CONTROL SYSTEM OF THE SUPERCONDUCTING INSERTION DEVICE AT TLS

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Abstract

Taiwan Light Source has three superconducting insertion devices. Two more are under construction. These insertions enhance hard X-ray production to satisfy the research requirements of the X-ray community. The control system is implemented to support the operation of all these superconducting insertion devices. The control system coordinates the operation of the main power supply and the trimming power supply to charge/discharge the magnets and provide essential interlock protection for the coils and vacuum ducts. A friendly user interface supports routine operation. Various applications are also developed to aid the operation of these insertion devices. This report summarizes design considerations and the details of the implementation.

INTRODUCTION

Superconducting insertion devices are important in the 1.5 GeV Taiwan Light Source (TLS). Three superconducting insertion devices [1, 2] have been installed and the other two will be installed in the future to enhance hard X-ray production to support diffraction, scattering, spectroscopy, EXAFS, imaging, and protein crystallography. The three installed superconducting IDs are SWLS, SW6 and IASW6-R6. The other two IDs, IASW6-R2 and IASW6-R4 will be installed next year. The control system of these superconducting insertion devices is designed, implemented and commissioned to support the operation of these devices. The control system is based on the VME crate system as a standard configuration. The interlock logic is implemented using a programmable logic controller (PLC) to protect the coils of the magnet. The user interface and various application programs enable routine operation.

HARDWARE STRUCTURE FOR SUPERCONDUCTING INSERTION DEVICES CONTROL

The control system adopts a standard VME crate to accommodate various control modules. The crate includes a PowerPC-based CPU module, which runs a LynxOS real-time operating system as a local controller of the superconducting IDs control system. The crate includes analog input/output modules, digital input/output modules and the RS-232 interface module. The control system of superconducting IDs depends on the coordination of the operation of power supplies, cryogenic instruments and interlock protection logic. Figure 1 illustrates the infrastructure of the superconducting IDs control system. The control system integrates superconducting system to ensure conventional and reliable operation. Control consoles communicate with the VME host module through the control Ethernet network. A precision bipolar main power supply is used to charge/discharge the magnet. The main power supply charges all coils in series and the two trimming power supplies are connected to the two end pole coils respectively. The trimming power supplies are used to correct the dipole field error. During the charging of a main power supply, a slow slew rate is used in the beginning because the inductance is high at low field. A high slew rate can be obtained after the field saturates the internal ion core, and the inductance is then considerably reduced. The slew rate is controlled automatically by the control system. The trimming power supply can be set to be independent of or consistent with a predefined table, to follow the output of the main power supply. The purpose is to nullify the first and second field integrals. Two correctors are added upstream and downstream of all of the installed superconducting IDs. The control system coordinates the outputs of the corrector power supplies to compensate for distortion of the beam orbit.

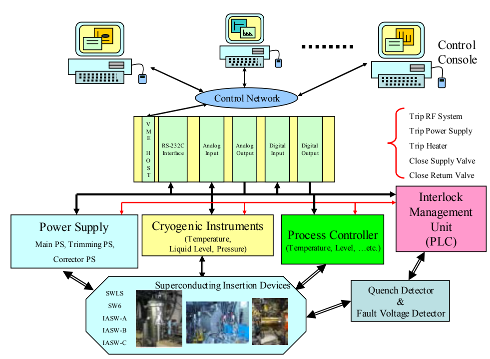

Figure 1: The control system infrastructure of the superconducting insertion devices.

The cryogenic instruments monitor the parameters of the SWLS, SW6 and IASW-R6 during routine operation. The coil of the superconducting IDs is cooled by submergence in liquid helium (LHe). Hence, the LHe level and the He pressure in the vessel must be maintained in safe ranges. The instruments include a temperature monitor, level meters for LHe and liquid nitrogen (LN_2), pressure meters for He and N_2 and a vacuum gauge. Figure 2 shows the control system of the SW6 in the equipment area of the NSRRC. The control system monitors these data and presents the operational situation of these superconducting IDs. The high

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temperature, low level and high pressure limits can be set using these instruments. The pressure and the liquid level of the superconducting IDs control are also sent to the automatic filling system [3]. The auto-filling system automatically maintains the liquid level within the safe range.

