# ITER CENTRAL SOLENOID MODEL COIL TEST PROGRAM

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Abstract

A large pulsed coil (CS Model Coil) with a stored energy of 640MJ was developed and its fabrication is now being completed. In addition, three Insert Coils for different purposes are also being built. The objectives of the CS Model Coil Testing are to demonstrate the technology to generate 13T with the operating current of 46kA, to measure the pulsed operation performance and to validate the engineering design of the Central Solenoid Coil of the ITER. Two of the Insert Coils are tested to demonstrate the performance of 13-T, 40-kA $Nb_3Sn$ and $Nb_3Al$ conductors for the ITER toroidal field coil. For these testings, Japan Atomic Energy Research Institute has constructed the CS Model Coil Test Facility which can charge the coils up to the power of 250MVA under a 800-g/s, 4.5-K supercritical helium circulation in a vacuum tank with a diameter of 6.5m and a height of 9.5m.

## 1. INTRODUCTION

Under the Engineering Design Activities (EDA) of the International Thermonuclear Experimental Reactor (ITER) Program, the Central Solenoid (CS) Model Coil, the CS Insert Coil, the Toroidal Field (TF) Insert Coil and $Nb_3Al$ Insert Coil have been developed by collaboration of European Union (EU), the ITER Joint Center Team (JCT), Japan, Russia and USA. The major features of these coils are shown in Table 1. While, Japan has constructed the CS Model Coil Test Facility (CSMCTF) at Naka Fusion Research Establishment of the Japan Atomic Energy Research Institute (JAERI).

All the coils will be brought to the CSMCTF and initial installation will be carried out with the CS Model Coil and CS Insert Coil. After the first phase experiment by these coils, the next Insert Coil (TF Insert Coil or $Nb_3Al$ Insert Coil that comes earlier) will be replaced by the CS Insert Coil and be tested with the CS Model Coil and so on with the last Insert Coil. The testing objective of the CS Model Coil and CS Insert Coil is to demonstrate the coil technology developed for the ITER CS coil and those of the TF Insert Coil and $Nb_3Al$ Insert Coil are to demonstrate the conductor technology for the ITER TF coils. The requirements for the CS Model Coil Testing are summarized in Table 2.

TABLE 1 Major Features of the coils to be tested by the CS Model Coil Program

| | CS Model Coil | CS Insert Coil | TF Insert Coil | $Nb_3Al$ Inset Coil |
|---|---|---|---|---|
| Superconductor | $Nb_3Sn$ | $Nb_3Sn$ | $Nb_3Sn$ | $Nb_3Al$ |
| Max. Magnetic Field | 13 T | 13 T | 13 T | 13 T |
| Operating Current | 46 kA | 40 kA | 40 kA | 46kA |
| Number of Layers | 18 | 1 | 1 | 1 |
| Outer Diameter | 3.60 m | 1.50 m | 1.50 m | 1.50 m |
| Charging Mode | DC and Pulsed | DC and Pulsed | DC | DC |

TABLE 2 Requirements for the CS Model Coil Testing

| | |
|---|---|
| | **Electromagnetic** |
| **E1** | Produce 13-T peak field in DC and pulsed mode consistent with ITER CS coil |
| **E2** | Charge CS Insert Coil to 40-kA current at 13T in reverse mode. |
| **E3** | Demonstrate low AC loss in the conductor |
| **E4** | Demonstrate operation with temperature margin of 2K |
| **E5** | Withstand high-voltage discharge including 5-s quench detection time |
| **E6** | Demonstrate quench detection and coil protection |
| **E7** | Demonstrate stable operation and operating margins of leads and joints |
| | **Cryogenic** |
| **C1** | Cool down / Warm up in 480hours with specified constraints |
| **C2** | Demonstrate helium leak tightness at cryogenic temperature |
| | **Mechanical** |
| **M1** | Demonstrate the mechanism of vertical pre loading |
| **M2** | Demonstrate stresses and displacements during cool down/warm up and charging operation within the allowables of the material properties |
| **M3** | Demonstrate structural characteristics during cyclic testing |

## 2. TEST PROGRAM

2.1 Cool down Tests

The purpose of this test is to demonstrate the reliable cool down of the coils in 20days. The total weight including the CS Model Coil, CS Insert Coil and supporting structures is about 180tons. The helium refrigerator/liquefier of the CSMCTF whose capacity is 5kW/800Liters/h is used. During the cool down by the computer monitoring and control, the temperature difference between the inlet and any other part of the coil assembly, including the support structures will be maintained below 50K. The rate of cool down will be controlled by the inlet temperature and the mass flow distribution to coils and structures. The inlet pressure to the coils is to be kept constant around 1.0MPa by the inlet valves and the outlet pressure will be controlled by the outlet valve so as to provide the desired mass flow rate. During the cool down, the temperatures, pressures, and coil displacement will be measured at every 30seconds. The resistance of each coil will also monitored by applying 10A through each coil. After the maximum measured temperature goes below 10K, a 4-K, 800-g/s supercritical helium circulation pump will be started to complete the initial cool down.

