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Effect of plasma disruption on superconducting magnet in EAST

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ABSTRACT

For the safe operation of Experimental Advanced Superconducting Tokamak (EAST) with higher plasma performance discharge in future, it is important to study the effect of plasma disruption on central solenoid (CS) coils. The outlet temperature rise of CS1-6 coils measured in experiment is analyzed. It is found that the outlet temperature rise of CS1-6 coils caused by plasma disruption cannot be observed in experimental data, because the effect of plasma disruption on outlet of CS coils is a small value, and the discretization error of experimental data is bigger than this value. In addition, the maximum temperature of CS coils during the plasma discharge is simulated by SAITOKPF code, and it appears that the maximum temperature of CS coils increases a little in the plasma disruption, but the temperature rise is a small quantity.

1. Introduction

Experimental Advanced Superconducting Tokamak (EAST) is the first fully superconducting tokamak in the world [1]. The physical mission of the EAST device is to study the physical issues in steady-state advanced tokamak devices, while its engineering mission is to establish and support the technologic basis of fully superconducting fusion reactor in future.

The magnet system of EAST comprises two main subsystems: 16 D-shaped Toroidal Field (TF) coils and 14 Poloidal Field (PF) coils including 6 central solenoid (CS) coils, 4 large Poloidal Field coils, and 4 divertor coils [2]. All PF coils are made of NbTi Cable-In-Conduit Conductor (CICC). The main parameters of the CS and PF conductors are listed in Table 1 [3]. The CS and PF coils have been stably operated for more than five years. The operations of EAST superconducting coils are stable enough as expected in the presently experimental phase up to 1 MA plasma discharges. However, the advanced operations with higher plasma parameter are planned in the future plasma experiments. Therefore, it is necessary to study the operation state of magnet for future safe running.

It is known that plasma disruptions are rapid events in which the plasma current quickly decays in a time scale of 10–100 ms [4,5]. Due to short time scale, large induced currents are generated in the CS and PF coils, and great change rate of magnetic field caused by this phenomenon could induce the large AC losses in superconducting coils. Theoretically, the AC losses may heat the CS and PF coils up additionally in the plasma disruption. In order to study the effect of plasma disruptions on CS and PF coils, the outlet temperature rise of CS1-6 coils measured in experiment is analyzed. In addition, the SAITOKPF code developed by Wang et al. [6] is employed to study the situation of plasma disruption.

2. Experimental setup

An equivalent cooling power of 2 kW/4.4 K helium refrigerator is set up for the normal operation of EAST. The CS and PF coils are cooled with supercritical helium stream from J-T valve in the helium refrigerator. In order to provide enough mass flow to each cooling channel, the CS and PF coils are arranged into two groups and connected in series for cooling. Before entering the CS1-6 and PF13-14 coils, the helium is cooled to 4.5 K in the sub-cooler. To avoid the increment of the temperature in superconducting strands, the helium is re-cooled in the sub-cooler before it cools PF7-12 coils [7,8]. Some control valves are employed to regulate the mass flows in the parallel-connected cooling lines. The cooling scheme of CS and PF coils is shown in Fig. 1. The inlet temperature and pressure for first group, CS1-6 and PF13-14 coils, are 4.5 K and 0.3 MPa, respectively, and the outlet pressure is 0.23 MPa. The cryogenic cooling parameters for second group, PF7-12 coils, are inlet temperature of 4.5 K, inlet pressure of 0.23 MPa and the outlet pressure of 0.15 MPa. This pressure is not supercritical region for helium, and it is not good for cooling of superconducting magnet. For the higher current of PF coils, the outlet pressure of CS and PF coils will be increased to 0.3 MPa in future.

In the experiments, the plasma is controlled by adjusting the variation of the operating currents with time in CS and PF coils. The

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Table 1
Parameters of CS and PF conductor.

Conductor	CS1-6	PF7-14
Configuration	(2SC + 2Cu) × 3 × 4 × 5 + 1CCC[a]	(1SC + 2Cu) × 3 × 4 × 5 + 1CCC
Number of SC strands	120	60
Number of Cu strands	120 + 21	120 + 21
Diameter of SC strands (mm)	0.87	0.87
Diameter of Cu strands (mm)	0.98	0.98
RRR of Cu strands	>100	>100
316LN conduit thickness (mm)	1.5	1.5
Size of CICC (mm^2)	20.35 × 20.35	18.6 × 18.6
Void fraction	35.0%	35.9%

[a] 1CCC (copper cable core) is 3 copper strands × 7.

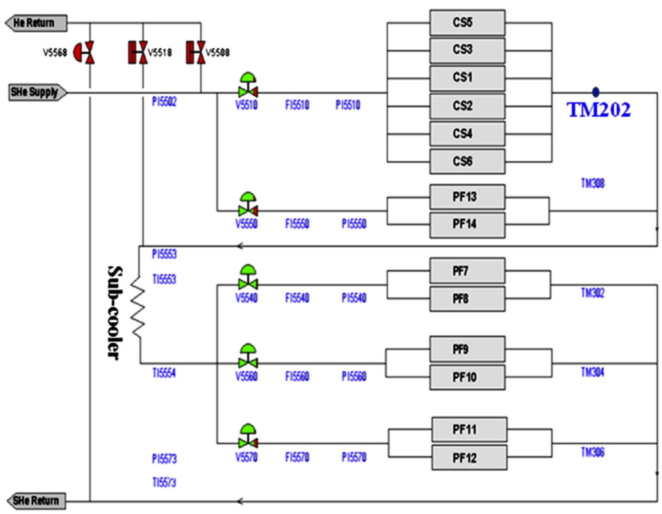

Fig. 1. Configuration of cooling scheme of CS and PF coils.

actual operating status is based on the requirements of physical experiment. The maximum current and ramping rates of CS coils are much higher than those of other PF coils. The temperature rise of CS coils is higher than PF coils, so the outlet temperature rise of CS coils measured in experiment is analyzed in the following.

