# New Facility for the Cryogenic Test of ITER Current Leads at ASIPP

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***Abstract*—Based on the procurement agreement signed by the ITER IO and the Chinese domestic agency, the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) will produce the 60 single high-temperature superconducting (HTS) current leads in-kind for ITER. All of the ITER HTS current leads will be cold tested before assembly in the coil feeder systems. Therefore, a dedicated test facility was built in 2011 and completed in 2014 to perform the factory acceptance test of the HTS current leads. This paper describes the design of the test facility and its key components, including the cryogenic system, the power supply system, and the data acquisition as well as quench detection system. As an example, some results of the ITER HTS current lead prototype test campaigns will be shown.**

***Index Terms*—Control system, cryogenics, current lead, high-temperature superconductors, test facilities.**

## I. Introduction

According to the procurement agreement between the ITER International Organization (IO) and the ITER China Domestic Agency, China will deliver to ITER site the 31 sets of superconducting Feeder system containing 60 single HTS current leads which are manufactured by Institute of Plasma Physics Chinese Academy of Science (ASIPP) [1]. As part of the factory acceptance test the ITER current leads will be tested at nominal current and cryogenic temperature condition before shipping to ITER. Previously during the R&D for the development of the ITER leads, the test setup constructed was based on the cryo and power facilities of the EAST Tokamak [2]–[4]. Unfortunately the EAST test hall has no space available anymore for the cold test of the ITER current lead prototypes after the EAST was upgraded in 2011. Therefore ASIPP decided to design and construct a new test facility for the cold test of the ITER lead prototypes and series units (Fig. 1). ASIPP started building construction in 2011. The cryogenic system and the power supply system were completed in 2013.

There are other 5 K test facilities for the cold test of large HTS current leads, such as Current Lead Test facility Karlsruhe (CuLTKa) facility for the W7-X and the JT60-SA HTS current leads [5], [6], or the facility CERN developed to test the HTS current leads for the Large Hadron Collider project [7]. Although the newly built facility at ASIPP was specified to fit the needs for testing of the HTS current leads for ITER, it can also provide for a wider range of conditions for testing other types of superconducting systems.

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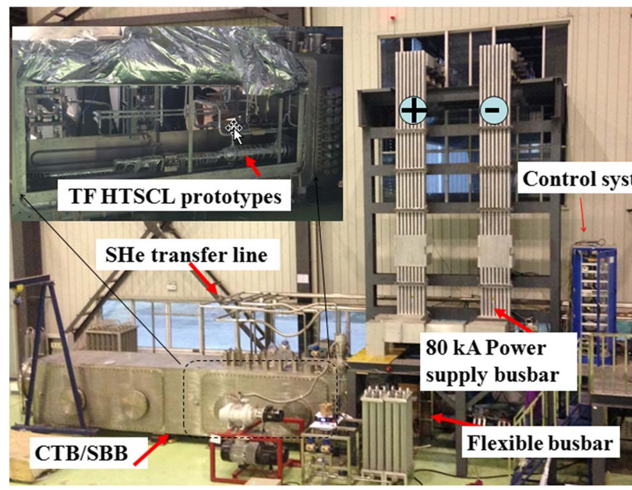


Fig. 1. Overview of the cold test of ITER TF/PF/CS current leads.

This paper will present the subsystems of the newly built test facility including the cryogenic system, power supply units and control system. As examples some recent tests are also discussed.

## II. Acceptance Test of ITER HTS Leads

The design of the ITER HTS leads is described shown in [8]. In order to minimize cryo-power the warm end of the HTS section of the leads operates at 65 K by cooled with 50 K helium gas. The cold end of the HTS, low temperature superconducting twin-box joint and U-bend are cooled by 5 K supercritical helium. Table I shows the operational parameters of the ITER leads. The specification of the test station subsystems was based on the operational requirement.

