DATA ACQUISITION AND FAULT DIAGNOSTIC SYSTEM OF SAMSUNG SUPERCONDUCTOR TEST FACILITY

Y. Chu, H. Yonekawa, S. Baek, Y. K. Oh, S. Lee, W. Chung, K. Park, B. Lim, H. Park, K. Kim
Korea Basic Science Institute, Daejeon, Korea
S. Lee, FREECOM SYSTEM LTD., Seoul, Korea

Abstract

Samsung Superconductor Test Facility (SSTF) has been constructed and operated in order to fulfil the test requirement of KSTAR (Korea Superconducting Tokamak Advanced Research) superconducting magnet system. The current status of the data acquisition & control (DAC) system of SSTF was briefly described in this paper. The system for detecting unexpected fault conditions is the key device to guarantee the stable magnet system operation. In order to detect unexpected faults accurately in noisy environment, a analog quench detection system was installed and tested for the prototype TF (Toroidal Field) magnet test, and also a system for digitally detecting superconducting quenches in real time has been under development for the subsequent tests. The digital signal processing algorithms such as inductance estimation, Wavelet transformation, and so on, has been under development for the future use to detect quenches in severe noisy environment.

In this paper, the brief description and the hardware configuration of fault diagnostic system, its processing algorithm, and the future plan are described.

INTRODUCTION

KSTAR device uses a fully superconducting magnet system, which enables an advanced quasi-steady-state operation. The major radius of the tokamak is 1.8 m and the minor radius is 0.5 m with the elongation of 2. The superconducting magnet system consists of 16 TF coils and 14 PF (Poloidal Field) coils. Both of the TF and PF coil systems use internally cooled superconductors, which enables a long-pulse operation over 20-second [1].

TF coil system provides the toroidal field of 3.5 T at the plasma centre. All 16 coils are connected in series and the nominal current is 35.2 kA. Each of TF coils has 56 turns, arranged in 8 layers of 7 turns, without any internal joints along the entire length of the conductor. The PF coil system provides a pulse-mode operation of 17 V-sec and sustains the plasma current of 2 MA for 20 seconds.

In order to confirm the TF coil performance, a full size prototype TF coil has been fabricated and tested at the superconductor test facility in KBSI during Aug. 2003. The major objectives of this test were to validate the engineering issues in the coil design and fabrication and to measure the TF coil performance [3].

The background magnetic field coil system is designed and fabricated to confirm the PF coil performance and test CICC (Cable-In-Conduit Conductor) under the fast varying magnetic field. It can provide a changing magnetic field of a 3 T/second for 5 seconds and a 20 T/second for 0.05 seconds. It is comprised of main coil, blip coil, and passive cancellation coil. Main coils (MC) with inner diameter 740 mm providing background field up to 8T in the 250mm gap between two MC halves. These two halves of MC are almost full scale models of KSTAR central solenoid (CS) sections. They are made from the same CICC planed to be used for CS and should have the field ramp up rate up to 3 T/s. Blip coils (BC) placed inside MC also consist of two halves with the same gap between them as that of MC halves. These coils provide the operating space 250 mm x 400 mm (in diameter) with the additional field +/- 1T directed along the main MC field axis at the ramp rate up to 20 T/s to simulate the disturbances from KSTAR superconducting magnets during plasma initiation and disruption. Passive cancellation coils (PCC) displaced co-axially between MC and BC reduce the disturbances onto MC during fast BC discharge, such as stray field variation and high voltage induction [4].

According to the type of experiment performed, the data acquisition system was run in two different modes, a high-speed data measurement and a low-speed data monitoring. The low-speed monitoring system is used to control slow-varying parameters such as Helium flow rate, temperature, and pressure, etc. However, the diagnostic system for detecting unexpected fault conditions such as quench, ground fault, and so on, requires a high-speed data acquisition and control [2].

The quench detection system is the key device to guarantee the stable magnet system operation. In order to detect quench accurately in noisy environment, a traditional quench detection method by using analog circuit, and a novel quench detection methods by using digital signal processor were developed or under development.

DAC SYSTEM

SSTF DAC involves the acquisition and storage of all critical magnet operating parameters, operation of cryogenic cooling system, and initiation of the proper sequence to protect the magnets if the limits are exceeds. The functions of SSTF DAC for magnet test are divided as follows.

- To operate the cooling valves for controlling He flow rate.
- To detect quench and activate proper sequence to protect the magnet.
- To monitor the status of magnet, supporting structure, superconducting current bus and current leads during cool-down period.

SSTF DAC is comprised of the following sub-systems.