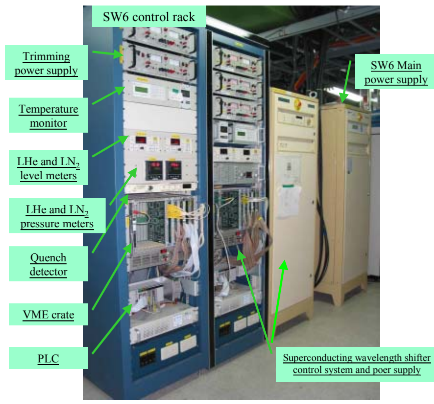
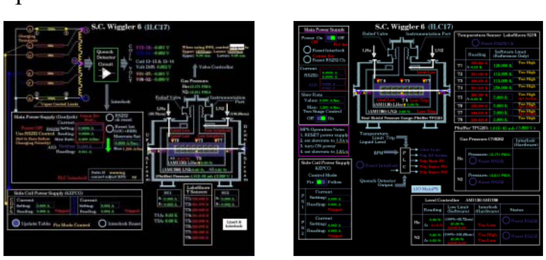


Figure 2: The control system of the SW6.

SOFTWARE ENVIRONMENT

The control system provides various application programs for the routine operation of all superconducting IDs, which involves the on/off control of the power supplies and the charge/discharge control of the magnet. The control system also provides software protection for the magnet. The power supply cannot be enabled until the temperature of the magnet, the levels of LHe and LN_2 and the pressures of He and N_2 are in safe ranges. These are stored in the database. The control system supports two types of archiver. A long-term data archive records data every 10 sec. Another fast 0.1 sec archiver with a 1-week lifetime is also available. The archiver records provide much useful information that can be used to improve the operation of superconducting IDs. The user interface provides two pages for all superconducting IDs to support normal operation. In the SW6 case, operator can use the first page to monitor the status of the SW6 and set the output current and slew rate of the main power supply, as shown in Fig. 3 (a). The second page presents interlock information and the alarm limits the temperature, the levels of LHe and LN_2 and the pressures of He and N_2, as shown in Fig. 3 (b). The operator can reset the interlock status and set the alarm limit by software protection on this page. The user interface presents real-time information about the magnet and provides a convenient manipulation environment.



(a) Operation page (b) Maintenance page

Figure 3. SW6 user interface for routine operation and user interface for interlock information.

QUENCH PROTECTION

The quench detector and interlock logic are developed for all superconducting IDs to protect the coil form damage. The first layer of the hardware protection circuit consists of R620 diodes and 6 mΩ stainless steel resistors. This parallel circuitry protects the coils form overheating during quenching. The circuit is connected to the coils of the magnet in parallel. The voltage across the coils increases rapidly when a quench occurs. The quenched coil voltage is limited by the conducting diode. The resistors in series with the diodes help to dissipate the energy stored in the coils. The diodes provide a bypass route for the coil current. However, this scheme is only for short-term protection; the main power supply must be disabled after a quenching event. The power supply trip is triggered by the quench detector with a response time of under 10 msec. Figure 4 shows the block diagram of quench protection and the quench detector circuit. A bridge circuit is used to detect quench events. An imbalance voltage in the bridge circuit indicates the occurrence of a quench event. An imbalance between the voltages of the coil arm and the resistor arm cause the signal of the quench detector to trigger the protection logic in PLC. Since the quench detector for the first several superconducting insertion devices have different mechanical form factors, a newly designed quench detector with a VME form factor, as shown in Fig. 4, is expected to replace all of these detectors. The interlock logic is designed to protect the coils of the magnet. It is integrated in a fast scan PLC. The PLC manages the alarm signal from the cryogenic instruments, which measure the temperature, the LHe and LN_2 levels and the pressures of He and N_2 in the vessel. The quench detector and the voltage tap monitor are also treated as hardware interlock signals. When the temperature is too high or the quench detector is triggered, the protective action is to shutdown the power supply, preventing excess heat from increasing the temperature, and dissipating LHe. The level meters and pressure meters are connected to the process controller of the valve box for an auto-fill system. The auto-fill system fills the vessel with LHe and LN_2 to maintain them at a constant level [3]. If the pressure of He or N_2 exceeds the upper limit of the safety range, the PLC will immediately shutdown the power supply. The action of the PLC can make all decisions within 5 msec. The relief valve of the vessel is released when the pressure of He and N_2 vapour exceeds its rated value. The reliability of the quench detector is important. The coils of the magnet are soaked in LHe, so the variation in temperature of the magnet caused by quenching is very small. The transient of the main power supply is large during turn-on and turn-off, and a surge, as a fault alarm signal, triggers the quench detector, shutdown the power supply. The interlock logic applies a 10 sec delay to disable this shutting down.

