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Discharge Simulation of EAST First Plasma

B. Wu[1], C.Y. Liu[1,2], B.J. Xiao[1], Y.D. Pan[3]

1, Institute of Plasma Physics, Chinese Academy of Science, Hefei, Anhui,230031, China,

2, Hefei University of Technology, Hefei, Anhui,230009, China

3, Southwest Institute of Physics, Chengdu, Sichuan, 610041, China

Abstract: TSC code has been used to model the time dependence of the first ohmic discharges in EAST experiment. A good agreement between the simulation and the experiment is obtained in the plasma current, major radius, electron temperature, loop voltage and PF current for the entire duration of the discharge, which indicates the code has a high credence and allows us to make a further study on EAST discharge with confidence. At the same time, the code also simulates some important plasma parameters with no experimental measurements so far, such as plasma minor radius, central and edge safety factors, elongation and dalta etc., which can play an important role in the analysis of EAST experiments.

Keywords: Numerical Simulation, EAST, TSC code, Volt-second consumption

1 Introduction

The EAST is a non-circular advanced steady-capable and long duration plasma device, which can afford a scientific and technological reference for an attractive fusion reactor ITER to be built in France. The evolution of plasma and control of configuration are vital to steady operation and long duration. In this paper, we model several ohmic discharges in the EAST experiment using TSC code[1] and present the results of the evolution of plasma and shape. The modeling results follow a good agreement with experiment. In section 2, we briefly introduce the simulation model. The modeling results and experimental comparison are described in section 3. The analysis of volt-second consumption for the entire duration is presented in section 4 and conclusions are described in section 5.

2 Simulation Model

TSC is a numerical model of an axisymmetric tokamak and simulates the evolution of two-dimensional time dependent free boundary plasma by advancing the MHD equations coupled with the external circuits. The initial free-boundary plasma equilibrium formed on a rectangular computational domain with boundary conditions is mostly dependent on the initial plasma and coil currents, the initial toroidal field, the initial safety factor and the initial pressure.

The plasma electron and ion temperatures are evolved by solving a set of $1^1/_2$-D flux-surface averaged transport equations. Here, we adopt the neo-ALCATOR transport model. In the simulation of particle density transport, we force the density to have a profile given by $\mathrm{n_e}(\hat{\psi},\mathrm{t}) = n_e^0(t)\left[1-\hat{\psi}^{\beta_N}\right]^{\alpha_N} + n_b(t)$, . Here we only present a brief description of the simulation model and a detailed mathematical description can be referenced in [1, 2]

3 Simulation results and comparisons

For the modeling of the EAST ohmic discharges, we randomly selected several shots. The peak plasma currents in these shots are between 148 and 250KA, the duration of the discharges are 2.05-4.5s, the densities are between 0.4－1.0× $10^{19}\mathrm{m}^{-3}$.We performed the simulations of these shots starting at about 30ms into the discharges as the TSC code does not simulate the initial plasma breakdown..

The experimental PF coils specified in simulation through their actual location, dimension and number of turns are shown in table 1 and in figure 1 and major parameters of EAST are referenced in table 2

The poloidal magnet system in EAST consists of three pair of Central Solenoid coils（PF1－PF6） and four pair of Poloidal Field coils(PF7－PF14). They are placed symmetrically about the device horizontal mid-plane. The primary purpose of

Central Solenoid coils is to induce current in the plasma through transformer action and Poloidal Field coils are used to control the shape and position of plasma.

Table 1. Poloid field parameters of EAST

Name	R[m]	Z[m]	ΔR [m]	ΔZ [m]	Nr	Nz
PF1	0.62866	0.25132	0.16078	0.45177	7	20
PF3	0.62866	0.75396	0.16078	0.45177	7	20
PF5	0.62866	1.2566	0.16078	0.45177	7	20
PF7	1.07217	1.7537	0.24694	0.09769	11	4
PF9	1.13679	1.94092	0.37618	0.27473	17	12
PF11	2.94558	1.59073	0.12844	0.21256	6	10
PF13	3.2698	0.90419	0.08896	0.17188	4	8

