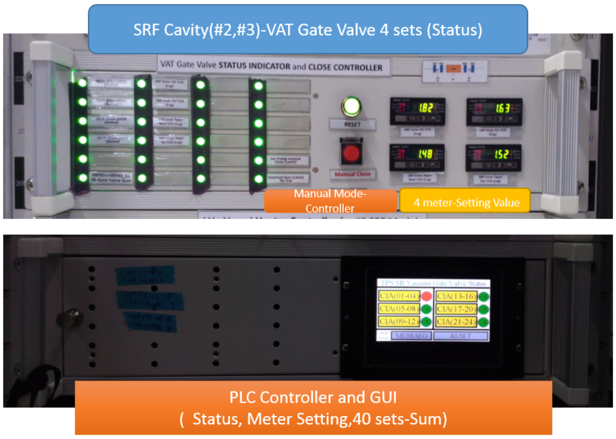

Figure 5: SRF VAT gate-valve controller and vacuum interlock module.

Control of the Gate Valve

1. To control the gate valve, besides a logic judgment output from the vacuum group that is shown in the first level of the PLC module, the RF group has threshold settings for the pressure in the vacuum system.
2. The pressure threshold at the RF group has rapid and slow outputs; the slow-type relay outputs are applied for the SRF front-end gate valves.
3. Depending on the particular situation, an operator can switch to a manual mode to close the gate valves. Switching to a manual mode should follow particular procedures to avoid human negligence; this condition can also prevent a malfunction of switches. The procedure is shown in Fig. 6.
4. If more than three vacuum gauges of the total storage ring attain their upper threshold limits, the gate valves of SRF modules would close automatically.
5. Beside the setup of PLC, a GUI MMI (man-machine interface) is set to monitor all vacuum status in the storage ring. There are 48 vacuum gauges in the TPS SR; a relay output accompanies each vacuum gauge. Because of the numerous vacuum gauges, a GUI must record the time of all events arising and the trouble-shooting time simultaneously. It must also display the appropriate current status.

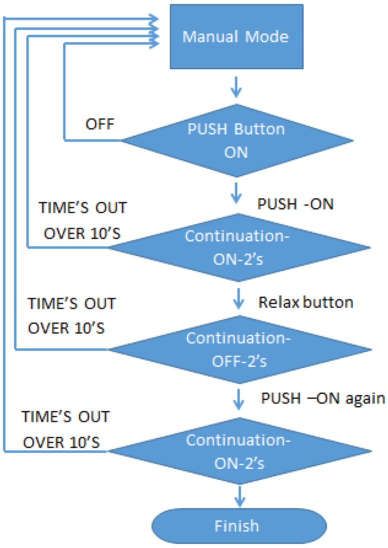

Figure 6: Flow diagram for the state of the machine to switch to the manual operation module.

SUMMARY

Several important improvements were made after the installation of KEKB SRF modules and their operation including high-power commissioning of the SRF modules and storage ring. The electronic system was improved with several functions, mainly in security. This paper provides several brief descriptions for these added functions, such as control of the helium flow for the coupler tower and pressure monitoring. Future work could be with PID diode modules, to measure the X-radiation of the SRF cavity. Finding appropriate issues that might affect the system operation and deducing applicable solutions can help us to improve the understanding and operation of our SRF system.

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