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Development of simulator for plasma position and shape control in JT-60SA

JT-60SA位置形状制御シミュレータの開発

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The plasma position and shape control is important issue in JT-60SA, ITER and future fusion reactor which has a small number of coils. In order to study the plasma position and shape control, we are developing a simulator which consists of an equilibrium solver and an 'isoflux' controller. The controller controls poloidal field (PF) coil currents so as to keep the poloidal flux is equal at all of specified locations. The equilibrium solver identifies an equilibrium under the specified PF coil current and implements the effect of eddy current. The position and shape control has been simulated in response to prescribed change in the poloidal beta and the internal inductance due to heating.

1. Introduction

The plasma position and shape control is important issue in JT-60SA, ITER and future fusion reactor which has a small number of coils. The precise control of the plasma position is key issue in order to avoid damages on the first wall. It is necessary that the control logic implements the effect of shielding magnetic field because of large eddy current on the vacuum vessel in JT-60SA. The position and shape control simulator which implements the effect of eddy current is developed with the intention of studying technique of plasma position and shape control. In section 2, we describe the outline of control simulator. In section 3, the position and shape control has been simulated in response to prescribed change in the poloidal beta and internal inductance.

2. Outline of Control Simulator

The simulator consists of the equilibrium calculation part and the controller part. The plasma equilibrium for a given set of coil current is obtained in the equilibrium calculation part. The set of coil current is modified to adjust the plasma position and shape at the next time step in the controller part. By iterating these procedures, feedback control of plasma position and shape by control of the coil current is simulated. The control logic of coil current will be optimized by the simulator. Figure 1 shows calculation flow. In a usual equilibrium code, the plasma position and shape is given and the coil current is adjusted to obtain the equilibrium with a given position and shape. On the other hand, in the equilibrium calculation part of the simulator, the position and shape of the plasma is obtained as a result of

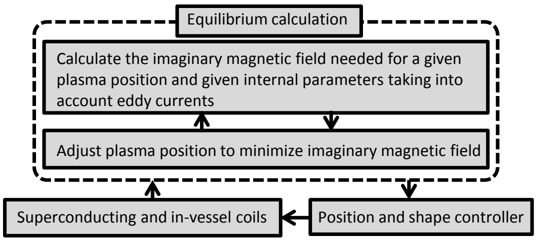

Fig.1. Calculation flow of control simulator.

equilibrium calculation. To do this, we introduced an imaginary magnetic field. We assume a plasma position and calculate the equilibrium by adjusting the imaginary field. In the equilibrium calculation, plasma internal parameters (poloidal beta and internal inductance) are also fixed to given values by adjusting the plasma pressure and current profile. The eddy current induced in the conducting structures around the plasma (the in-vessel stabilizing plate and the vacuum vessel) is calculated using the voltage induced by change in the magnetic field and is taken into account for the equilibrium calculation (calculating the necessary imaginary field). The plasma position is adjusted to minimize the imaginary magnetic field and then an equilibrium realized for a given set of coil currents is obtained. In the controller part, the 'isoflux' technique is employed as the position and shape control. A set of locations that defines the desired plasma separatrix is specified as the reference positions. The poloidal field coil currents are adjusted to keep the poloidal flux is equal at all of these locations. The controller modifies the coil current according to the follow equation,

$$\{dI_j\} = M^{-1}(G_P + G_I\int dt + G_D(d/dt))\{\delta\Psi_i\}dt \quad (1)$$

where, $\delta\Psi_i$ is the difference between flux and its reference value at the control point, dI_j is the amount of modification in the coil current and M^{-1} is the control matrix which is the inverse of Green's function M calculated by use of singular decomposition method, respectively. The G_P, G_I and G_D are the proportional (P), integral (I) and derivative (D) control gains for modifying the coil current, respectively. The superconducting coils use the P-I control, and the in-vessel coils use the D control.

