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Investigation of long time constants of magnetic fields generated by the JT-60SA CS1 module

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ABSTRACT

In a cold test of the JT-60SA CS1 module, which is composed of six octa-pancake coils and one quad-pancake coil wound with Nb_3Sn CIC conductors, the measurement of self-magnetic fields generated by the CS1 module was conducted. As a result, the decay of the self-magnetic field was observed after the CS1 module was degaussed. The time constant of the decay was from 90 s to 269 s. The measurement results indicate that loop currents with long time constants occurred in the CS1 module due to coil energization. The loop currents with long time constants, which are also called 'supercurrents', are irregular coupling currents that are an unexpected phenomenon from the conductor design.

Loop currents with long time constants in CIC conductors have only been observed in large superconducting coils so far. To verify an occurrence of loop currents with long time constants in a CIC conductor without coil winding configuration, self-magnetic fields were measured using a short straight CIC conductor where a multi-strand cable was connected electrically at the conductor ends. As a result, loop currents with long time constants ranging from 57 s to 105 s occurred in the short straight CIC conductor, the length of which is approximately 1 m. The measurement results indicate that the conductor length is not always related to loop currents with long time constants. The occurrence of loop currents with long time constants in the CIC conductor depends on the presence of current paths at the conductor ends.

1. Introduction

The JT-60 tokamak is being upgraded to an advanced superconducting tokamak to be called the JT-60 Super Advanced (JT-60SA) at the National Institutes for Quantum and Radiological Science and Technology (QST) in Japan [1–5]. In the JT-60SA, the magnet system consists of a central solenoid (CS), 18 toroidal field coils, and six plasma equilibrium field (EF) coils. All coils were wound with cable-in-conduit (CIC) conductors. As illustrated in Fig. 1, the CS is composed of four modules, CS1, CS2, CS3, and CS4. In the superconducting coil test facility of the National Institute for Fusion Science (NIFS) [6,7], a cold test of the CS1 module was conducted before the CS1 module was installed in the magnet system of the JT-60SA. This paper describes the measurement of self-magnetic fields generated by the CS1 module in the cold test. And magnetic fields with long time constants observed in the CS1 module are discussed while comparing the measurements of a CS model coil. In addition, the measurement of self-magnetic fields generated by an EF joint sample are described to investigate the relation between conductor length and the occurrence of loop currents having long time constants in the CIC conductor.

2. JT-60 SA CS1 module

Figs. 2 and 3 show a photograph and the configuration of the JT-60SA CS1 module, respectively. The CS1 module is composed of six octa-pancake coils and one quad-pancake coil [3,4]. The specification

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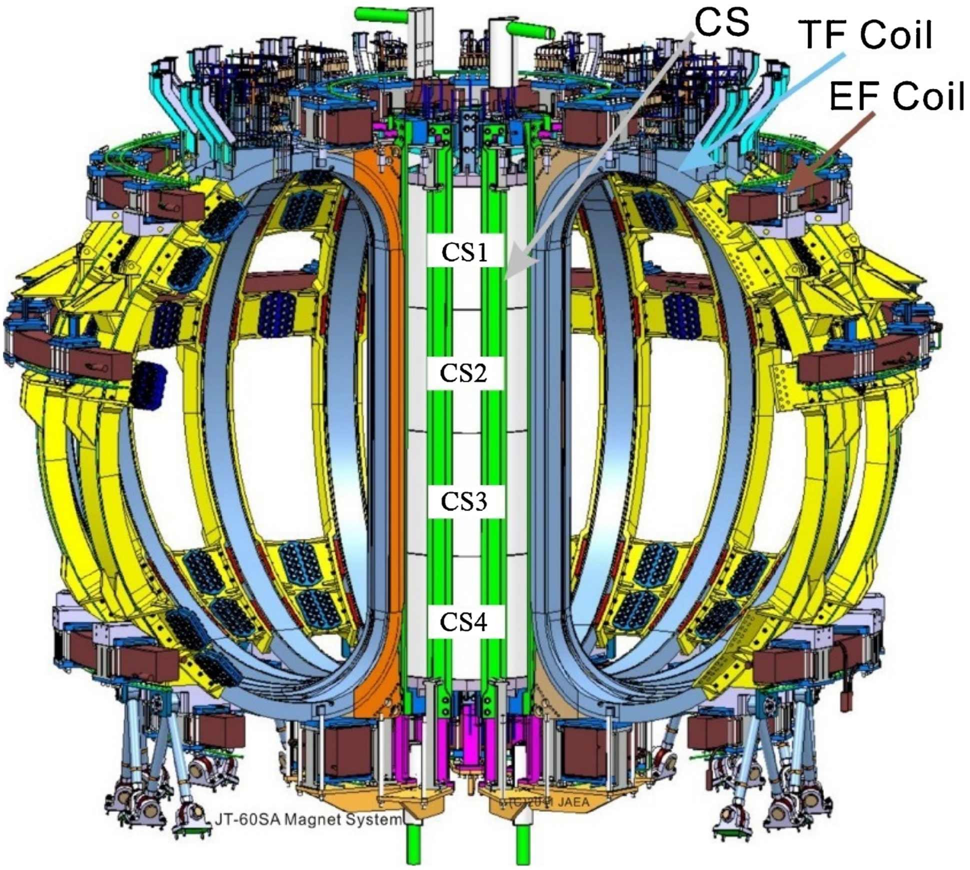

