The Test Facility for the KSTAR Superconducting Magnets at SAIT

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***Abstract*—SSTF (Samsung Superconductor Test Facility) has been built with the primary goal of testing the KSTAR TF (Toroidal Field) and PF (Poloidal Field) magnets as well as CICC (Cable-in-Conduit Conductor) and superconducting strands in the most relevant manner. The facility is located at SAIT (Samsung Advanced Institute of Technology) near the KSTAR project home site. Two helium liquefiers of 120 liter/hr capacity have been utilized as refrigerators demonstrating simultaneous double mode operation of refrigeration and liquefaction. A forced flow supercritical helium cooling circuit allows the test facility to be operated at temperatures down to 4.5 K. Other major SSTF components are a large vacuum vessel (6 m diameter and 7.3 m height) with liquid nitrogen temperature shield, data acquisition and control system with EPICS (Experimental Physics and Industrial Control System), current leads, and 50 kA modular power supply with fast dump quench protection circuitry. SSTF has been used for the first test-phase of KSTAR CICC sample. The current status of SSTF as the KSTAR magnet test facility for components and qualification test is presented in detail.**

***Index Terms*—KSTAR, Superconductor, Magnet, Test Facility**

I. Introduction

The KSTAR (Korean Superconducting Tokamak Advanced Research) device is a steady-state-capable advanced superconducting tokamak to establish a scientific and technological basis for an attractive fusion reactor [1]. The superconducting magnet system of KSTAR will use internally-cooled, cable-in-conduit superconductors. The KSTAR TF magnet system has 16 coils, providing a magnetic field of 3.5 T at the plasma major radius of 1.8 m. The peak flux density at the TF magnets is 7.5 T using Nb_3Sn strands in an Incoloy 908 conduit. The PF system consists of 8 CS (Central Solenoid) magnets and 6 outer PF magnets installed symmetrically about the plasma equator. The CS and PF5 magnets use Nb_3Sn strands in an Incoloy 908 conduit, while the other PF magnets use NbTi in an SS 316LN conduit [2].

SAIT (Samsung Advanced Institute of Technology) is the principal organization for the fabrication of KSTAR superconducting magnets. A test facility named SSTF (Samsung Superconductor Test Facility) has been built for the test of the KSTAR conductors and magnets, at the Daduk campus of SAIT, Taejon, Korea near the home site of KSTAR.

SSTF has been conceptually designed in collaboration with Quantum Technology since May 1997 and has been constructed in cooperation with Samsung Aerospace Industries Ltd., CVE Co., and Hanyang Engineering Co. The test facility is located in an extension hall next to the fabrication high bay area of 60 m × 24 m × 14 m. Detailed information can be found in the design description document of KSTAR WBS T135 [3] and the review document [4].

The manuscript received September 27, 1999. This work is supported by Korean Ministry of Science and Technology. S. Baang: phone 82-42-865-4078, baang15@samsung.co.kr

II. Design Description

Specific functions of SSTF include the following activities:

- Mounting the superconducting conductor/magnet in the test facility
- Vacuum pumping
- Pre-cooling the conductor/magnet under test
- Establishing a supercritical helium cooling flow in the conductor/magnet under test
- Operating the conductor/magnet with a test current profile, continuous or pulsed
- Measurements of temperatures, heat loadings, helium flows, magnet currents, magnetic field intensities and other important parameters of the conductor/magnet
- Taking automatic logs of data and measurements
- Warming the conductor/magnet back to an ambient temperature
- Removing the conductor/magnet from the test facility

SSTF consists of a vacuum cryostat, helium cooling system, LN2 cooling system, background magnet system, power supply system and control system. These sub-systems include the following components:

- A test vacuum chamber to be easily opened to insert the test objects.
- Liquid nitrogen cooled thermal shielding inside of the test vacuum chamber
- Thermally insulating mechanical supports to hold the weight of the test objects
- Removable connections for up to 7 supercritical helium cooling loops