Table 2. Major parameters of EAST

Item(unit)	value
B_t(T)	3.5-4.0
Ip(MA)	1.0－1.5
R(m)	1.70
a(m)	0.4
κ	1.5-2
δ	0.3-0.5
NBI(MW)	4.0-8
ICRH(MW)	3.0-6.0
LHCD(MW)	3.5-8.0
ECRH(MW)	0.5-1.5
Pulse length(s)	1000
Configuration	Double-null divertor
Single-null divertor	

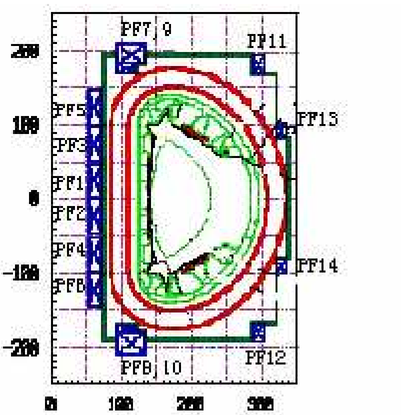

Fig.1

Table 3. The main input parameters of EAST discharge simulation for shot#2422

Time(s)		0.03	0.8732	3.034	3.3
PF	PF1(KA)	6.64	2.86	−2.42	2.54
Coil	PF3(KA)	6.91	3.31	−1.61	−1.81
Curr	PF5(KA)	7.99	3.70	−3.86	−4.20
e-nt	PF7/9(KA)	3.16	1.59	−2.69	−2.80
	PF11(KA)	0.85	−0.52	−1.16	−1.09
	PF13(KA)	0.46	−1.38	−1.03	−0.81
Plasma current(KA)		13.94	195.01	194.0	85.26
Plasma density($10^{19}m^{3}$)		0.07	0.38	0.40	0.35
Toroidalfield function		4.45	4.45	4.45	4.45

The main input parameters of EAST discharge simulation for shot#2422 are presented in table 3.The control system assumes that the current in each of the poloidal field coils is the sum of a preprogrammed current and a much smaller correction current. The correction currents are computed during the simulation to adjust the position and shape of the plasma. This is accomplished by letting the feedback current in each coil group be proportional to a flux difference between two observation points ($\vec{x}_1$, $\vec{x}_2$). The observation points are the coordinates at which the flux is measured for the feedback system. The location of these points is dependent on what the feedback system is to control and can vary in time. Thus, the current in each coil group is computed by

$$I_w^k(t)=I_0^k(t)+I_{FB}^k(t)=I_0^k(t)+\alpha_p^k(\psi(\vec{x}_1)-\psi(\vec{x}_2))$$

where $I_w^k(t)$ is desired current, $I_0^k(t)$ is the preprogrammed current, $I_{FB}^k(t)$ is the feedback current, $\alpha_p^k(t)$ is the proportional gain.

The initial plasma equilibrium is computed by specifying the experimental coil currents and plasma parameters at that time. After the initial equilibrium, it is evolved in time. A typical EAST ohmic discharge chosen in these simulations, for shot#2422 is shown in Figure 2. The temporal evolution of plasma current, loop voltage, major radius and electron temperature follows a good match with experiment. The simulation time ranges from 0.03 to 3.3s after plasma initiation. The plasma current reached the flat-top with the value 195KA at 0.8732s and began to ramp down at the time of 3.034s. Note that the Te measurements are from the soft x-ray diagnostics in EAST, which measures the Bremsstrahlung radiation. It can be seen that there is a good agreement between simulation result and experiment for the temporal evolution of PF currents shown in figure 3, which shows the stability of feedback control of PF current and configuration. As there are no experimental measurements of minor radius, dalta, elongation and edge and central safety factors in EAST so far, only the simulated values have been plotted in the figure4, which has a vital importance for EAST experimental analysis. Figure 5(a) shows the plasma magnetic configuration simulated by the TSC code at the time of 2.5 s , which is validated by Figure 5(b) fitted by the EFIT code.