## III. Major Subsystems of the Facility

### A. Cryogenic System

The cryogenic system needs to provide helium at 4.5, 50, and 80 K. The cryo-plant, including main screw compressor, oil filter system, gas detection unit, three turbines, cold box and control system was provided by Linde. ASIPP designed and

TABLE I
OPERATIONAL PARAMETERS OF ITER LEADS

| *Design Parameters* | *Values* |
|---|---|
| Design current | 68/55/10 kA |
| Quantity | 18/24/18 |
| HTS Temperature | 5~65 K |
| HEX Temperature | 65~300 K |
| Mass flow rate | 5/3.8/0.7 g/s |
| HEX-HTS joint | < 10/25 nΩ |
| HTS-LTS 5 K joint | < 1/2.5 nΩ |
| HTS hotspot | 200 K |
| Overheating time (5mV) | 15/18 s |
| Temperature margin of HTS | 10K |
| He temp. of HEX's inlet | 50 K |
| Heat load end 5 K end | <15/12/3 W |

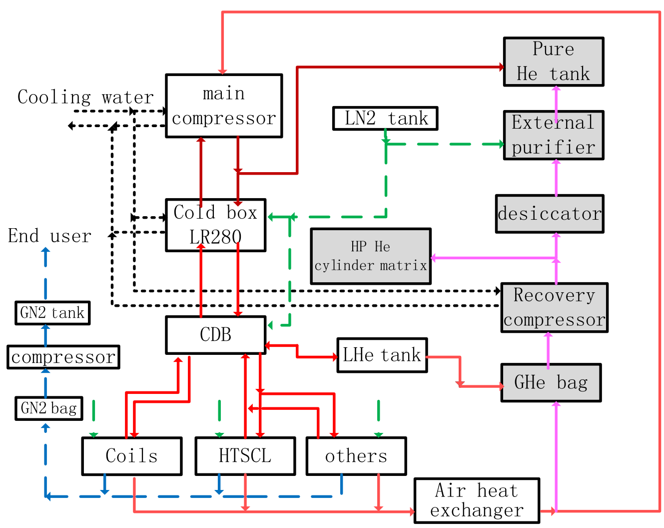


Fig. 2. Layout of the cryogenic system operation.

built the Cold Distribution Box system (CDB) [9], a 100 $m^3$ quench helium recovery system, a 20 $m^3$ LN2 tank, two 50 $m^3$ He tank transfer lines, and the purifier system. The layout of cryogenic system is shown in Fig. 2. Table II lists the main parameters. The system operates in two operational modes: helium liquefying mode and refrigeration mode. During the first commissioning test, the liquefying helium level was stabilized with additional electrical heater loads applied (900 W) in the liquid helium tank shown in Fig. 3. The cryogenic system can also supply about 10 g/s from the special intermediate 50 K helium circuit in the refrigeration mode to cool down the resistive section of current leads. Actually the 50 K helium circuit can reach ~40 K. Higher temperature than 50 K can also be reached with inline heaters in the transfer line. The SHe cooling loop for the LTS end of the leads (including the U-jumper) is warmed up to 300 K in large heat exchanger from the test cryostat. It is then merged with the 300 K exiting from the resistive heat exchanger and returned to the cryo-plant compressor system.

The distribution box is used to feed the different cooling paths to the expected end users. At present the HTS current leads, superconducting joint and ITER feeder system are the main users of this facility. In the future, it is planned to also provide coolant for superconducting coils tests. For that reason

TABLE II
OPERATIONAL PARAMETERS OF CRYOGENIC SYSTEM

| Parameters | values |
|---|---|
| Model No. | Linde LR280 |
| Nominal Refrigeration Capacity | 900 W/4.5 K |
| Maximum Refrigeration Capacity | 1020 W/4.5 K |
| Operation SHe Temperature | 4.0 K/4.5 K |
| Maximum liquefier Rate | 150 L/hr |
| Maximum SHe Pressure | 10 barA |
| Main compressor power | 350 kW |