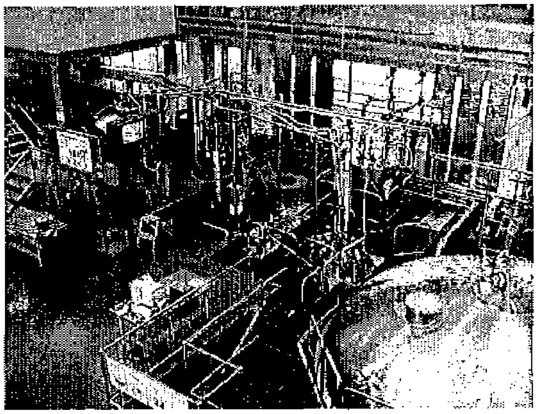

Fig. 1. SSTF overview

- Thermally insulated high current leads with active cooling and vacuum penetration for the high current connections
- Cryogenic insulators for liquid helium connections
- Forced flow helium cooling loop including cold box, heat exchanger and valves
- Helium liquefier system
- Liquid helium reservoir (dewar)
- Helium gas recovery system
- Liquid helium interconnecting lines
- Background magnets
- Power supplies
- Superconducting transformer
- Instrumentation (flow, temperature, pressure, strain, magnetic field) and display electronics
- Control system
- Data acquisition system

The SSTF facility is located at the east end of the coil assembly building and a continuous procedure line is established for the fabrication and the test of coils. An overview of SSTF is shown in Fig. 1. All of the major components of the facility are shown, while the high pressure helium storage cylinders and the liquid nitrogen dewar are located outside the building.

The 6 m diameter vacuum cryostat is located in a 9 m × 9 m × 6 m deep cubic pit as shown in Fig. 1. It is approximately 12 m apart from any other equipment, so the stray field from the coils being tested is sufficiently low and no shielding is necessary if the coils are mounted in a specific orientation.

A. Cryostat

The SSTF vacuum cryostat and cold boxes are designed to satisfy the following performance and operation requirements:

- Base vacuum pressure < 10^{-5} Torr at room temperature
- Leak rate < 2×10^{-9} Torr-liter/s
- Over pressure requirement : 0.07 MPa

The thermal shields are designed to maintain the temperature change below 5 K at the given heat load and the external surfaces of the shield are covered with a multi-layered "superinsulation" blanket.

B. Refrigerators

The helium cryogenic system must be able to provide adequate flow rate, pressure, and refrigeration capacity to cool down and maintain the magnets or conductors being tested in superconducting state under normal operating conditions.

Steady state heat loads to the cryogenic system include thermal radiation, conduction from warm cryostat parts and the helium required for the gas-cooled current leads. The heat load to the test object with no current is estimated to be ~52 W. Other substantial cryogenic loads include eddy current heating of cold metal, occurred in a pulse mode test. The eddy current heat load for a TF magnet is estimated to be ~44 kJ.

The SSTF cryogenic system supplies supercritical helium to the superconducting magnet system and liquid helium to the gas cooled current leads. Table I lists the conditions of the helium in the magnet system.

TABLE I
HELIUM SUPPLY AND RETURN TEMPERATURE AND PRESSURES

Item	Flow Rate	Supply Press.	Supply Temp.	Return Press.	Return Temp.
TF Magnet	25 g/s	0.5-0.7 MPa	4.2–5 K	0.3 MPa	6 – 9 K
PF Magnet	10 g/s	0.5-0.7 MPa	4.2–5 K	0.3 MPa	6 – 9 K
Current Leads	160 l/hr	0.11-0.14 MPa	4.3–5 K	0.1 MPa	300 K

A number of helium transfer lines from two liquefiers (L1 and L2) and a helium storage dewar are connected to Cold Box #1 containing several flow control valves. The cryogenic transfer line connects to Cold Box #2. The liquid helium and supercritical helium tubes in Cold Box #2 are connected to the conductors or magnets under test in the vacuum vessel. Cold Box #2 also houses valves, flow meters, temperature sensors and other devices that control and monitor the cooling fluid flow to the magnet. Fig. 2 shows the schematic diagram of the helium cooling system.