4.The analysis of volt-seconds consumption in the discharge[6,7,8]

For a pure ohmic tokamak discharge, the plasma current is driven only inductively and the volt-second variation afforded by the PF currents is limited, so we must make an efficient use of the available volt-seconds. The volt-seconds consumption is very important for the plasma rampup and configuration control during the entire duration. The poloidal flux consumed by the plasma during the current rampup $\Delta\Phi_{total}$ can be divided into two parts: an external part $\Delta\Phi^{external}$ corresponding to the flux between the machine axis(X=0) and the inside edge of the plasma (X=R-a) and internal part $\Delta\Phi^{internal}$ corresponding to R-a ≤ X ≤ R. The plasma $\Delta\Phi^{internal}$ piece can also be divided into two parts: an inductive volt-second $\Delta\Phi^{inductive}$ required to establish the magnetic configuration and a resistive volt-second $\Delta\Phi^{resistive}$ to sustain the Ohmic dissipation. Thus,

$$\Delta\Phi_{total} = \Delta\Phi^{external} + \Delta\Phi^{internal} \qquad (1)$$

$$\Delta\Phi^{internal} = \Delta\Phi^{inductive} + \Delta\Phi^{resistive} \qquad (2)$$

$$\Delta\Phi^{external} = L^{ext} I_P \qquad (3)$$

where:

$$L^{ext} = L_s - \mu_0 \mathrm{R} \frac{\mathrm{M}-1}{4} \left(\ln 8/\varepsilon + \beta_{\mathrm{p}} + l_i/2 - 3/2\right)$$

$$L_s = \mu_0 \mathrm{R} \frac{\mathrm{f}_1(\varepsilon)(1-\varepsilon)}{1-\varepsilon+\mathrm{f}_2(\varepsilon)\kappa}$$

$$M = \frac{(1-\varepsilon)^2}{(1-\varepsilon)^2 \mathrm{f}_3(\varepsilon) + \mathrm{f}_4(\varepsilon)\kappa^{1/2}}$$

$$\mathrm{f}_1(\varepsilon) = \left(1 + 1.81\sqrt{\varepsilon} + 2.05\varepsilon\right)\ln 8/\varepsilon - \left(2 + 9.25\sqrt{\varepsilon} - 1.21\varepsilon\right) \qquad (4)$$

$$\mathrm{f}_2(\varepsilon) = 0.73\sqrt{\varepsilon}\left(1 + 2\varepsilon^4 - 6\varepsilon^5 + 3.7\varepsilon^6\right)$$

$$\mathrm{f}_3(\varepsilon) = 1 + 1.98\varepsilon^2 + 0.49\varepsilon^4 + 1.47\varepsilon^6$$

$$\mathrm{f}_4(\varepsilon) = 0.25\varepsilon\left(1 + 0.84\varepsilon - 1.44\varepsilon^2\right)$$

L^{ext} , I_P , R , ε , β_{p} , l_i are plasma external inductance, plasma current, plasma major radius, plasma inverse aspect ratio, poloidal beta and plasma internal inductance. While internal inductive component and resistive component are expressed by introducing the Ejima coefficient C_E[7], which is a function of time for a given discharge.

$$\Delta\Phi^{inductive} = \mu_0 \mathrm{R} \mathrm{I}_{\mathrm{P}} \frac{l_i}{2} \qquad (5)$$

$$\Delta\Phi^{resistive} = C_E \mu_0 \mathrm{R} I_P \qquad (6)$$

The modeling results of volt-seconds consumption for EAST shot#2422 are shown in Figure 6. After the flat-top is reached, it is noted that the resistive volt-second consumption increases almost linearly and the curves of total, internal and resistive volt-second consumption are parallel to each other, which indicates that the inductive and external fluxes remain constant and the total flux increase is only due to the resistive contribution which is equal to the product of the loop voltage and flat top duration. Another conclusion is made that plasma resistive volt-second consumption is much greater than inductive component for first EAST discharge due to the high Z_{eff} arising from the high percentage of impurity. So, for next turn EAST discharge, some effective measures must be taken to decrease the level of impurity percentage, because it has a great influence on transport and radiation.

5 Conclusions

we have modeled the first EAST ohmic discharge using TSC code and a good agreement between simulation and experiment is obtained in the plasma current, major radius, loop voltage, electron temperature and PF current .Some important plasma parameters not measured so far have also been modeled, such as central and edge safety factors, elongation, dalta and minor radius, which enables us to use the code for predictive simulations for EAST future experiments with confidence.

