Development of ITER Diagnostic Upper Port Plug

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The designs and analyses of the diagnostic port plug for installing diagnostics have been carried out from various aspects in order to advance the port plug concept to the realistic design. Manufacturing processes have been studied for the alternative structure using the rolling plates and ribs, in addition to the reference structure using forging material. Electromagnetic loads onto the upper port plug during a vertical displacement event have been evaluated. It has been shown that maximum moments are about half of the reference ones. The design integration of three diagnostics into one of the upper port plugs has been performed by considering required aspects such as diagnostic functions, neutron shielding, maintenance of diagnostic components and cooling channels.

Keywords: diagnostic, port plug, manufacturing process, electro-magnetic analysis, neutronics analysis, integration design

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1. Introduction

In a high fusion power machine, access of diagnostics to the plasma is severely limited because diagnostic components located near the plasma are exposed to high neutron fluxes. In order to resolve this problem, a concept of "diagnostic port plug", which works as both a neutron shield and a container of diagnostics to access the plasma in the harsh radiation circumstances, has been established in ITER [1]. Only the basic concept of the port plug has been given so far. The comprehensive design of the port plug from various aspects has been required to improve the concept of the port plug towards the realistic design. In this work, the study of manufacturing processes, analyses of electromagnetic loads and neutronics, and integration study of diagnostics into the port plug have been performed for the upper port plug.

A schematic of one of upper port plugs is shown in Figure 1. The length of the port plug is ~6 m and the weight is ~22 tons, including a blanket shield module (BSM) attached at the front end of the port plug. The port plug is inserted into the vacuum vessel port and is cantilevered at the vacuum vessel flange. In addition to the roles of the port plug mentioned above, the following roles are required to the port plug: support the BSM for protecting tokamak and diagnostic components from high heat and neutron fluxes, close the vacuum vessel ports, supply cooling water to the BSM and diagnostic modules and shield modules installed in the port plug. Diagnostic components are installed in the diagnostic modules with shielding material.

In this paper, two manufacturing processes of the upper port plug are compared in Section 2. The analyses of

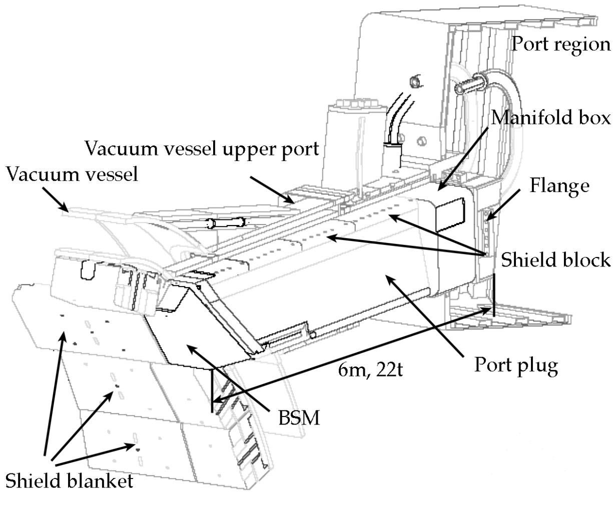

Fig. 1 Schematic of one of the upper port plug.

the electromagnetic loads and neutronics are presented in Section 3 and 4, respectively. The integration of diagnostics into the port plug is shown in Section 5. Conclusions are given in Section 6.

2. Manufacturing Processes

The upper port plug should have high stiffness since the port plug is a cantilevered structure. To achieve such high stiffness, the upper port plug is designed to be composed of forging material with a thickness of 100 mm. Concerns of using the thick forging material are; i) a large temperature differences in the material are expected in a early phase of the baking and plasma burning, ii) procurement

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lead time of the material is long, iii) manufacturing cost is high. An alternative structure using commercial rolling material has been also studied as a candidate to resolve the above concerns. To obtain high stiffness, a combination of rolling plates and ribs was considered and thick forging material is used for the bottom plate for the alternative structure. The second moment of area and strains was calculated to evaluate both structures. It has been confirmed that the alternative structure can achieve a similar level of stiffness compared to the reference structure.

The manufacturing processes were studied for both the reference structure using forging material and the alternative structure using rolling plates and ribs. For the reference structure, all parts of the port plug are machined from forging material and are welded at first. Cooling channels in the forging material are processed by the boring trepanning method. The number of cooling channels in the side and the bottom plates was decided from the thermal analysis for the baking and the cooling of the port plug. A maximum temperature difference of within 10°C could be kept in the baking operation.