- Sensors: voltage taps in the coils, temperature sensors, pressure transducers, and flow meters in the cooling lines, strain gauge on the supporting structure, vacuum gauges, residual gas analyser, and magnetic field sensors at various locations.
- Sensor Interface: wiring & cables, signal conditioners, and voltage isolation system.
- Data acquisition system
- Quench detection system
- Interface to other systems: Cryogenic facility and Power supply

Sensor

Temperature sensors were installed at the helium cooling lines in the cryostat, supporting structure, current feeding system including electrical joints, and thermal shield. At present, four types of sensor, which are Platinum resistance thermometer, Cernox^{TM}, TVO and GaAlAs sensors, respectively, are being used. Analog input modules without any intermediate signal conditioners, directly read platinum thermometers that measure the thermal shield temperature. All of Cernox^{TM} and GaAlAs sensors are powered by its own excitation current source of 10 μA. Pressure transducers were installed at the helium-cooling inlets and outlets in the cryostat. The pressure transducer is a commercial type that uses strain gages bonded to a flexible stainless-steel diaphragm in an entirely welded cavity and housing. Absolute pressures up to 150 psia are measured. Helium flows of the helium inlets and outlets were monitored by orifices installed in each line. A differential pressure transducer measured the pressure drop across the orifice. A differential pressure transducer is powered by 12~48 VDC. A differential pressure drop is read via 4~20mA current-loops. Strain gauges were used to measure the response of the supporting structure to cool-down phase and to current charging/discharging. Actual locations were determined from structural analysis. The strain measurement was used to check the accuracy of stress analysis, and to determine peak stress levels in the magnet supporting structures. Standard vacuum and residual gas analyser monitors are commercially available. Hall probes were installed at various locations to measure the magnetic field during testing. Voltage taps are also installed to measure magnet voltage and to detect quench.

Data Acquisition System

Figure 1 shows the schematic used for the prototype TF coil test. The layout will be changed a bit according to the test requirement.

Data acquisition system consists of functionally separated components that are local device, I/O controller (IOC), Channel Access (CA) server, Archivers and OPI (Operator Interface). Each component processes simple specific task.

The local device consists of isolation amplifier, A/D converter and sensor specific device. In-house developed isolation amplifier and A/D converter of VMIC VMIVME 3122 housed in a VME crate are used for sensors such as voltage taps, where electric potential may become very high. The amplifier is specially designed for high voltage isolation up to 3.5 kV, and it adopts Burr Brown ISO 106 and Burr Brown PWS 726A.

Isolation amplifier of NI-1125 housed in a SCXI crate and A/D converter of NI PXI-6071E housed in a PXI crate are used for sensors such as temperature sensor, where electric potential does not become very high. Its amplifier filter eliminates high frequency noise nicely, even though its isolation voltage is relatively lower. Many kinds of sensor specific devices are used for sensors such as RGA and strain gauge for convenient data handling.

The IOC controls local devices via Bus or cable such as GPIB, and sends the values obtained from local devices to CA servers via Bus or Ethernet. The IOC consists of VME system with VxWorks, PXI system with RT-engine, and Windows PC.

The VME system, where EPICS core resides, controls local devices that are housed in the VME crate. The PXI system is used for local devices that are housed in the PXI crate. This system is linked to its host Windows PC for sending values to CA servers. The Windows PC, where LabVIEW and device drivers are installed, is used for sensor specific devices.

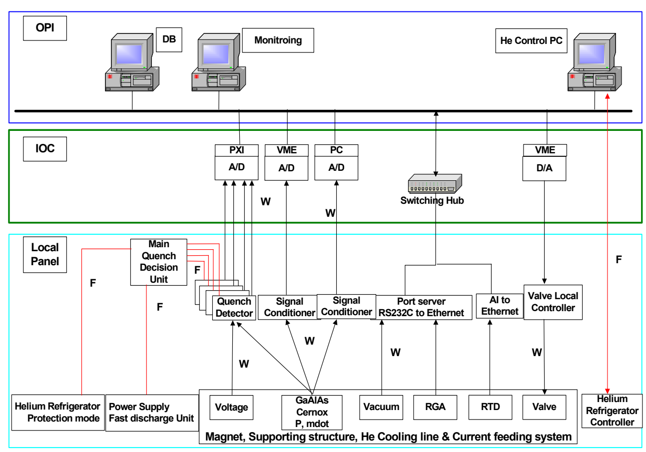

Figure 1: DAC system of SSTF

SCA (Simple CA) programs are installed at all the Windows PCs. The CA server stores values sent from IOC and provides values for archiver and monitor via Ethernet according to the user request. The CA server consists of VME system and PC. Each system is implemented real-time OS of VxWorks or RTEMS, respectively. Database of EPICS is managed by using ORACLE RDBMS [4]. The archiver records values that are read from CA server to its database, and provides values for monitor via Ethernet. The archiver consists of Linux workstation installed in-house developed database system. The operator interface accepts user's request, reads values from CA server and archiver, and presents quasi-real time data plots. The OPI consists of Linux workstation, UNIX workstation and Windows PC. The Linux and UNIX workstations are installed MEDM that is convenient to present values obtained from CA server.

