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# Analysis of Plasma Position Control for Broader Approach DEMO Reactor

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Plasma position control for DEMO reactor on Broader Approach Activities has been studied using numerical simulation, which consists of plasma equilibrium, eddy current and active feedback control analyses. The stabilization effect of conducting shell and the rated power of active feedback control coils are evaluated. It is shown that the stabilization effect becomes weak by considering of the actual shape of vacuum vessel, in-vessel components and maintenance port. As a result, it is also necessary for the position control to consider the maintenance scenario that is related to the arrangement of the maintenance port.

## 1. Introduction

Pre-conceptual designs of DEMO reactor have proceeded under collaboration Japan and Europe (Broader Approach activities (BA)) and maximum plasma elongation is a research focus for the design since the plasma performance (fusion power, high beta, high density…) is improved. On the other hand, the vertical motion of high elongated tokamak plasma is unstable in principle, and it is necessary for elongated tokamak devices to provide the position control system, which consists of passive conducting shells and active feedback control coils for positional stability. In the case of DEMO reactor, it is important to take into account the actual shape of vacuum vessel and in-vessel components precisely since the design condition of DEMO reactor is different from current tokamak devices and ITER. For example, distance between the plasma surface and the conducting shells of DEMO reactor is longer than that of ITER since the conducting shells are installed behind breeding blankets. Therefore, the stabilization effect by the conducting shell fades off. As a result, the plasma elongation is restricted comparing with ITER and we need to design DEMO reactor within the restricted elongation. Considering difference between ITER and DEMO, we need to investigate several issues for the plasma position control as described below:

1) As mentioned above, more space between plasma surface and conducting shell must be given to install the breeding blankets. The plasma elongation is restricted since the stabilization effect by the conducting shells decreases with the distance. As a result, this influences on plasma performance.
2) Maintenance scenario also influences on the stabilization effect by the conducting shell. In general, the stabilization effect can be obtained by the external current in toroidal direction. However, the conducting shell must be partitioned for the maintenance in the case of DEMO reactor. Therefore, the stabilization effect by the conducting shell decreases with number of partition in toroidal direction.
3) As well known, integral error of magnetic detectors increases with operating time. In addition, we need to reduce noise generated by the eddy current in the breeding blanket and the vacuum vessel.
4) The adaptability of controller is also important since various situations (for examples, VDE, ELM) for DEMO reactor should be assumed.

In this study, we focus on 1) and 2) issues using numerical simulation. That is, we study the influence on the plasma position control for DEMO reactor by the actual shape of the in-vessel components and the vacuum vessel.

## 2. Numerical Model

The numerical model is assumed as follows: a) the plasma model is assumed as the rigid one which the plasma current density profile are taken into account, b) the in-vessel components and the vacuum vessel are approximated as 3-dimensional thin-layer structure, and c) the time evolution of eddy currents and coil currents is expressed as circuit equations. The numerical simulation code for analysis of plasma position control consists of three modules as follows:

i) Plasma equilibrium code [1] to setup plasma current density profile and magnetic surface by solving Grad-Shafranov equation,
ii) Eddy current code to evaluate passive stabilization effect on in-vessel components and

vacuum vessel by Finite Element Method [2],

iii) Active feedback control code to calculate the time evolution of eddy currents and feedback control coil currents [3]

The developed numerical simulation code can handle the precise model of in-vessel components and vacuum vessel of DEMO reactor by CAD and evaluate the frequency characteristics of stability index ($n_S$) and the electric power of control coils.

## 3. Evaluation of Stability Index for DEMO

The main parameters of plasma used for numerical simulation are the major radius $R_p$=8.2m, the minor radius $a_p$=2.57m, the plasma current $I_p$=14.6MA, the elongation $\kappa_{95}$=1.65, the triangularity $\delta_{95}$=0.33, the safety factor $q_{95}$=4.2, the poloidal beta $\beta_p$=1.8, the plasma internal inductance $\ell_i$=0.9 and the n-index $n$=-0.81.

Figures 1 and 2 show an design example of the conducting shells and the vacuum vessel, the mesh model and the frequency characteristics of $n_S$, respectively. $n_S$ is defined as follows:

$$n_S = \sum_i \frac{s}{1+s\tau_i}\left\{-\frac{I_P}{2\pi B_{V0}}\left(\frac{\partial M_{pi}}{\partial Z}\right)^2\right\}, \qquad (1)$$

where $s$ is the frequency, $\tau_{si}$ is the time constant of i-th eddy current mode, $B_{V0}$ is the vertical field, $M_{pi}$ is the mutual inductance between plasma and i-th eddy current mode and $Z$ is the plasma vertical position, respectively. In Fig. 2, the frequency characteristics of $n_S$ in the cases of the continuous shell, the separated shell with/without maintenance ports are shown, respectively and the growth time is defined as $n+n_S$=0, which is the stability condition. Fig.2 shows that $n_S$ and growth time decreases by considering several design conditions. The stability is affected by arrangement of maintenance port. The adoption of vertical port is related to the choice of the maintenance scenario.

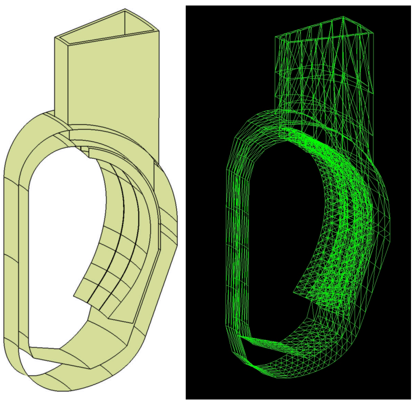

Fig.1 Example of conducting shells and vacuum vessel with maintenance port (left hand side) and (b) mesh model for eddy current analysis (right hand side)

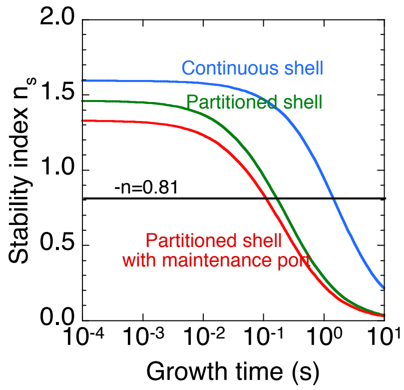


Fig.2 Frequency of characteristics of stability index

## 4. Active Feedback Control for DEMO

The numerical simulation of active feedback control in the case of the partitioned shell with maintenance port has been carried out. The control coils are arranged outside of the vacuum vessel and the magnetic error field in perpendicular direction is given as disturbance.

Figure 3 shows maximum displacement in vertical direction versus maximum rated control power of coils. It is shown that several MVA for the rated control power is necessary for DEMO reactor at least. However, it is anticipated that the DEMO reactor needs more control power in case of ELM as the disturbance.

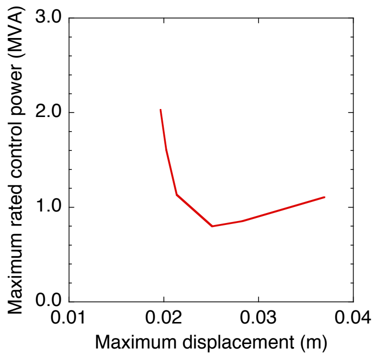


Fig.3 Maximum displacement versus maximum rated power of active control

In summary, it is important for DEMO reactor design to evaluate the position control analysis by considering the actual shape and the maintenance scenario. That needs some kind of countermeasure against reducing the stabilization effect.


### References

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