The manufacturing process of the alternative structure requires some different processes from that of the reference structure. On the side plates, cooling channels are welded in grooves. The arrangement of the cooling channel on the side plate was determined based on the temperature distribution because design of the cooling channel is flexible in this structure. A maximum temperature difference of about 20°C was obtained in the baking operation. It can be reduced by the rearrangement of the cooling channels because it has larger margins for space and design of the cooling channel compared to the reference structure. The ribs are also welded on the side plates. This many welding and machining processes require a long manufacturing period, which will result in an increase in the manufacturing cost.

The preliminary structure analysis for displacement of the port plug for the both structures was also performed. Maximum displacement of 3.2 mm for the reference structure and that of 5 mm for alternative structure appears at the front end of the port plug.

From these results, it is not clear which structure should be chosen from the manufacturing point of view. It is necessary to perform a structural analysis, which includes diagnostic components, and to study maintenance scenarios.

3. Analysis of Electromagnetic Loads

The mechanical strength of the upper port plug must be evaluated for the expected electromagnetic (EM) loads. Here, the EM loads have been evaluated by establishing a three-dimensional (3D) model. Figure 2 shows the 3D models of the partial vacuum vessel with the upper port and the upper port plug with the BSM. The EM load has been analyzed including adjacent shield blankets (SBs) around the port plug since the eddy current conducted in the BSM is affected by those in the adjacent SBs. The optical path in the port plug (Port Plug No. 11 for the Thomson Scattering (edge) was considered here) was also modeled because the path of the eddy current is affected by the continuous path of the structure. In addition, dependence of the EM loads on the number of slits in the BSM, which decrease the EM loads, was also investigated. The upward fast vertical displacement event (VDE) (one type of plasma disruption) was selected for the evaluation of the EM loads because it produces the most severe load on the upper port plug. A linear decay over 35 ms from a plasma current of 15 MA to zero was used as the VDE condition. The electric resistance of the material at 100°C was adopted to simulate the operational temperature. The volumetric ratio of SUS/water of 1/0.616 was assumed based on the EM analysis for the SBs [2].

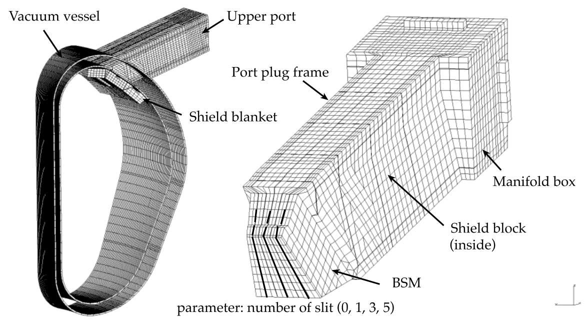

Fig. 2 Three-directional model for analysis of the electromagnetic loads on the upper port plug.

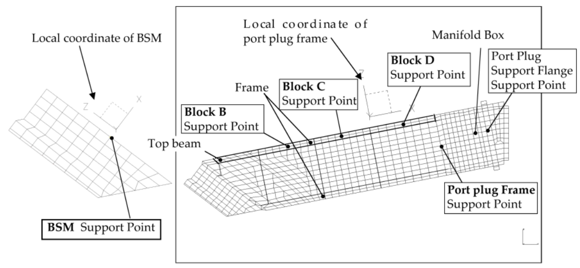

Fig. 3 Support points and local coordinate of port plug components.

The EM forces at several support points of the port plug have been calculated since they are key points in designing the port plug. Figure 3 shows the support points and the local coordinate of the upper port plug in this analysis. In this figure, the X-axis, Y-axis and Z-axis is chosen in the radial direction, torus direction and vertical direction, respectively. Since the diagnostic and shield modules are supported at the top beam, the EM forces have been calculated at the center of the top surface in the figure. Each EM force is a total of each component. For the EM force on the support flange, the total EM force on the port plug has been calculated since it is a key parameter for the design of the support flange.

Table 1 Maximum EM forces and moments on upper port plug.

Components	Fx [N]	Fy [N]	Fz [N]	Mx [Nm]	My [Nm]	Mz [Nm]
BSM	3.39E4	-9.33E4	2.67E4	5.76E5	6.83E4	2.63E5
Port plug frame	6.89E4	3.44E4	-2.04E4	5.82E5	-3.46E4	1.62E5
Block B	4.20E3	-3.00E3	-3.59E3	4.78E4	-1.62E3	2.68E4
Block C	-4.91E2	1.49E3	-3.52E2	4.76E3	5.10E2	8.11E2
Block D	-1.13E2	6.76E1	-8.38E1	1.88E2	1.90E2	4.40E1
Support flange	1.03E5	-6.70E4	-2.41E4	1.02E6	1.49E5	1.10E6

