Fusion Engineering and Design xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Calibration and uncertainty analysis of magnetic measurement for plasma shape reconstruction on EAST

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HIGHLIGHTS

- The calibration of EAST magnetic diagnostics.
- The uncertainties analysis of magnetics sensors.
- The uncertainties influence on the plasma shape reconstruction.

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form 14 February 2016
Accepted 15 February 2016
Available online xxx

Keywords:
Magnetic diagnostics
Calibration
Uncertainly
Plasma shape reconstruction

ABSTRACT

Magnetic diagnostics is one of basic measurement systems for Tokamak plasma current and shape control. The accuracy of magnetic data will influence the plasma shape reconstruction. In this paper, the calibration of magnetic diagnostics is carried out on the EAST Tokamak. The overall uncertainties of magnetic sensors are analyzed from the calibration and vacuum shots. The uncertainty results are used as fitting weight in plasma shape reconstruction code (EFIT). Based on EFIT simulation and experiment data fitting results, the sensitivity of the magnetic data uncertainty in the plasma shape reconstruction is analyzed.

1. Introduction

Magnetic diagnostics is one of basic measurement systems in Tokamak device. On EAST superconducting Tokamak, the magnetic diagnostics includes plasma current rogowski coils, magnetic pickup coils, mirnov probes, poloidal flux/saddle loops, diamagnetic loops, Halo current monitors, and poloidal field coil current sensors. The configuration of EAST magnetic diagnostics is showed in Fig. 1 [1].

In magnetic diagnostics, sensors which are used for equilibrium reconstruction contain: plasma current rogowski coil, 38 poloidal pickup coils, 35 poloidal flux loops and 12 poloidal field coil currents.

The basic principle to reconstruct the plasma shape is to solve the Grad-Shafranov equation [2], the plasma shape parameters are determined from magnetic sensors data by using the least squares fitting:

$$\chi^2 = \frac{1}{k}\sum_{i=1}^{k}\frac{\left(X_i^c - X_i^e\right)^2}{\sigma_i^2} \quad (1)$$

$$X^c = G\left(\vec{r_d}, \vec{r_{PF}}, \vec{r_{plasma}}, \vec{r_{eddy}}\right) \times I \quad (2)$$

where X_i^c and X_i^e are the computational and experimental values of magnetic measurement. Fitting weight σ_i should stand for the offset $\Delta_i = X_i^c - X_i^e$. G is matrix of green functions, I and $\vec{r}$ are the matrix of currents and positions.

The total offset comes from green functions and measurement:

$$\Delta = \Delta^c + \Delta^e \approx G\left(\vec{r_d}, \vec{r_{PF}}\right) \times I_{PF}^{\Delta} + G^{\Delta} \times I_{PF} + \sigma_d \quad (3)$$

The offset contains the effects of all uncertainty sources. They can be divided into two parts, the system uncertainties and the random uncertainties. The system uncertainties include PF current, and uncertainty of magnetic diagnostics σ_d. The uncertainty of magnetic diagnostics contains the error of diagnostics active areas, the error of integrator-acquisition system, the signal attenuation of the 70 m twisted pair, and the imperfection of the diagnostics. They are

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http://dx.doi.org/10.1016/j.fusengdes.2016.02.051
0920-3796/

Please cite this article in press as: B. Shen, Calibration and uncertainty analysis of magnetic measurement for plasma shape reconstruction on EAST, Fusion Eng. Des. (2016), http://dx.doi.org/10.1016/j.fusengdes.2016.02.051