3. Simulation Result

The position and shape control has been simulated during heating phase in which the plasma position and shape were attempted to be fixed while the poloidal beta and internal inductance are changing. Figure 2 shows the flux contour and input control points at the initial time. A typical JT-60SA lower single null equilibrium with I_P=5.5 MA is shown. There are 10 poloidal field coils and 2 fast plasma position control coils (FPPCCs) in JT-60SA. The poloidal field coils and FPPCCs are superconducting and in-vessel copper coils, respectively. The poloidal field coils consist of central solenoid (CS) modules and equilibrium field (EF) coils. The input control points as the reference of position and shape are 6 points (P1 to P6). The P0 is the X point. The value of control gain is shown in Table I. The controller modifies the current of CS and EF to adjust the flux at the reference and X points. The controller modifies the current of FPPCC with reference to the flux of P1 and P2. The vacuum vessel and stabilizing plate are modeled as 71 and 27 toroidal conducting elements, respectively. Figure 3 shows waveforms of internal parameter, plasma position, coil current, coil voltage and eddy current.

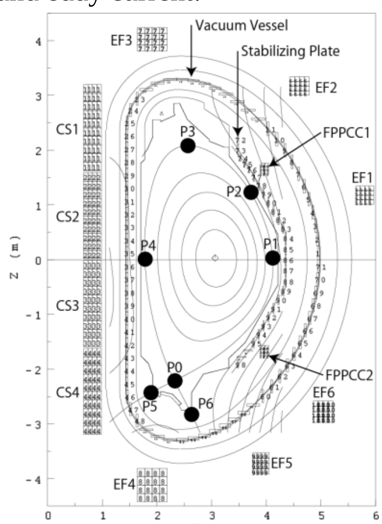

Fig.2. Flux contour and control points at the initial time.

Table I. Value of control gain

	G_P[1]	G_I[1/s]	G_D[s]
Reference Point(CS and EF)	0.5	1.0	-
X point(CS and EF)	0.1	0.8	-
FPPCC	-	-	0.005

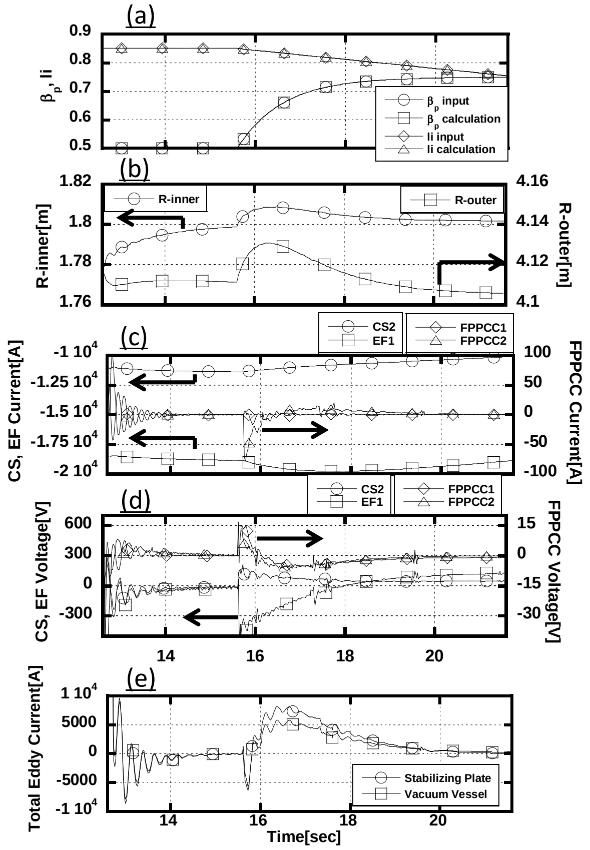

Fig.3. Waveform of (a) input and calculation value of the poloidal beta and internal inductance. (b) inner and outer position of the separatrix in the major radius direction. (c) coil current of CS2, EF1, FPPCC1 and FPPCC2. (d) voltage of CS2, EF1, FPPCC1 and FPPCC2. (e) total eddy current on the stabilizing plate and vacuum vessel.

The poloidal beta increased exponentially from about 0.5 to 0.75 with a time constant of 1 sec. The internal inductance decreased linearly from about 0.85 to 0.75 with time. The internal parameters are converged at each time step. The outer position increased from about 4.11 to 4.13 m initially due to an increase in the poloidal beta. The current of EF1 slowly increased (in the negative direction) to move the outer position inward, to the reference position. The plasma position and shape have been approached to the input reference values at 21.6 sec. It was possible to simulate the position and shape control in response to prescribed change in the poloidal beta and internal inductance with a small number of coils. The position and shape control of the transition from limiter to diverter configuration is also reported. The control characteristics induced by changing the control gain are discussed.