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ロバスト制御理論の核融合炉への適用
Application of robust control theory for the fusion plasma

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To operate the future reactor, the following three subjects should be considered. First, many parameters will have to be controlled at the same time. For example, in addition to total fusion power, plasma parameters such as plasma current and density might be controlled so as to assure a stable plasma operation. Second, relationship between actuators and control parameters is not in one-to-one correspondence, but complexly coupled with each other. For example, NBI affects not only on the plasma current, but also on the fusion power. Finally, the actuators and diagnostics which can be installed in a reactor will be limited because of high heat flux or neutron flux. To tackle this MIMO (Multi-Input Multi-Output) system control problem, the modern control theory should be applied. In modern control theory, the state equation is used. The state equation is formed as follows,

$$\frac{d}{dt}\boldsymbol{x} = \boldsymbol{Ax} + \boldsymbol{Bu} \quad , \qquad (1)$$

$$\boldsymbol{y} = \boldsymbol{Cx} + \boldsymbol{Du} \quad , \qquad (2)$$

where, $\boldsymbol{x}$ is state vector, $\boldsymbol{u}$ is actuator vector, $\boldsymbol{y}$ is output vector respectively and $\boldsymbol{A}$, $\boldsymbol{B}$, $\boldsymbol{C}$, $\boldsymbol{D}$ are matrix. This state equation represents the physics model of the system. Writing system physics model into this form, one can deal the control problems as the matrix algebra problems. Of course, the state equation doesn't represent the exact system physics model, and there are model error between the state equation and the real system. The effect of the model error, however, can be dealt as the disturbance.

Considering the fusion plasma, the effect of the model error will be significant. Thus, the robust controller, (i.e. the controller which decreases the effect of the model error) should be applied to the fusion reactor. In this research, H-infinity control theory, which is the typical robust control theory, is applied to the fusion plasma control simulation. In this simulation, the zero-dimensional plasma model is solved with the software Matlab/Simulink. In this simulation, the plasma current, plasma density and the fusion power are controlled by the induced current, gas-puff and the NBI. Figure 1 shows the simulation result. In this simulation, the controller is designed from the state equation and PID theory.

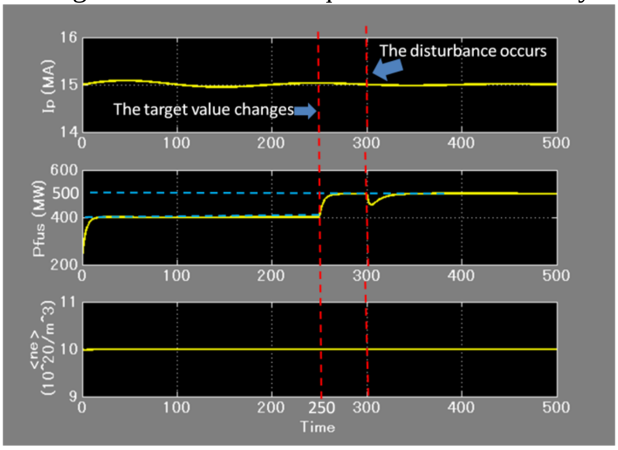

Fig. 1 The time evaluation of the plasma current I_p, the fusion power P_{fus} and the plasma electron density $< ne >$. I_p and $< ne >$ is kept in the constant target value. P_{fus} follows the target value from 400MW to 500MW at 250sec and is recovered from the disturbance (HH becomes 1.0 to 0.95) at 300sec.

In this presentation, the controller, designed with the H-infinity theory will be demonstrated. In H-infinity theory, the 'size' of the transfer function is evaluated as the H-infinity norm, and the controller is designed to minimize the H-infinity norm. To minimize the model error effect, the H-infinity norm of the transfer function from the model error to the output (it is called complementary sensitivity function) should be minimized. In general, however, as the H-infinity norm of the complementary sensitivity function decreases, the H-infinity norm of the sensitivity function, which is the transfer function from the reference value to the deviation, increases. Thus, generally, the controller is designed with high or low pass filter. In H-infinity theory, choosing the appropriate transfer functions and the pass filters, the controller which adapts the various purposes can be designed.

In this research, using this H-infinity theory, these three parameters can be controlled with high accuracy and high disturbance suppression performance.