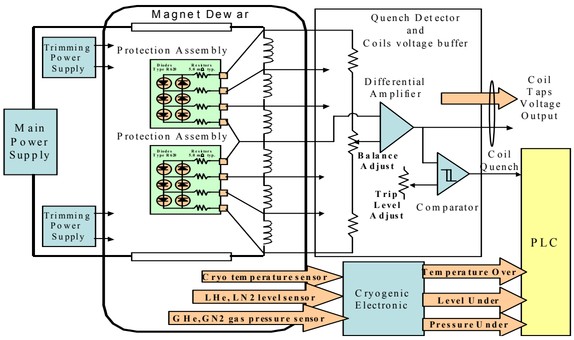


Figure 4: The superconducting insertion devices protection environment.

Figure 5: New quench detector prototype.

OPERATION STATUS

The rate of charging and discharge of the superconducting insertion devices is limited by the circuit time constant. Figure 6 plots the output current of the main power supply during the charge/discharge of the SW6 superconducting wiggler. Ramping the output current from 0 A to 291.5 A takes around 8 minutes and reducing it from 291.5 A to 0 A takes around 4 minutes. The lower slew rate at the beginning of charging is intended to test the main power supply. The output of the trimming power supplies nullifies the field integral. The control system also coordinates the upstream and downstream correctors to compensate for the distortion of the beam orbit. Figure 7 shows the typical liquid helium level and pressure. The pressure is slightly increased during the filling with liquid helium. Variation of coil voltage, the vapour pressure and the temperature is shown in Fig. 8 when the main power supply is suddenly turned off. The pressure and temperature rise slightly and then return to their normal values within 200 sec.

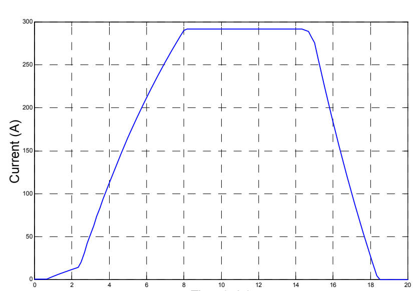


Figure 6: A charge/discharge current history of the SW6 superconducting wiggler.

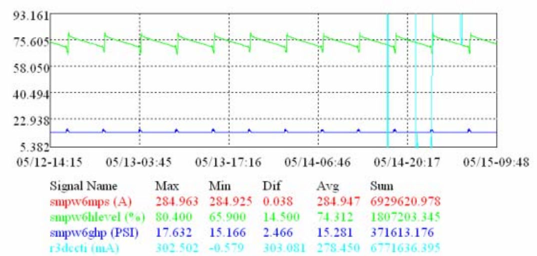


Figure 7: Typical liquid Helium level and pressure of Helium vapor.

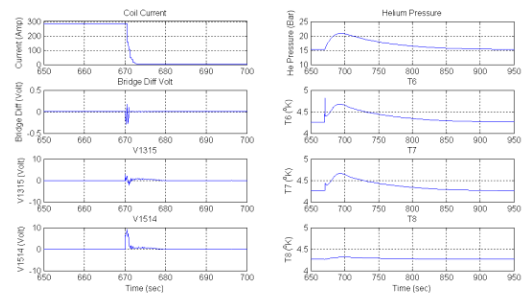


Figure 8: Coils voltage, pressure of He vapor, and temperature variation when power supply sudden turn off.

SUMMARY

The control system is implemented to support routine operation and provide interlock protection to the three installed superconducting IDs. The infrastructure is the same for all IDs. The other two superconducting IDs will be constructed with the same architecture. Some unknown trip event of the superconducting insertion devices during operation accompany beam trip and/or superconducting RF system trip are still unclear. A diagnostic system that can elucidate the reason for a trip will be established and a useful solution is being sought. Better diagnostics of an superconducting IDs trip event are essential to obtaining detailed information, and improve system reliability. Based upon the accumulated over the last several years, the control system of the superconducting IDs will continue to be improved to ensure its stable operation and reliability.

REFERENCES

[1] C. S. Hwang, et al., “Construction and Performance of Superconducting Magnets for Synchrotron Radiation”, Proc. of PAC 2005, Knoxville, TN, USA, May 2005, p. 2218.

[2] C. S. Hwang, et al., “Superconducting wiggler with semi-cold beam duct at Taiwan Light Source”, Nucl. Instr. and Meth. A 556, (2006) 607-615.

[3] F. Y. Lin, et al., “Auto-filling Cryogenic System for Superconducting Wiggler”, Proc. of EPAC 2004, Lucerne, Switzerland, June 2004, p. 1726.