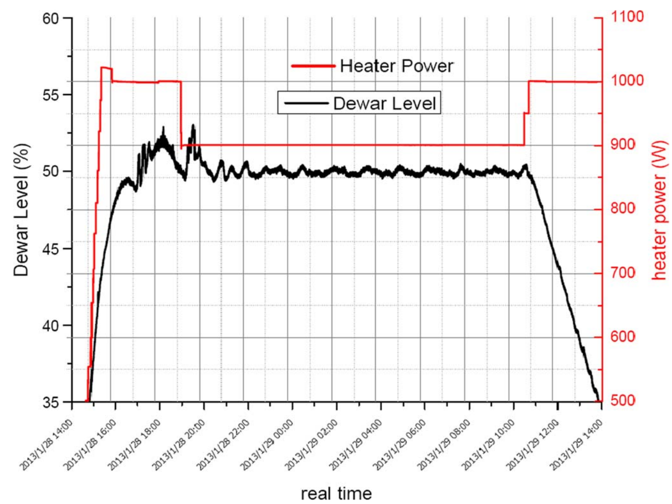


Fig. 3. Commissioning and site acceptance test of the cryogenic system. The black line is helium-level measurement reading. The red line is additional heater power that shall be a balance with cooling power of refrigerating mode. The level becoming stable means the refrigerating power of the cryogenic system is 900 W at 4.2 K.

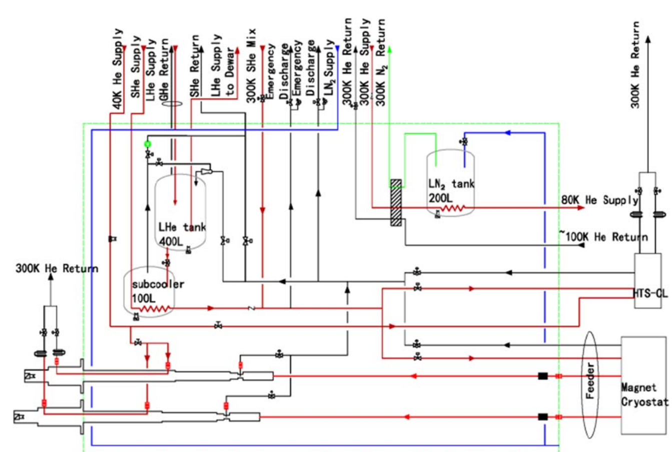


Fig. 4. Schematic of CDB.

the CDB also includes a set of the liquid or SHe returning at low temperature to the cryo-plant. Both systems are presently not used for the test of the ITER HTS current leads. Fig. 4 shows a more detailed schematic of the distribution valve box including the 4.5 K sub-cooler.

## B. Power System

The power supply system is a key component of the test facility, as it needs to supply the huge current with a small current ripple, while allowing to be remotely shut down during

Fig. 5. Photograph of an 80-kA PS system.

TABLE III
OPERATIONAL PARAMETERS OF POWER SYSTEM

| *Parameters* | *Values(for CC)* | *Values (for TF/PF/CS)* |
|---|---|---|
| normal. voltage | 10 V | 500 V |
| Normal current | 20 kA | 80 kA |
| Current ramp rate | 12 kA/s | 40 kA/s |
| Current ripple | <1% | 1% |
| Withstand. voltage | 100 V | 12.5 kV |
| Input power | 200 kVA | 4 MVA |

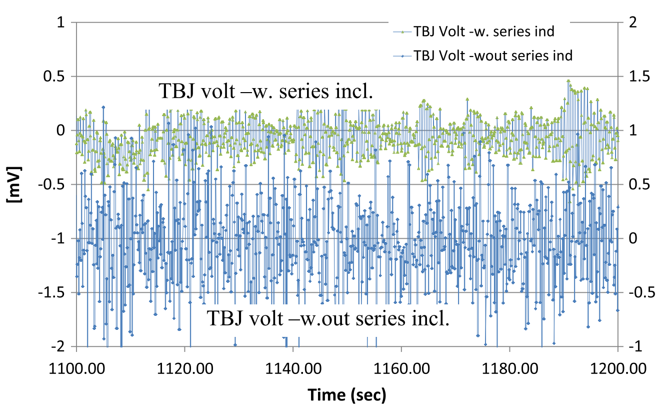


Fig. 6. Voltage over a twin box joint at 68 kA with and without series inductance.