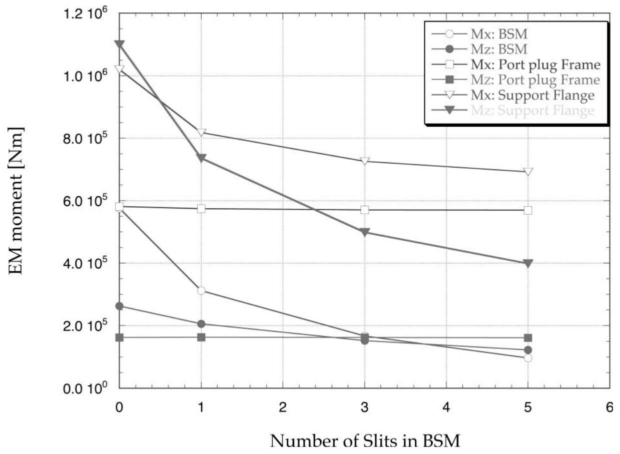

Fig. 4 Dependence of EM moments on the number of slits.

The time evolution of the EM force was calculated at first. The EM force on the support flange reaches its maximum at 35 ms, it corresponds to the time when the plasma current vanishes. Other EM forces such as that loading the shield module increase gradually after the end of the VDE. The EM force in the shield module does not affect the design of the port plug because it is sufficiently small. Table 1 shows the maximum EM force at each support point of the upper port plug. The EM forces induced by eddy currents are mainly radial rotation moment and vertical rotation moment. Maximum moments appear at the support flange and are $Mx = 1$ MNm, $Mz = 1.1$ MNm, which are about half of the design guideline of the port plug [3]. These moments are mainly produced by the combination of moments on the BSM and the port plug frame.

The effect of the slit in the BSM was investigated by changing the number of slits. The EM moments on the support point of the BSM, the port plug frame and the support flange are shown in Figure 4. The EM moment on the BSM decreases with an increase in the number of slits. On the other hand, the EM moments on the port plug frame are almost constant. Since the EM moment on the support flange is the sum of those on the BSM and on the port plug frame, it decreases with increase in the number of slits as shown in the figure. The EM moment on the support flange with three slits is about half of that with no slits. It is thought that the number of slits must be determined taking the EM loads and the required margin into account.

Table 2 Maximum EM force of upper port plug (halo).

Components	Fx [N]	Fy [N]	Fz [N]	Mx [Nm]	My [Nm]	Mz [Nm]
BSM	-1.08E+03	-7.20E+02	-1.02E+04	6.74E+01	-3.27E+03	1.51E+02
Port plug frame	-1.15E+03	-1.03E+04	-3.50E+04	-6.71E+02	-9.50E+04	2.21E+04
Support flange	4.86E+03	-1.24E+04	-4.35E+04	-9.41E+02	-1.69E+05	3.50E+04

The influence of the halo current on the EM force on the upper port plug also has been estimated. The halo current induced in the BSM in the upward slow VDE is higher than that in the upward fast VDE. According to the Load Specification [4], a maximum ratio of the halo current (I_{halo}) to the plasma current (I_{plasma}) is given as I_{halo} (downward) $\times P_f/I_{plasma} = 0.70$, where P_f is a peaking factor in the toroidal direction. The halo current in the upward VDE is 80 % of that in the downward VDE. A ratio of the halo current in the upward slow VDE to the plasma current is I_{halo} (upward) $\times P_f/I_{plasma} = 0.70 \times 0.8 = 0.56$. Therefore, I_{halo} (upward) $= 15 \times 0.56 = 8.4$ [MA]. The halo current flowing into the BSM was estimated from these values and the ratio of the blanket surface area to the inner vacuum vessel surface area. Since the BSM for the upper port plug is located at the same poloidal position as the No.10 blanket module, the surface ratio of the BSM to No.10 blanket module is 1/3.9. The halo current ratio induced in the No.10 module is 50 % of the total halo current [3]. Therefore, the halo current into the BSM is estimated to be $I_{halo} = 8.40 \times 10^6 \times 1/2 \times 1/(1+3.90)/18 = 4.76 \times 10^4$ [A]. However, this value is overestimated because the BSM surface will be located ~30 mm behind the surface of the adjacent SBs. In this case, the halo current from the upward slow VDE is lower than the estimated value.

The EM analysis for halo current was performed using the estimated halo currents. In the analysis, the electric contact between the BSM and the port plug frame was assumed since the halo current enters the BSM and the port plug frame towards the vacuum vessel. Other analysis conditions were the same as those for the EM analysis for the eddy current. Table 2 summarizes the results of the EM analysis. The halo current induced EM forces on key components are lower than 10 % of the EM force induced by the eddy current. Therefore, the EM force induced by the halo current is negligible compared to that by the eddy current.