Outlet temperature of total CS1-6 coils for continuous shots, which is measured by temperature sensor TM202 (see Fig. 1), is shown in Fig. 2, and every peak represents one shot. Before the plasma discharge, the minimum temperature T_{min} is acquired. After the plasma operation, the maximum temperature T_{max} is obtained, and the outlet temperature rise of CS coils, ΔT is calculated by subtracting the T_{min} from T_{max}.

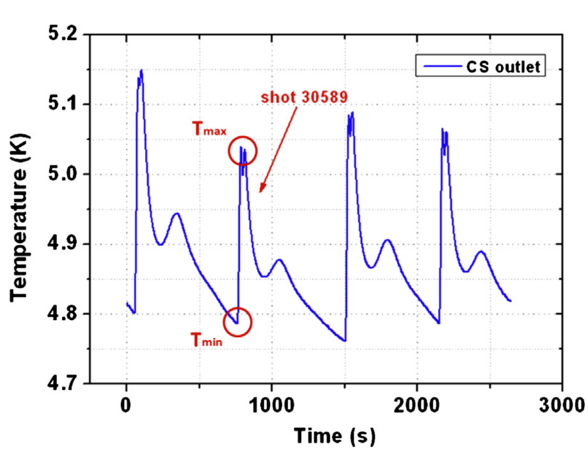

Fig. 2. Outlet temperature rise of CS1-6 coils with respect to time for continuous discharges (shot 30588–30591). It is measured by temperature sensor TM202.

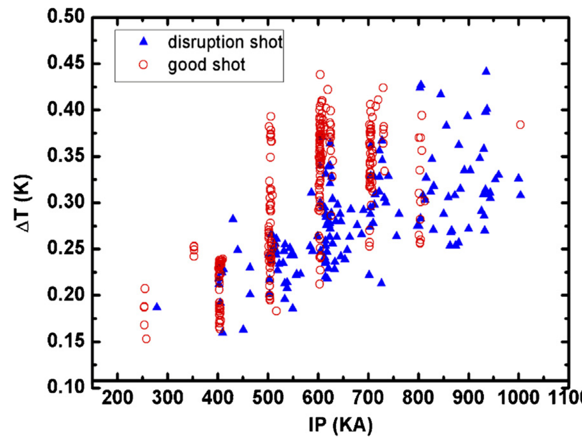

Fig. 3. The comparison of good shots and disruption shots on the effect of temperature rise in CS coils for LHCD discharges. The horizontal abscissa is plasma current. The red circle indicates the good shot, and the blue triangle represents disruption shot. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

3. Experimental results and discussion

In order to study the effect of plasma disruption on CS and PF coils, the outlet temperature rise of CS1-6 coils in good shots is compared with that in disruption shots. Fig. 3 shows the comparison of temperature rise between good shots and disruption shots for lower hybrid current drive (LHCD) discharges, and the horizontal ordinate is plasma current. The blue triangle represents temperature rise of disruption shots, and the red circle denotes that of good shots. It is obvious that outlet temperature rise of CS1-6 coils of disruption shots is lower than that of good shots. This phenomenon is also observed for ohmic discharges, and it is shown in Fig. 4.

Therefore, the current waveform of CS and PF coils is analyzed, it is found that the energizing time of CS and PF coils in disruption shot is lower than that in good shot. The comparison of typical current waveform of CS and PF coils between good shot and disruption shot is shown in Fig. 5. The red line indicates the good shot (shot number 30588), plasma current is 630 kA, duration of plasma

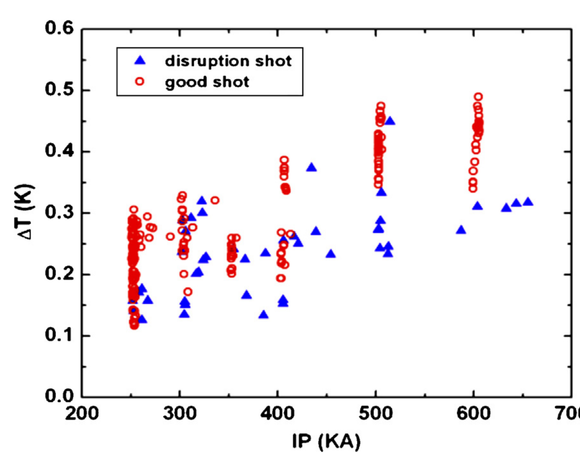

Fig. 4. The comparison of good shots and disruption shots on the effect of temperature rise in CS coils for ohmic discharges. The horizontal abscissa is plasma current. The red circle indicates the good shot, and the blue triangle represents disruption shot. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)