C. Vacuum Pumping System

The vacuum pumping system for the cryostat satisfies the following performance and operation requirements:

- Rough pumping time to bring the vacuum vessel down to 100 mTorr ≤ 2 days

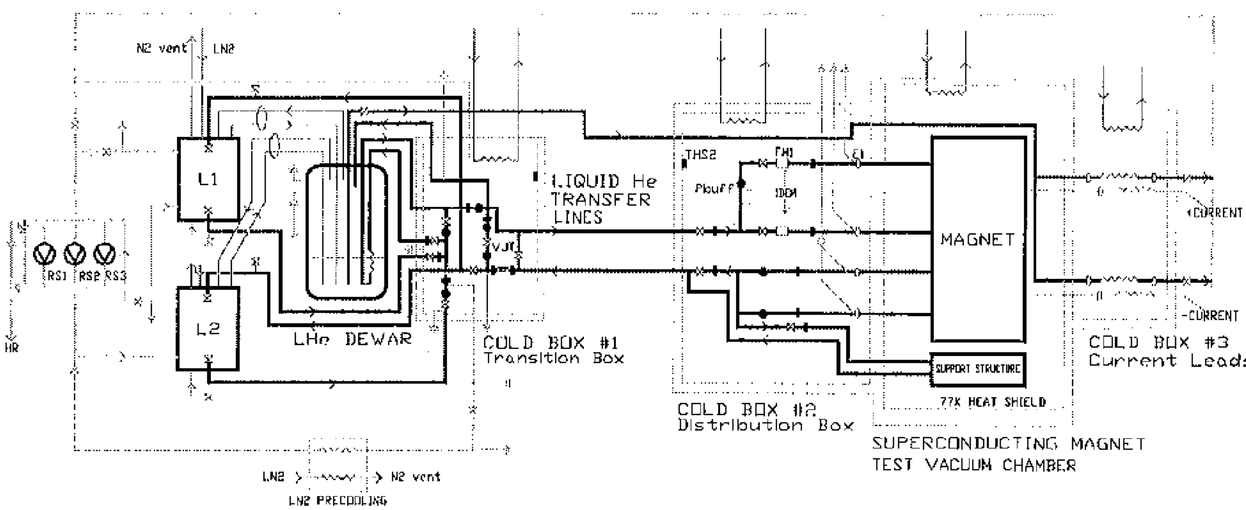

Fig. 2. Schematic flow diagram of SSTF helium cooling system

- High vacuum pumping with oil diffusion pump to less than 10^{-5} Torr ≤ 12 hours

The mechanical pumps for the vacuum vessel are in the pump room located outside of the building and are connected to the vessel with a 15 cm diameter pipe. A diffusion pump, with pumping speed of 10,000 l/s, brings the chamber pressure to below 10^{-4} Torr before cooling of the liquid nitrogen shield is started. This pump is also intended to handle small helium leaks of the helium tubes inside the vessel.

D. Current Leads and Superconducting Link

The helium vapor cooled current leads have been installed in SSTF. The use of HTS (high temperature superconductor) leads to SSTF has also been considered. However, high cost, experimental nature (the largest ones built to date carry 12.5 kA), the requirement for magnetic shielding (to prevent the HTS material from going normal) and the danger of an HTS quench require more R&D activities. R&D on HTS current leads for KSTAR may lead to the replacement of current leads in SSTF in the future.

The current leads for SSTF satisfies the following performance and operation requirements:

- Maximum Current: 50 kA
- Voltage Drop: < 0.10 V
- Coolant required (per pair): 160 *l* liquid helium (LHe) per hour at 50 kA, 96 *l* LHe per hour at 0 kA
- Coolant pressure drop at 50 kA: < 206 Pa
- Active cooling length of copper leads: 0.9 m

The vapor cooled high current leads are located on a stub near the power supply on the north side of the vacuum vessel in the Cold Box #3, in order to meet the requirements on current busbar length, magnetic field strength and high current bus length.

The current leads would present an unacceptably large heat leak to the superconducting magnet during the long cool down period if they were connected directly to the magnet. Hence it was decided to put a superconducting busbar between the current lead and the magnet, of sufficient length to reduce the heat leak to a reasonable value. These busbars are also designed to accommodate the thermal contraction in the magnet and the current lead during cooldown.

The superconducting current busbars are being developed to satisfy the following requirements:

- The area of copper stabilizer of the superconducting busbar is > 2.07 cm^2
- The maximum heat leak per link is < 3 W

E. Helium Storage

A 3000 liter liquid helium storage dewar (made by Cryofab) has a large central port to allow inserting a heat exchanger into the liquid helium, which is used to enhance the refrigeration capacity, and two liquid withdrawal ports with horizontal bayonets and VJ valves. The boil-off rate is designed to be less than 60 *l*/day. The heat exchanger is of a compact design permitting insertion into the small top opening of the dewar.