4. Neutronics Analysis

Dose equivalent rate at the outside of the port flange 11 days after shutdown was calculated. In the analysis, the gap between the vacuum vessel port and the upper port plug was assumed to be 20 mm based on the reference design. The labyrinth of the optical path for the Thomson scattering was also modeled as voids. The MCNP code was used and the operational scenario I defined in Ref. [5] was assumed for the neutron condition. The dose equivalent rate outside the port flange has been estimated to be ∼6 μSv/h (According to the assumption of this calculation, the fractional standard deviation is 20 %.), which is well below the design guideline of the ITER maintenance phase.

5. Integration of Diagnostics into Upper Port Plug

The integration of diagnostics into the port plug has been studied for the Upper Port Plug No.11, where the Thomson scattering (edge) system, the visible-IR TV divertor viewing system and the neutron activation system will be installed. To integrate theses diagnostic systems into the port plug, the labyrinth of optical path, the driving mechanism and cooling systems for shutters and mirrors, the maintenance space and the interference with each other were considered. In addition, the neutron shield block, cooling channels, the support of the BSM and the driving lines for shutter and mirror were also designed for the integration.

Optical components such as mirrors and lenses for the Thomson scattering system were arranged based on the optical design [6]. The structure and the position of the BSM supports, on which the EM force on the BSM is induced mainly, have been considered to avoid the optical path through the BSM. For the other two diagnostic systems, only space was given from their functions. Figure 5 shows a schematic of the integrated layout of three diagnostics. Here, a change in the design of the diagnostic/shield module just behind the BSM (around A) was proposed in order to keep enough space for maintenance and installation of mirrors and a shutter mechanism. The neutron shield in the module is removed and a neutron shield is added in front of the flange instead to maintain shielding performance.

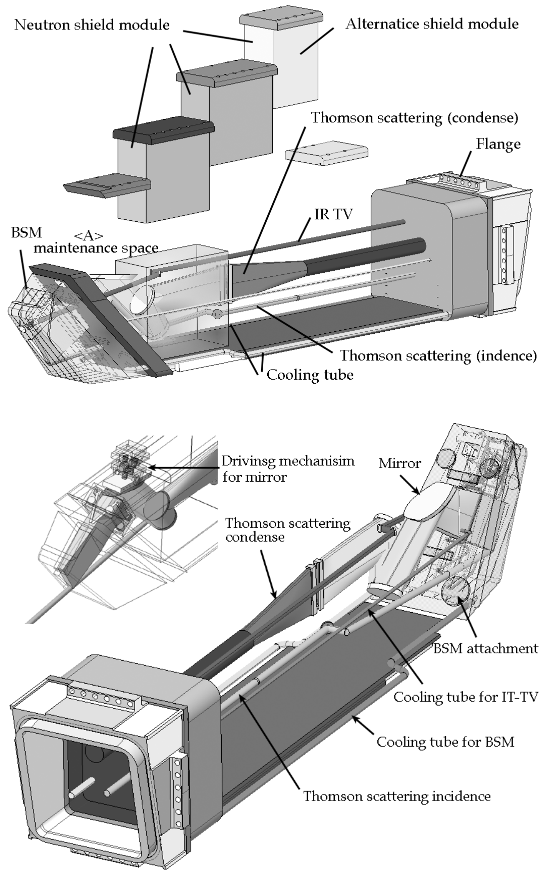

Fig. 5 Integration of diagnostics into upper port plug No.11.

6. Concluding Remarks

The studies of the diagnostic port plug for the upper diagnostic port have been performed in order to advance the port plug concept to the realistic design. The manufacturing processes were studied for both the reference structure using forging material and the alternative structure using rolling plates. The second moment of area and strains was calculated to evaluate both structures. It has been confirmed that the alternative structure can achieve a similar level of stiffness compared to the reference structure. The preliminary structure analysis for displacement of the port plug for both structures was also performed. Maximum displacement of 3.2 mm for the reference structure and that of 5 mm for alternative structure appears at the front end of the port plug. The EM loads onto the upper port plug due to the VDE have been analyzed by establishing the 3D model. The maximum moments appear at the support flange and are $Mx \sim 1$ MNm and $Mz \sim 1.1$ MNm, which are about a half of the referred values. The effect of the slit in the BSM for reducing the EM force was clearly shown on the dependence of the EM force on the number of slits. It is thought that the number of slits must be determined taking the EM loads and the required margins into account. The EM force from the halo current is negligible compared to that from the eddy current. The dose equivalent rate at the outside of the port flange has been estimated at ∼ 6 μSv/h, which is within the design guideline in the ITER maintenance phase. The design integration study has been performed for upper port plug No.11. The labyrinth of the optical path, the driving mechanism and cooling systems for shutters and mirrors, the maintenance space and the interference of each other were arranged.

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[2] ITER Design Description Document 16 Blanket, September 2004.
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