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Design concept of conducting shell and in-vessel components suitable for plasma vertical stability and remote maintenance scheme in DEMO reactor

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HIGHLIGHTS

- Conceptual design of in-vessel component including conducting shell has been investigated.
- The conducting shell design for plasma vertical stability was clarified from the plasma vertical stability analysis.
- The calculation results showed that the double-loop shell has the most effect on plasma vertical stability.

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ABSTRACT

In order to realize a feasible DEMO, we designed an in-vessel component including the conducting shell. The project is affiliated with the broader approach DEMO design activities and is conceptualized from a plasma vertical stability and engineering viewpoint. The dependence of the plasma vertical stability on the conducing shell parameters and the electromagnetic force at plasma disruption were investigated in numerical simulations (programmed in the 3D eddy current analysis code and a plasma position control code). The simulations assumed the actual shape and position of the vacuum vessel and in-vessel components. The plasma vertical stability was most effectively maintained by the double-loop shell.

1. Introduction

Remote maintenance of DEMO should be reliably consistent with the plasma operation. As part of the broader approach (BA) DEMO design activities, a feasible reactor maintenance scheme for DEMO was investigated from an engineering design perspective. Previously, comparative assessment of remote maintenance schemes for DEMO was based on the requirements of DEMO remote maintenance [1]. In terms of reliability of hot cell inspection, consistency with the superconducting magnet and segment portability, the most feasible DEMO reactor maintenance scheme is the banana-shaped segment transport using all vertical maintenance ports (BSAV). An important engineering problem is designing the conducting shell to maintain plasma vertical stability. To solve this problem in the BSAV scheme, both the conducting shell and in-vessel components must ensure plasma vertical stability and must be compatible with remote maintenance. To this end, the conducting shell is incorporated behind a blanket module, which requires a sufficient tritium breeding ratio (TBR > 1.05). For plasma stabilization, the conducting shell should be placed as close as possible to the plasma surface. The tokamak system design must account for the plasma parameters (plasma elongation, aspect ratio, poloidal beta, and internal inductance) and the conducting shell parameters (conducting shell position, resistivity, and shell shape). In addition, the conducting shell is divided in the toroidal direction, which must

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be considered in the blanket replacement. The conducting shell design (shell shape and thickness) was clarified from the physical requirements. In the European DEMO design, the stability margin and control power were evaluated without the copper conducting shell [2,3]. In the Japanese DEMO design activity, the copper conducting shell is included to reduce the control coil power and increase the plasma elongation. This paper analyzes the plasma vertical stability and electromagnetic (EM) forces and presents the conceptual design of the back plate (including the conducing shell).

2. Analysis model of plasma vertical stability

2.1. Remote maintenance scheme

The BSAV concept is schematized in Fig. 1. This maintenance scheme is similar to the multimodule segment maintenance scheme [4–6]. The banana-shaped segment includes the blanket modules, back plate, and conducting shell and is divided into five segments: two inboard segments (with 32 parts) and three outboard segments (48 parts; width = 7.5°) in the toroidal direction. Collectively, the segments comprise 80 parts. Each segment weighs ~90 tons and has dimensions of 10 m × 4 m × 1 m. The divertor was segmented into 48 cassettes, each of width 7.5°.

2.2. Vertical stability analysis code

The Alfven timescale instability is mainly stabilized by the conducting shell structures in the blanket segments [7,8]. Therefore, the conducting shell structures must exert a high stabilizing effect and their characteristic time must be sufficiently long to control the plasma position by the feedback control system. To evaluate the dependence of the plasma vertical stability on the conducing shell parameters, we employed the 3D eddy current analysis code (EDDYCAL) and plasma position control code [9], and we assumed the actual shape and position of the vacuum vessel and in-vessel components. The plasma equilibrium was analyzed by the 2D plasma equilibrium code *tokamak equilibrium and operation scenario with closed-circuit coil analysis* (TOSCA) [10]. In the EDDYCAL numerical model, we assumed the thin layer approximation. In the active control code, we modeled the magnetic detector that estimates the position of the plasma current center by the filament current model using the least-squares method. The outputs of TOSCA and EDDYCAL were fed to the plasma position control code, which calculates the time evolution of the plasma's vertical and radial motions, the eddy currents, and the feedback control coil currents of the proportional integral derivative.

