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The magnetic field configuration measurement on EAST tokamak

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ABSTRACT

The magnetic field configurations of poloidal field (PF) and toloidal field (TF) are the base of tokamak plasma operation. They are determined by the parameters such as positions and structures of PF and TF coils. Parameters of TF and PF coils of a new fully superconducting tokamak with non-circular cross-section EAST will change when the coils are cooled down from the ambient temperature to 4 K. Because of the cryogenic and refrigerator system, these parameters cannot be measured directly. Using magnetic probes signals, we measured and reconstructed magnetic field configuration of TF and PF coils. Parameters such as the positions of PF coils, the profile of the toloidal field in radial direction, the ripple and error field of toloidal field are obtained from the measurements.

1. Introduction

For a new tokamak machine, the magnetic field configuration measurement is one of the basic tasks before the first experiment. From the measurement, the distributions of each magnetic field could be obtained, both poloidal field (PF) and toloidal field (TF), and some other important data also can be gotten such as the error field, the ripple of the toloidal field in low field position. All of these data are very important data for tokamak machine operation [1].

The experimental advanced superconducting tokamak (EAST) is a non-circular advanced steady-state experimental device in the Institute of Plasma Physics, Chinese Academy of Science. Table 1 shows the main parameters of EAST.

For EAST, a full superconducting tokamak (both PF and TF coils are superconducting magnets), the positions and shapes of TF and PF coils will change when cooled down from the normal temperature to 4 K. For example, the TF and PF coils may sink and lean. Here, each coil is a rigid circular body and only its movement and tilting is considered. In the design of TF and PF coils system, these factors have been taken into account, but they still should be measured in the experiment to check whether the design parameters are correct. When the magnets are cooled down, because of the cryogenic refrigerator and inner vacuum vessel, these coils' positions cannot be measured directly from the outside. To avoid this difficulty, we used magnetic probes to measure all the field configuration parameters. In the first engineering testing of EAST tokamak, magnetic field configuration measurement was done successfully [2].

There are two normal ways to measure the magnetic field. The magnetic probe is one of the important techniques to measure the dB/dt in tokamak experiment. The magnetic field value can be obtained when the probe signal is sent into an integrator [3]. The advantage of magnetic probe is that it has high sensitivity when a suitable NS value of probe is given. But it cannot be use to measure the constant field, such as toloidal field. The disadvantage is that the size will be too big if large output signal is needed. The other one is hall probe. It is usually used to measure the static state field. In general, the output signal of hall probe is very small when the magnetic field is not very high. In the EAST magnetic configuration experiment, both magnetic probe and hall probe are used. The magnetic probes are used in PF system measurement, and hall probes are used in TF system measurement.

The measurement system is installed in the inner vacuum vessel. Because it is adiabatic with the superconducting magnet, the measurement system is in the normal temperature. The position of the measurement system does not change when the PF and TF coils are cooled down. From the signals of the measurement system we reconstruct the magnetic configuration.

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Table 1
Main parameters of EAST

Toroidal field, B_T (T)	3.5
Plasma current, I_p (MA)	1.0
Major radius, R (m)	1.75
Minor radius, a (m)	0.4
Elongation (K)	1.6–2.0
Triangularity	δ 0.4–0.8
Ion cyclotron, PICRF (MW)	3.0
Lower hybrid, PLH (MW)	3.5
Electron cyclotron, PEC (MW)	0.5
Pulse length (s)	1–1000
Plasma species	Hydrogen and/or deuterium
Configuration	Double-null divertor Single-null divertor Pump limiter

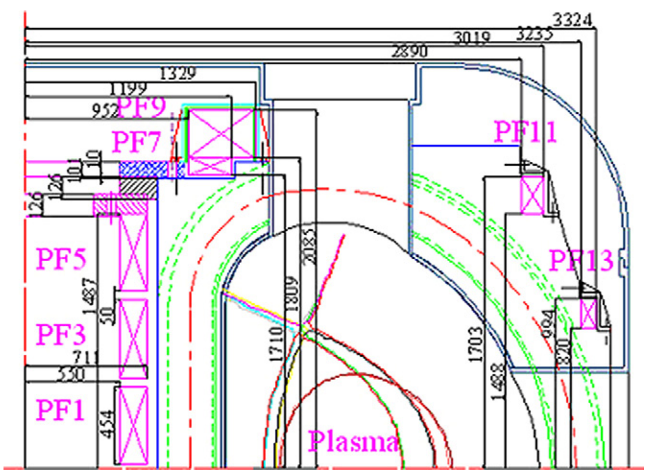

Fig. 1. EAST PF coil positions.