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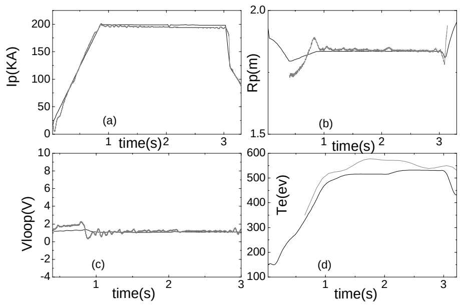

Fig. 2

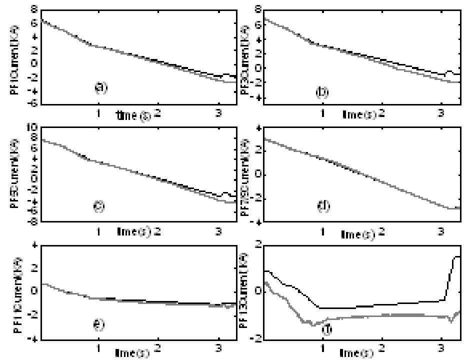

Fig. 3

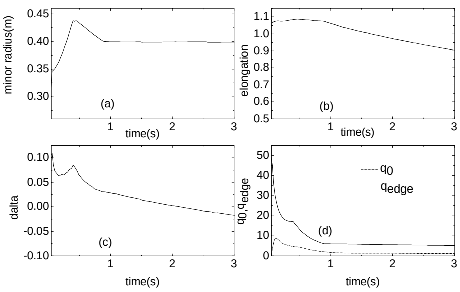

Fig. 4

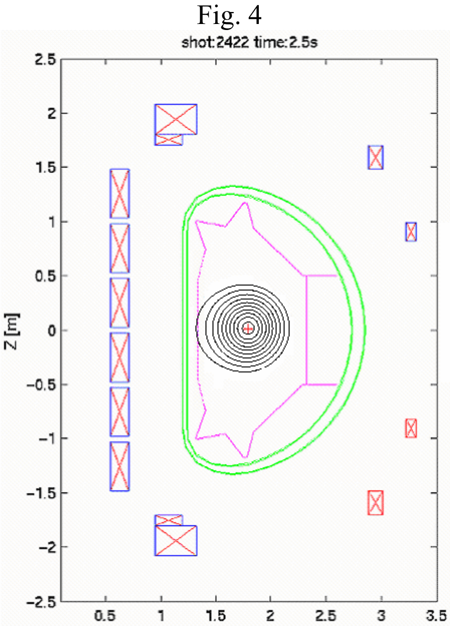

Fig.5 (a)

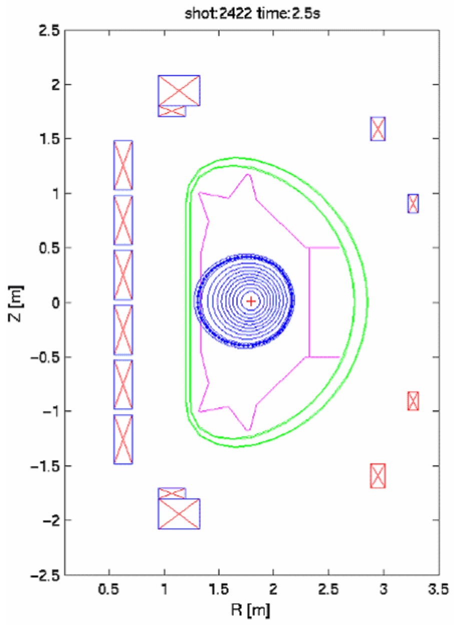

Fig. 5(b)

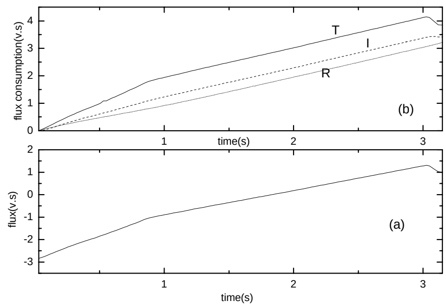

Fig. 6