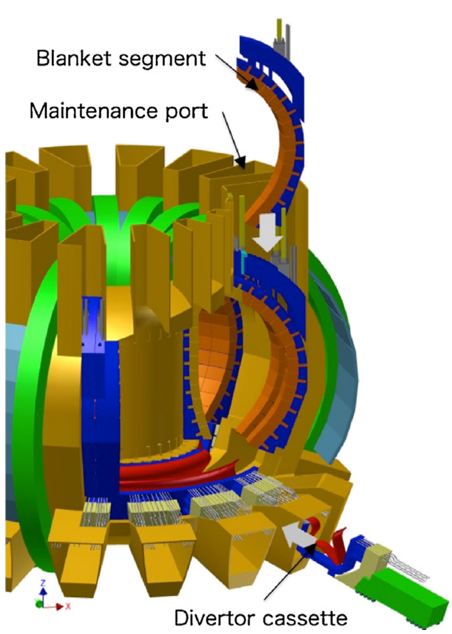

Fig. 1. Schematic of banana-shaped segment transport using all vertical maintenance ports (BSAV).

Table 1
Constant parameters in the plasma equilibrium analyses.

Major radius, R_p	8.2 m
Minor radius, a_p	2.6 m
Aspect ratio, A	3.2
Elongation, κ	1.65
Triangularity, δ	0.33
Plasma current I_p	14.6 MA
Poloidal beta, β_p	1.8
Internal inductance, l_i	0.9

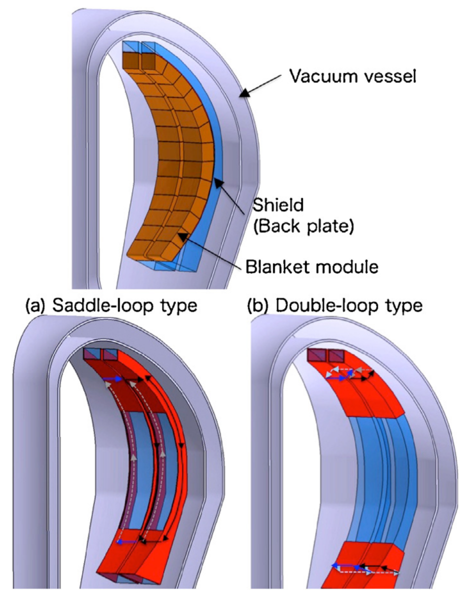

Fig. 2. Schematic of (a) saddle-loop type and (b) double-loop type shell.

2.3. Vertical stability analysis model

Table 1 lists the constant parameters in the plasma equilibrium analyses. In all the analyses, the position of the common first-wall boundary was given. In the radial build, a 0.2-m gap was preserved between the first wall and the separatrix on the inboard side.

The locations, sizes, materials, and connections of the conducting shell structures were constrained by the restricted space, TBR, the severe heat and radiation conditions, and remote maintenance. To preserve the plasma vertical stability, researchers have proposed saddle-loop type [11–13] and double-loop type [14] active conducting shells. The structures of both shell types are schematized in Fig. 2. In the saddle-loop type, the major stabilizing current flows along the upper and lower plasma facing plates, which connect with the vertical copper plates attached on the back plate walls. Because the stabilizing current loop is limited to the back plate, the saddle-loop shell confers independence from the toroidal one-turn resistance of the vacuum vessel. However, the vertical current flow path is rather long in the Japanese DEMO concept (>10 m), which reduces the stabilizing effect on highly elongated plasmas. On the