They are also installed in-house developed browser that presents value from both of CA server and archiver.

Quench detection system

Quench detection uses various independent detection methods. Each quench detection method is implemented as a sub-quench detection unit, and it must provide the I/O module for the data monitoring and can transfer the alarm signal to the main quench decision unit. Through these modularization of sub-quench detection units, the flexibility for the further expansion and external operation interface can be improved. The main quench decision unit must be able to judge the quench with the alarm signals from sub-quench detection units. It also has the processor (or controller) to carry out the simple algorithm to judge the quench, and must have the output module to activate the power supply energy dump system. The figure 2 shows the layout of quench detection & protection system.

- ***Analog Quench Detector***

Quench detector measures the unbalanced voltage generated by quench through the balanced bridge circuit. This method works well when the coupled noise to the three voltage-taps changes linearly across their positions and could be implemented simply in an analog hardware. Four units of the quench detectors were installed for the prototype TF coil test, and tuned up before the test by applying high frequency signal into the coil with a 1 kHz function generator.

- ***Digital Quench Detector***

(1) Power spectrum analysis

Active power consumption and reactive power consumption are calculated by the cross-spectrum of magnet voltage and current. The active power starts to increase after the quench occurs.

(2) Inductance estimation

Magnet inductance is measured during current charging/discharging operation by sequential least square method. The magnet inductance is not a constant, that is, a function of current and magnetic field, continuous inductance estimation must be carried out. Based on this calculation, the magnet inductive voltage can be discriminated from resistive voltage due to quench.

(3) Wavelet transform

The signal is transformed from time domain to frequency domain by a transform such as z-transform. The signal has a distribution in the frequency domain, and the profile of the signal is characterised numerically by a Wavelet transform. The Wavelet transform is similar to Fourier transform, but it has advantages over traditional Fourier methods in analysing the physical situation where measured values have sharp spikes or discontinuities. The Wavelet transform cuts up data into different frequency components, and then examines the each component with a resolution matched to its scale. The Wavelet transform has a good nature to separate a selected signal profile. The Wavelet transformed profile is save sequentially and compared with previous ones continuously in time. Based on the result of the comparison, the measured signal is classified into normal or abnormal.

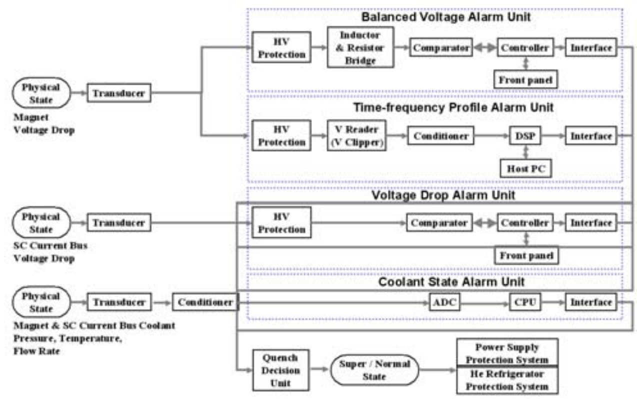

Figure 2: Quench detection system of SSTF

- ***Redundancy scheme for quench detection***

The redundancy scheme must be provided to prevent the magnet from being destroyed due to quench detection failure. This unit is operated as one of the sub-quench detection units and uses the magnet operating parameters such as helium temperature, pressure and flow-rate for the quench detection.

CONCLUSION

The data acquisition and quench detection system have been developed and operated according to the requirement of the prototype KSTAR TF coil test. The quench detection system using DSP is still under development for the future use.

REFERENCES

[1] K. Kim et al., submitted to the 2003 International Conference on Plasma Science.

[2] Y. Chu et al., 2001 ICALEPCS 2001 107-109

[3] S. Baek et al., submitted to the ICALEPCS 2003 Conference.

[4] S. Baang et al, ‘KSTAR Magnet System Review WBS135’, Samsung Advanced Institute of Technology, August 25, 1999.