a superconductor quench. For the ITER leads, two power supplies are available: a 20 kA system (provided by CAS-HIAU) for the ITER CC leads and a 80 kA system for the ITER TF/PF/CS leads (Fig. 5). The latter is located in an adjacent building and connected to the test hall from the ITER power test hall by large air cooled aluminum busbars. The 80 kA system has a larger output voltage for possible coil tests in the future. Table III shows the operational parameters of the power supply system. The 80 kA power supply includes the option to connect total 12 mH inductances to allow low noise measurement of joint resistances (micro-volts level voltages). See Fig. 6 for the reduction in current ripple obtained. Due to water-cooling limitations of inductance coils, the high current can only be sustained for a few tens of minutes in this mode.

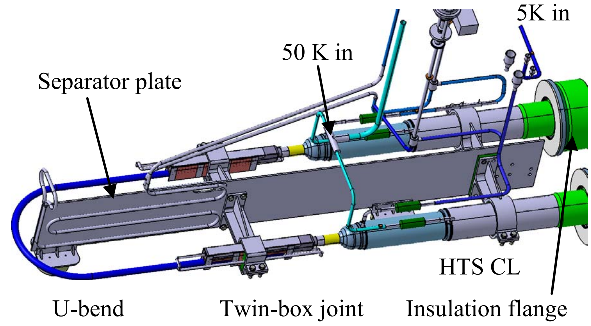


Fig. 7. Mounting of a pair of TF-type HTS current leads in the test cryostat.

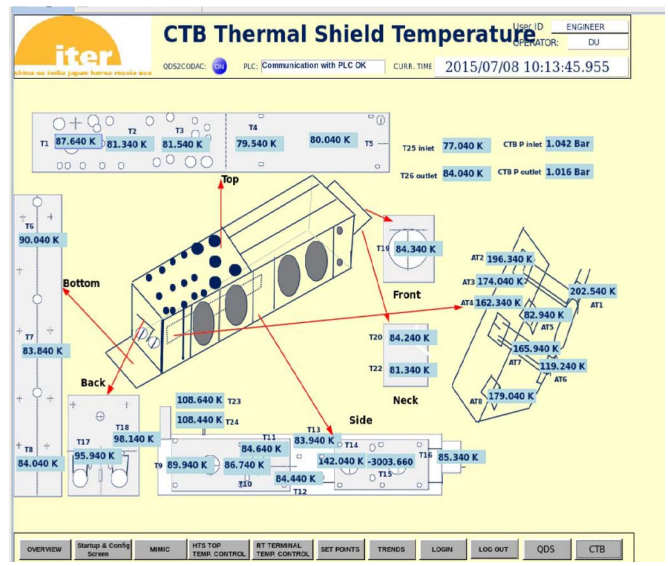


Fig. 8. Test cryostat thermal shield and internal component temperature monitoring.

## C. *Test Cryostat of ITER Current Leads*

A prototype of the ITER Coil Terminal Box and S-Bend Box (CTB/SBB) and its thermal shield, manufactured and tested in 2014 [10] was used as the vacuum cryostat for the TF current lead tests. A pair of current leads as shown in Fig. 7 is horizontally assembled, connected by a superconducting short (the so-called U-bend). The vacuum can be pumped to 0.01 Pa before cool down by a 400 l/min molecular pump in less than 48 hours. The cryostat vacuum reaches 1E-5 Pa when the whole system is cooled down. The thermal shield is cooled down by liquid nitrogen. Since some of the internal structural components (i.e., the so called separator plate) can take longer to cool down an array of temperature sensors is distributed over the different components to monitor the cool-down (Fig. 8). Smaller leads (such as for the ITER correction coils) can be tested vertically in a smaller test cryostat.