Fig. 1. Layout of the JT-60SA magnet system. The CS is composed of four modules (CS1, CS2, CS3, and CS4).

of the CS1 module is listed in Table 1. All coils were wound with a Nb_3Sn CIC conductor composed of 216 Cr-plated Nb_3Sn strands and 108 copper wires. In Table 2, the specification of the CS conductor is listed. Each coil was connected through butt joints [8,9] of the conductors.

3. Test facility

A cold test of the CS1 module was conducted using a test facility which can accommodate testing of a forced-cooling superconducting coil [6,7]. The details of the test facility are described in Refs. [6,7,10,11]. The helium cryogenics system of the test facility was upgraded in the 2014 Japanese Fiscal Year [12]. Fig. 4 shows the CS1 module installed in the cryostat of the test facility. The CS1 module was mounted on supporting posts, and was electrically connected with the current-leads of the cryostat through current feeders composed of NbTi CIC conductors.

4. Magnetic field measurements

4.1. Measurement setup

To measure a magnetic field generated by the CS1 module, Hall sensors were mounted on top of the CS1 module. The model references of the Hall sensors are F.W. BELL BHT 921 and Lake Shore HGCT-3020, and the Hall sensors were calibrated. Fig.3 (b) shows the position of the Hall sensors. These sensors were located at 60°, 140°, 260°, and 340° around the CS1 module. At each angle, the Hall sensors were placed evenly spaced apart in a radial direction as illustrated in Fig. 5. Self-magnetic fields in the axial direction of the CS1 module were measured using the Hall sensors. The axial direction corresponds to z direction in Fig. 5. As for the alignment error of the Hall sensor, about 2° angle with reference to the center of the CS1 module is considered to be the maximum error.

4.2. Results

The CS1 module was energized to 5 kA at a ramp rate of 20 A/s, and then the CS1 module was maintained at 5 kA for 300 s. The CS1 module was then degaussed at a ramp rate of 20 A/s. During the coil operation, supercritical helium whose temperature was about 6 K was supplied to the CS1 module. Fig. 6 shows the self-magnetic fields in the axial direction at 140° (P2) during the coil operation. The magnetic fields were larger toward the center of the CS1 module during coil energization. Figs. 7 and 8 show the magnetic fields at 140° and 260° after the current of the CS1 module reached to 0 A. Although the current was 0 A, the magnetic fields at each Hall sensor gradually decreased with several time constants. The time constants are listed in Table 3. The range of the time constants was from 90 s to 269 s.

5. Discussion

In large superconducting coils wound with CIC conductors, there are two types of coupling currents. One is the 'regular' coupling current which can be estimated by the cabling pattern of a CIC conductor [13,14]. The other is the 'irregular' coupling current which is an unexpected phenomenon from the conductor design. The 'irregular' coupling current is the same as 'supercurrent', which flows over the entire cable length, observed in a Rutherford type cable [15]. Regarding a decay time constant after coil excitation and demagnetization, the time constant of the regular coupling current is less than several hundred milliseconds. On the other hand, the time constant of irregular coupling current is much longer than one second.

In this study, a 'loop current' is defined as an irregular coupling