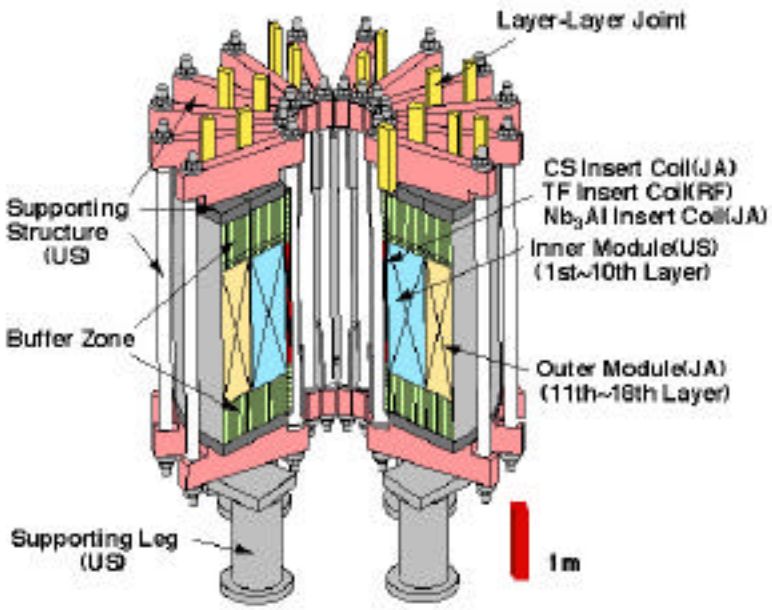


Fig. 1 Configuration of the CS Model Coil, an Insert Coil and supporting structures

2.2 DC Tests

The DC tests of the CS Model Coil are 1) to achieve the 13-T design field at the rated current of 46 kA in steps at a slow ramp rate of 10 to 15 A/s by the 15-V, 50-kA DC power supply as shown in Fig. 2 under the helium inlet condition of 4.6K, 0.6Mpa and 10g/s/channel, 2) to measure the mechanical performance at 13T and 46kA the stress and displacement of the coil and also the stress in the tension rods, 3) to demonstrate a safe dump of the coil current from selected levels of 10kA to 46kA with dump time constants from 30 down to 6seconds and finally to test the coil insulation system using a manual dump of 10kV, while the insulation test voltage to the ground is 20.7kV, 4) to measure the current sharing temperature by keeping the inlet temperature to a selected layer higher than 4.6K and then by increasing the coil current, 5) to measure the performances of the joints and superconducting bus-bars.

The DC tests of the Insert Coils, which are carried out by the 2 sets of 30-kA, 12-V DC power supply as shown in Fig. 2 are similar those of the CS Model Coil as above. The insulation test voltages to the ground are 20.7kV, 0.5kV and 3kV, for the CS Insert Coil, TF Insert Coil and $Nb_3Al$ Inset Coil, respectively. The Insert Coils are equipped with many voltage taps, temperature sensors, pressure sensors, strain gauges, inductive and resistive heaters and pick-up coils for detailed investigation of the coil performance. In addition to the detailed measurement of current sharing temperature, it is expected to measure the critical current of the coil under the field from 10 to 13T and the inlet temperature form 8 to 16K. Major charging tests will be carried out with the CS Model Coil charged up to 46kA by the separate 50-kA DC power supply. In this case, a special caution should be taken in case of dump of the coil currents. As the number of turns between an Insert Coil and the CS Model Coil is about 1:18, huge jump of the Insert Coil current should occur if the circuit breaker of the CS Model Coil would work earlier than that of the Insert Coil. In any case of dump operation, the circuit breaker of the Insert Coil circuit is to work 0.5s earlier than that of the CS Model Coil.

One of the important tests of the Insert Coil is to measure the current sharing temperature of the CS Insert Coil charged up to +40kA and –40kA (reverse charging) with the CS Model Coil charged up to +46kA. By this experiments, strain level can be varied and it is expected to measure the performance of the CS coil with many sensors under a compressive strain of 0.35% as was designed in the Engineering Design of the ITER CS coil. Insert Coils are equipped with inductive and resistive heaters, by which the stability margin against the external disturbance will be measured in detail.