F. Helium Gas Recovery

High pressure helium storage tanks are used to store helium at a pressure up to 20 MPa to minimize the space requirement. Storage tanks with total capacity of 11.2 Nm^3 are used to allow storage of a total of 3000 liquid liters of helium inventory as a room temperature gas. Each tank is 0.32 m in diameter by 11 m long.

The helium recovery compressors are located in a sound proof room adjacent to the main hall, as are the three rotary screw compressors (RS1, RS2, and RS3) used by the liquefiers, to minimize the piping length. The low pressure gasbags are suspended from the ceiling of the building along the east wall to minimize space requirement.

G. Liquid Nitrogen System

The liquid nitrogen system is a simple, open circuit system, which utilizes storage dewar pressure to supply liquid nitrogen to the load points. Flows to liquid nitrogen thermal shields are controlled by level controllers. Liquid nitrogen to the helium refrigerators is controlled by vent valves. For storage of liquid nitrogen, a standard 10,000 liter liquid nitrogen storage dewar is used.

H. Instrumentation and Control

It is desirable to have a flexible system to allow control and monitoring of the test facility. Modular design concepts are used to allow testing of each module prior to integration.

SSTF DAS (Data Acquisition System) is based on the VME (VersaModule Eurocard) bus with Solaris-OS host workstation. For the lower level of data acquisition and control, PLC's (Programmable Logic Controller) are widely used. Basically the PLC guarantees a specific response time (typically 0.1 second) to any input. The logic inside the PLC may be used for the safety circuits. Those PLC's are to be linked to VME masters through optical connections. Fig. 3 shows the schematic diagram of SSTF DAS and control system. EPICS (Experimental Physics and Industrial Control System) serves as the basis for the data acquisition and control system [5]. The EPICS run-time database in the IOC (Input Output Controller) and CA (Channel Access) constitute the core of the EPICS software.

During the SSTF operation, data from the various sensors are used for feedback control or monitored. They are eventually saved in the storage device connected to the host workstation for further analysis. Most of the operation data from the SSTF vacuum cryostat, cold box #1, #2, and #3 are monitored and saved every minute. Valves in the SSTF cryogenic system are controlled by PLC analog-out modules with the help of data from temperature and pressure sensors showing the current status. Vacuum, He liquefier and Magnet Power Supply systems are controlled by independent PLCs, which will be linked to the main VME system and LAN (Local Area Network).

During the magnet test, since it is important to protect the magnet from quench, most of the data from the magnet are sampled at much faster rates. For example, voltage tap signals and optical fiber data are sampled in about 100 kHz rate for quench detection and protection. Those signals are digitized by fast sampling ADC (Analog to Digital Converter) and transmitted via local bus to DSP (Digital Signal Processor). After DSP has performed calculations to determine if a quench has occurred, the DSP board produces trigger signal to the power supply energy dump circuit. For protection from other kinds of emergency, interrupt modules in PLC's send the fault signals to the lower level devices.

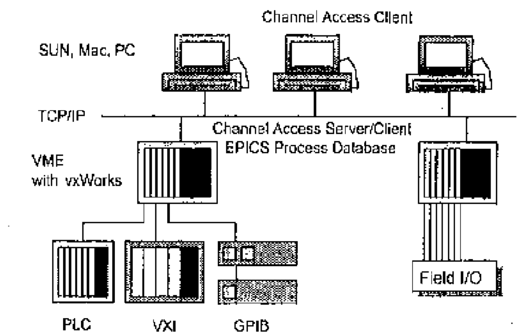

Fig. 3. SSTF DAS and control system

III. Summary and Future Work

As the test facility for the KSTAR superconducting magnets, SSTF has been designed and constructed at SAIT. The first use of SSTF was for the Phase I low current test of the full scale KSTAR TF CICC sample. It has been successfully cooled and the frequency response of the sample was tested. The results will be presented in other papers. The background magnet system and superconducting transformer system are currently under design. The design and test of these components will be reported in the near future. In fiscal year 1999 the magnet power supply being developed by Pohang Accelerator Laboratory Group for KSTAR will be installed at SSTF, and the test of the prototype KSTAR TF magnet is planned.

Acknowledgment

The authors wish to express gratitude to the scientists at FzK and IPP Germany, CRPP Switzerland and NIFS Japan for the valuable discussions for the design and construction of SSTF.

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