In this paper, we present the results of the magnetic field configuration measurement on EAST. In Section 2, the PF measurement system and measurement result is described in detail. The TF measurement system is present in Section 3.

Table 2
EAST PF coils design position

	PF1	PF3	PF5	PF7	PF9	PF11	PF13
R (mm)	628.66	628.66	628.66	1072.17	1136.79	2945.58	3269.8
Z (mm)	251.32	753.96	1256.6	1753.7	1940.92	1590.73	904.19

2. The PF configuration measurement system

2.1. The measurement system

The EAST tokamak PF coils system is illustrated in Fig. 1, and the design positions are listed in Table 2. Fig. 1 shows the upper half of the tokamak PF coil system. The lower half is not shown because the system is symmetrical by the mid-plane.

Based on the Ampere's law, the signal value is sensitive to the distance between the magnetic probe and corresponding PF coil. So near each PF coil positions, a magnetic probe is installed. There are 10 magnetic probes in different positions in the vacuum vessel. Each probe has two directions to measure B_r and B_z separately. There are four groups of these probes arrays installed in the toloidal directions to measure the symmetry (right figure in Fig. 2). In all there are 80 signals useful for reconstructing each PF magnets positions. Based on the distance between the magnetic probes and PF coils, different fit weight parameters are set in the reconstruction algorithm (Fig. 2). Detail of the reconstruction algorithm is explained below.

2.2. Reconstruction algorithm

Because the center position of each PF coils will be changed when the superconducting coils cool down. So in the experiment the general coordinate system in tokamak (r, z, θ) cannot be used. Instead we used the coordinate systems shown in Fig. 3. We assume that the design position of PF coil is (x, y, z). When cooled down, the PF coil position is shifted to (x', y', z'). Five parameters, Δx, Δy, Δz, θ, α are needed to calculate the new PF position (x', y', z'). The relationship between (x, y, z) and (x', y', z') is listed in the equation

$$\begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \cos(\alpha)\cos(\theta) & \sin(\alpha)\cos(\theta) & -\sin(\theta) \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ \cos(\alpha)\sin(\theta) & \sin(\alpha)\sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} x-\Delta x \\ y-\Delta y \\ z-\Delta z \end{pmatrix} = A \begin{pmatrix} x-\Delta x \\ y-\Delta y \\ z-\Delta z \end{pmatrix}$$

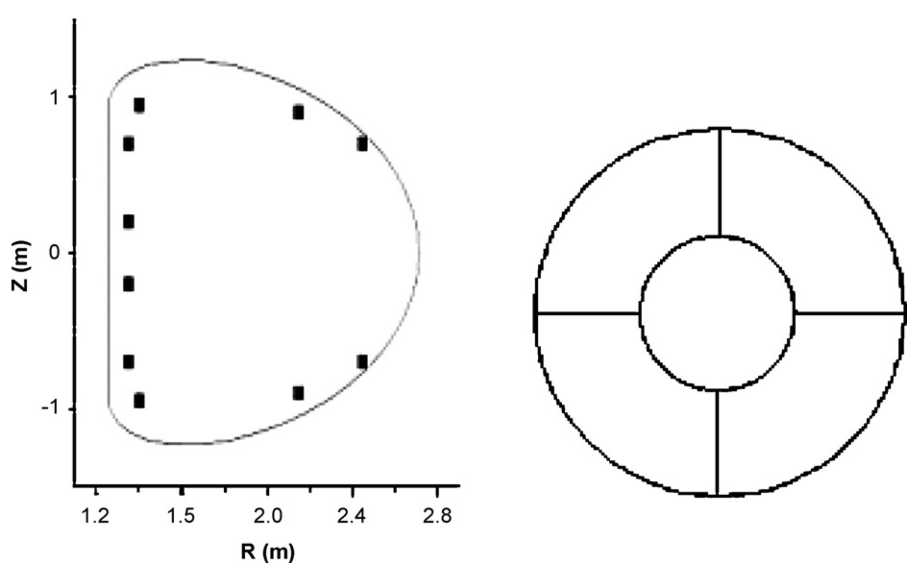

Fig. 2. The measurement system of poloidal field.