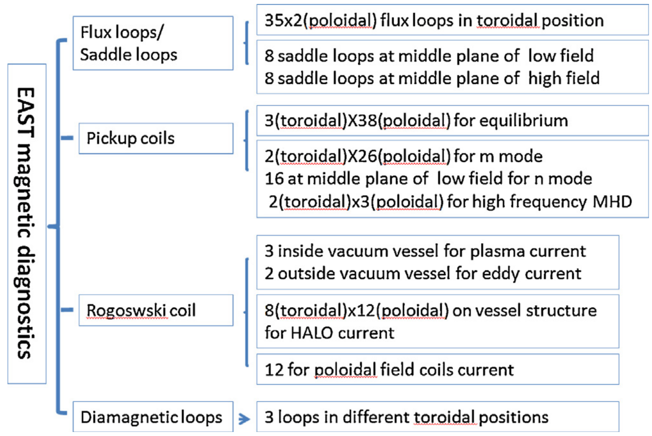

Fig. 1. EAST magnetic diagnostic configuration.

belonged to system uncertainties because all of these parameters can be calibrated accurately by different method. The mainly random uncertainties are base on the positions of poloidal field(PF) coils and magnetic sensors [3]. When the EAST machine is in operation, the relative positions between poloidal coils and magnetic sensors will be changed. The main reason is that the poloidal field coils will cool down to superconduction temperature and inner structure inside vacuum vessel will be in high temperature. They are belonged to random uncertainties, because these parameters cannot be measured accurately.

In EAST magnetic diagnostics system, the system uncertainty parameters which are needed to be calibrated are listed in following: sensors effective area, integrator and amplifier, signal transfer line. Different methods for calibration are introduced in detail in this paper.

For flux loop, $\phi = \int V_s dt = \frac{G}{RC} \int V_s dt \times T_{das\_fl}$

where: ϕ is the measurement result of the flux loop, and G is additional gain of the amplifier, and RC is the time constant of the integrator, NS is the pickup coil's effective areas, and T_{das} is the translation coefficient of the data acquisition system.

The random uncertainties are based on the PF coils and sensors positions, and cannot be obtained by measured directly. For example, when the superconducting coils are cooled down from room temperature to 4.5 K, the coils positions will be changed because of contraction. Also, the sensors positions will be changed when the vacuum vessel baked or pumped. These changes will influence the green functions. Because there is no exact plasma and eddy current model, so a lot of vacuum shots will used to analyze and estimated the error of plasma shape reconstruction.

2. Calibration of EAST magnetic diagnostics

In the whole magnetic measurements circuit, there are several system uncertainties sources from the sensor to signal processing

For magnetic pickup coil and rogowski coil,
$$\begin{cases} B = \frac{1}{NS} \int V_s dt = \frac{G}{RC} \int V_s dt \times T_{das\_probe} \\ I = \frac{1}{2\pi r_0} \times \frac{1}{NS} \int V_s dt = \frac{G}{RC} \int V_s dt \times T_{das\_PF} \end{cases}$$

Conductor size	Coil turns	Coil Inner diameter	Coil Length	Coil resistance
2.8×4mm	200×2=400	200mm	1000mm	0.562Ω

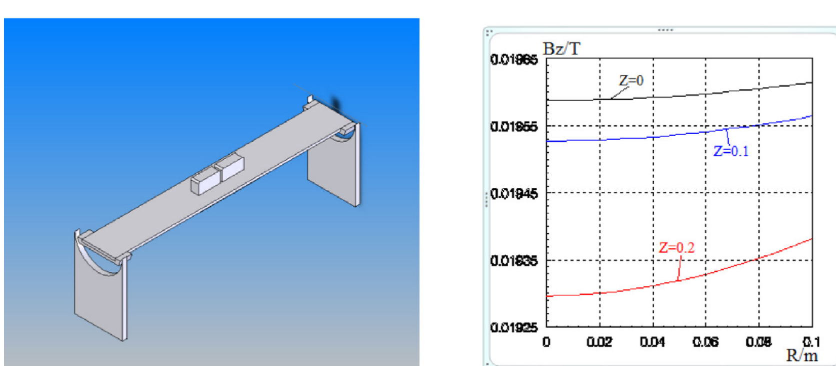

Fig. 2. The parameters of solenoid and magnetic field profile inside.

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