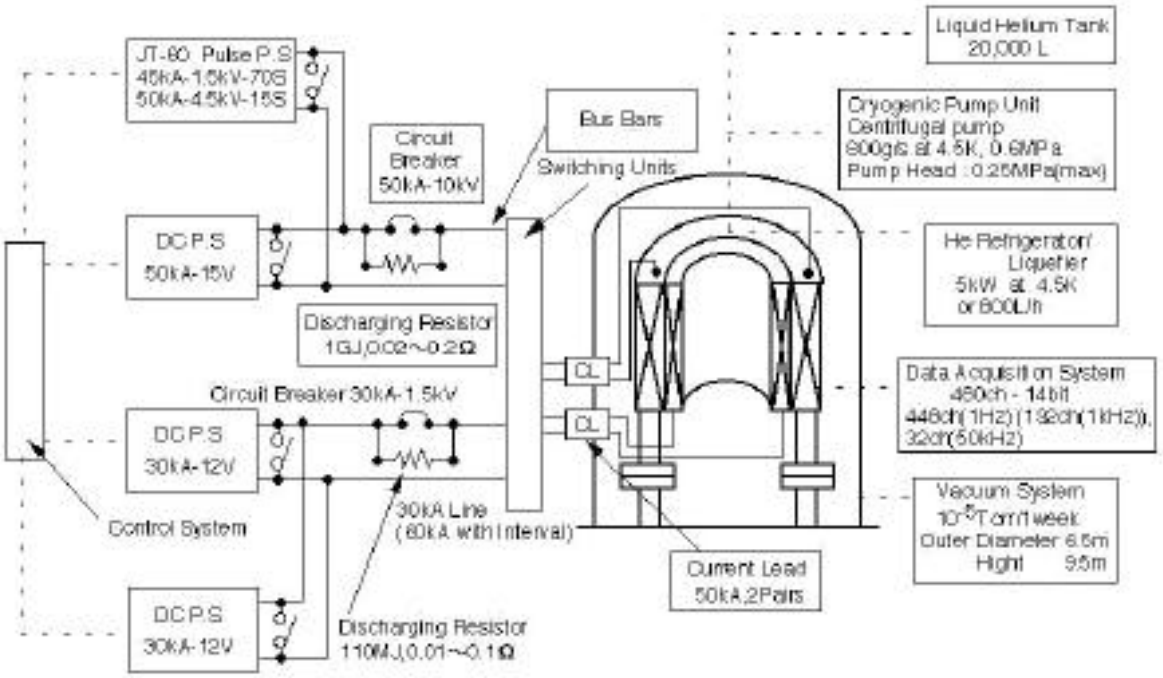


Fig. 2 The CS Model Coil Test Facility at JAERI

Fig. 3 Vacuum Tank and Refrigerator of the CS Model Coil Test Facility at JAERI

2.3 Pulsed Tests

Pulsed test will be carried out only on the CS Model Coil and CS Insert Coil by using the two units of the poloidal power supply whose outputs are 50kA, 1.5kV for 70seconds and 50kA, 4.5kV for 15seconds. Pulsed experiments will be carried out 1) with the CS Model Coil stand alone and 2) with the CS Model Coil in series with the CS Insert Coil. Due to the limitation of the available charging duration by the JT-60, it is not possible to simulate the ITER CS coils operation for 1000seconds, however the essential elements of the CS coil current wave forms can be tested by using the two units of the JT-60 power supply. The nominal pulsed operation waveform is to increase the magnetic field up to 13T in 26seconds (0.5T/s), to hold for 5second at 13T to confirm the superconducting performance and to decrease the field by resistive discharge (-1.2T/s) which is the same as the ITER CS coil operation (-1.2T/s) at the plasma initiation or to decrease the field by controlled discharge (-0.7T/s) to simulate the plasma current ramp-up (-0.25T/s). This pulsed operation is the required performance of the coil as the ITER CS coil and coil and should be demonstrated by the experiment of the CS Model Coil and the CS Insert Coil.

As the extended test, pulsed field loss will be measured up to the highest charging rate of 13T/6.5seconds (2T/s) so as to investigate the operation limit of the CS Model Coil and the CS Insert Coil. Under these rapid pulsed charging pulsed field loss of the coils will be measured by the temperature and pressure sensors by integrating in time the enthalpy increase of the helium from the inlet to the outlet of the coil. They are also very significant experiment 1) to measure the performance limit as called the ramp rate limitation, 2) to measure the choking phenomena of helium flow through the coil, 3) to observe quench performance and propagation velocity of the normal zone in case of the pulsed operation with choked cooling helium flow. In addition, by using DC supplies, 0kA - 40kA cyclic test of the CS Insert Coil for 10,000 times will be carried out under a 13T generated by the CS Mode Coil which is operated under the persistent mode by a short circuit switch.

3. The CS Model Coil Test Facility and Testing Schedule

The construction of the CS Model Coil Test Facility has almost been completed and construction to increase the reliability of the Insert Coil protection system by dual circuit breaker systems has been under way. The installation of the coil will begin in March 1999 and experiments in August 1999.

REFERENCES

[1] R. Jayakumar et al., “The Central Solenoid Model Coil Fabrication,” to be presented at this Conf.