## D. *Control System and Quench Detection System*

The control system for the ITER current leads test is based on the IO CODAC (Control, Data Access and Communication) specification and includes a plant system host, conventional data acquisition and controller systems, an interlock system,

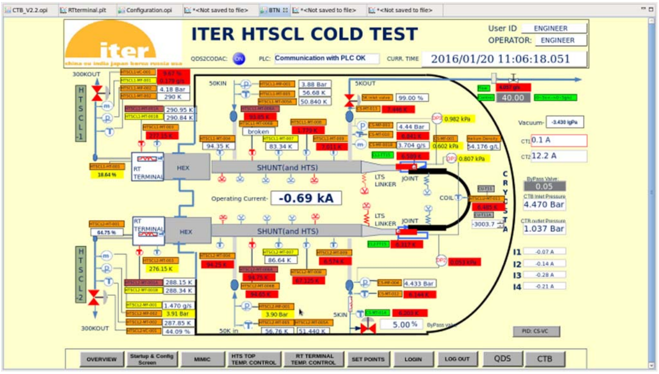


Fig. 9. HMI of the ITER HTS current lead control system.

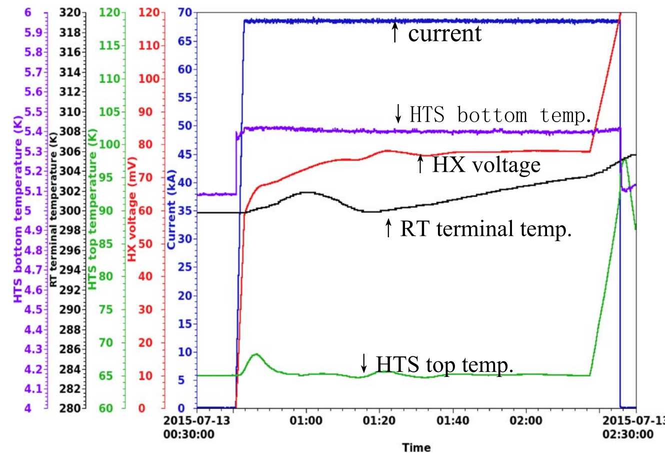


Fig. 10. Current and temperature profile during the TF prototype test.

and a quench protection system. The plant system communicates through the Ethernet network (PON). The time synchronization of each system is based on the TCN network. The Plant System Host (PSH) is used to deploy the input and output controllers (IOC). The conventional data acquisition and control system is implemented with a Siemens PLC. Two temperature controllers are used for the 65 K HTS top regulation and the 300 K room temperature terminal regulation. The interlock system is implemented on the basic of the redundancy scheme. Using a 2oo3 strategy(two units out of three are required for the system to operate), the interlock system will open the current loop when it detects the quench signal which then triggers a power-off of the power system. The signal conditioners are used to convert engineering temperature and pressure into a standard 4–20 mA standard signal. The quench detection system is built with a National Instruments compact Remote Input and Output module. A FPGA program is used to monitor the voltage along the current leads, twin-box joint and U-bend.

The recorded readings of the engineering system are obtained from the PLC system, and then transferred to the PSH via PON. Any client in the local network can access the engineering readings including temperature, pressure, vacuum, current, voltage, flow rate etc. to plot them in operator interface (OPI) and archive them in the database. An example of the HMI for the HTS current lead test is shown in Fig. 9.

## IV. Test of TF HTS Current Lead Prototypes

Based on the ITER project schedule, the prototypes of ITER current leads need to be qualified before 2017. At present, the CC prototypes and TF prototypes have been completed. The cold test of the CC prototype was performed in Jan of 2015, the cold test of TF prototypes in July of 2015.

Fig. 10 shows some of acquired parameter graphs for the nominal current steady state operation (SSO) for the ITER TF 68 kA prototypes. During the SSO, the HTS top temperature was regulated to 65 K +/− 1 K, while the supplying temperature of helium for cooling the HX was controlled at 50 K +/− 1 K. The steady state 50 K He mass-flow in the resistive heat exchanger was ∼4.7 g/s, as expected from calculation. At the end of the SSO a Loss-Of Flow Accident (LOFA) fault condition is induced by stopping the 50 K mass-flow to the heat exchanger. The HTS part of the lead eventually quenches after ∼7 mins. The heating in the no-flow-condition can be seen in the heat exchanger voltage and HTS top temperature.

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