Construction and Operation of an Internal Coil Device with a High Temperature Superconductor

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We have constructed and operated an internal coil device with a high temperature superconductor. Three different types of Ag-sheathed Bi-2223 tapes are employed; i.e., a high critical current tape with a low silver ratio for the main HTS coil, a 0.3wt%Mn-doped one for the persistent current switch, and a 3at%Au-doped one for the coil-leads. Cold gas helium is provided by a GM refrigerator and supplied to the coil through a check valve, and the coil current is directly excited by the external power supply through removable electrodes. It took about 11 hours to cool the coil to 21 K from room temperature, and a nominal cable current of 118 A (overall coil current: 50 kA) was achieved. A decay time constant of the persistent current is a few tens of hours. Plasma experiments in a dipole configuration have been initiated.

Keywords:
internal coil device, high temperature superconductor, persistent current mode, dipole plasma

Several devices with internal coils were constructed in the 1970's, and plasma confinement and MHD stability have been studied [1]. Since the internal coil device is suitable for studying basic physics in fusion plasmas, it has been recently revived for exploring high beta plasmas based on new relaxation theories [2,3]. Here we have constructed an internal coil device with a high temperature superconductor (HTS), called Mini-RT. This is the first challenge for utilizing a HTS coil in an experimental plasma device.

The major radius of the internal coil is 0.15 m and the nominal coil current is 50 kA. A schematic drawing of the internal coil is shown in Fig. 1. Ag-sheathed Bi-2223 tape with a low silver ratio of 1.57 is employed, which has a critical current $I_c$ (77 K, self-field (s.f.), 1 μV/cm criterion) of 108 A. The maximum magnetic field strength at the HTS coil is 0.51 T (0.76 T) in the perpendicular (parallel) direction of the tape.

Direct excitation of the coil current by an external power supply is achieved by utilizing removable electrodes. This requires a persistent current switch (PCS) in the coil. Here the PCS is made of a bifilar coil.
with a 0.3wt%Mn-doped Bi-2223 tape ($I_c = 52.5$ A at 77 K, s.f.). The HTS coil and the PCS are covered with a copper radiation shield and multi-layer insulators. A socket-type current feed-through is equipped inside the coil and a removable electrode is inserted. The coil-lead between the HTS coil and the current feed-through is made of a 3at%Au-doped Bi-2223 tape ($I_c = 62$ A at 77 K, s.f.), so as to keep high thermal resistance between the HTS coil and the current feed-through. In addition, in order to reduce the heat load to the coil-lead, the removable electrodes are cooled by liquid nitrogen.

The HTS coil and the PCS are cooled with cold gas helium, which is supplied to the internal coil via a cooling pipe and a check valve. Cold gas helium is supplied for the HTS coil and the PCS separately, because each temperature should be independently controlled. The internal coil is cooled down and excited at the bottom of the vacuum vessel. The coil position is precisely adjusted by means of a rotating stage and two-dimensionally sliding micrometers. Two electrodes and three transfer tubes are inserted into the internal coil. In addition, a multi-pin connector is inserted, and the temperatures and voltages of the HTS coil and the PCS are monitored. Cold gas helium with a flow rate of 0.5 g/s is supplied by two GM refrigerators, the total cooling power of which is 33 W at 20K. It took about 11 hours to cool the coil to 21 K from room temperature.

Excitation of the coil was performed. Figure 2 shows the waveforms of the currents of the coil cable and the power supply, and the temperatures of the HTS coil and the PCS. Here the coil current was evaluated by measuring the magnetic field using a Hall probe. Initially the HTS coil was cooled to 21 K, and then the PCS temperature was raised above the critical temperature (about 106 K) using a Manganin heater so as to keep the turn-off condition. In Fig. 2, a persistent current (of ~80A) due to the previous excitation was quickly discharged with an increase of the PCS temperature. The coil current was supplied by the external power supply within a few minutes. When the coil current was increased up to the nominal value of 118 A, the PCS was quickly cooled to below 40 K to recover the turn-on condition. The current of the power supply was then decreased, and the persistent current mode was achieved. The persistent current gradually decays with a time constant of ~20 hours at the initial phase. This time constant seems to be considerably shorter than the expected value of ~200 hours which can be obtained by integrating the flux-flow resistance and the joint resistance along the coil cable. We should consider some kind of electromagnetic effect for explaining the observed unexpectedly large resistance in the coil cable.

After achieving persistent current, the inserted electrodes and transfer tubes are removed, and the internal coil is mechanically lifted up to the middle position of the vacuum vessel. The magnetic field strength around the internal coil is around 0.1 T, and a radio-frequency wave of 2.45 GHz is applied for the plasma production. The first plasma with a dipole configuration is shown in Fig. 3.

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