Design evaluation of the HCCP TBM-shield model with improved manufacturability

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1. Introduction

The TBM-shield is one component of a TBM-set. A TBM-set typically consists of a TBM-box and a TBM-shield, and the TBM will be installed in ITER to generate the tritium by breeding and to transport the tritium. The TBM-shield is located on the rear end of the TBM-set and is responsible for reducing the radiation dose to provide the neuron and gamma-ray shielding [1-3]. The TBM-shield uses cooling water to remove heat from primary heat transfer system of ITER. In order for the TBM-shield to perform its role well, it must be structural integrity against pressure and various applied loads, and the proportion and arrangement of the structure and water in TBM-shield must be well designed. Countries that are planning to design and install TBM-set are also studying these design topics. In Korea, the TBM is being designed jointly with the EU. In particular, Korea is in charge of designing and manufacturing the TBM shield.

This study presents a model that reflects the manufacturability improvement of the basic design, HCPB TBM-shield, and discussed the design evaluation results.

2. Modification of TBM-shield design

The basic TBM-set model for the KO-EU joint design is the HCPB TBM-set developed by the EU. Figure 1 shows the HCPB TBM-shield geometry and internal structure. Since the TBM-set is installed in the port provided by ITER, the external shape of the TBM-shield itself does not differ significantly by TBM development country. However, there are complex structures inside to ensure cooling performance. These internal structures can provide the structural integrity of the TBM-shield.

However, the complexity of the internal structure for cooling and structural integrity may limit the manufacturing of the TBM-shield. Under operating conditions, the TBM-shield is directly exposed to water coolant at a high pressure of 4 MPa. RCM-MRx and ESPN regulations require 100% volumetric inspection of all welding lines [4, 5]. This complicates the fabrication of the TBM-shield, and the narrow gaps between the structures limit access for welding and inspection. Considering welding and inspection, it is advantageous to keep the internal structure of the TBM-shield simple, but it is also necessary to consider the internal structure to ensure cooling and structural integrity.

Figure 2 shows the geometry of the TBM-shield for improved manufacturability. The interior is simplified to facilitate access for welding and inspection. To improve the structural integrity, the thickness of the inner plates was increased to compensate for the weakening of structural integrity due to the increase in the gap between welds due to the decrease in the number of plates. A certain size of flow hole was made in the inner plate to allow the coolant to flow in a constant direction.

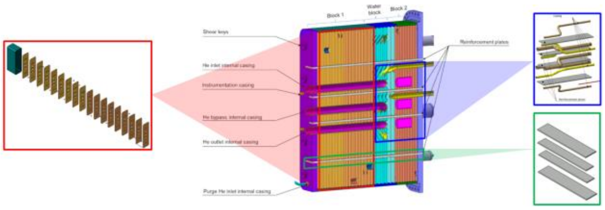


Fig. 1. HCPB TBM-shield

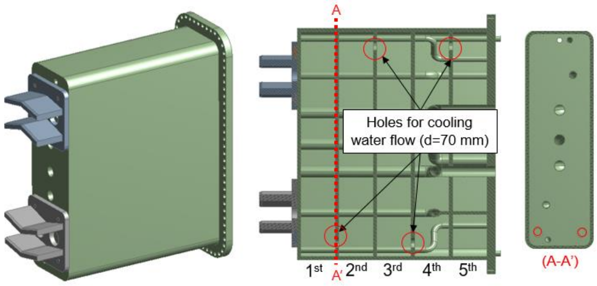


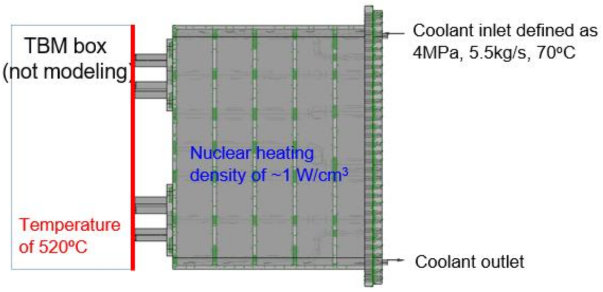
Fig. 2. Modified HCCP TBM-shield

3. FEM Analysis

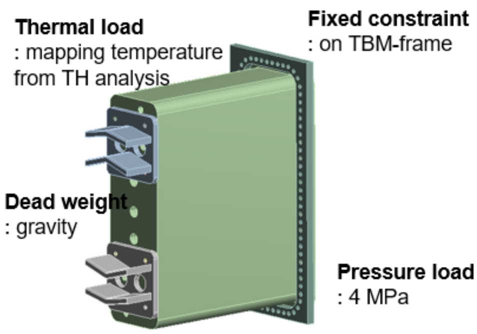
ANSYS analysis was performed to verify the thermo-hydraulic and structural soundness of the TBM-shield presented in the previous section [6].

3.1 Boundary Conditions

Figure 3 shows the analysis boundary conditions for the TBM-shield. In the thermo-hydraulic analysis, the boundary conditions are set such that coolant at a constant pressure and temperature enters and exits through a channel located at the rear of the TBM-shield. The heat generated by the TBM-shield structure was set by referring to the nuclear analysis results in HCCR TBM-set [7]. In addition, the boundary conditions for the structural analysis were set based on the actual installation of the TBM-shield on the TBM port frame. A certain shape of the TBM port frame was reflected in the analysis, and a fixed constraint condition was applied to the port frame. In the structural analysis, the temperature result obtained from the thermo-hydraulic analysis was mapped to the entire structure and used as the heat load, and the pressure load on the internal cooling water and the load on the weight of the structure were set as the loads received by the TBM-shield.



(a) Boundary condition for TH analysis



(b) Boundary condition for mechanical analysis

Fig. 3. Boundary conditions

2.2 Result of TH analysis

Figure 4 shows the results of the thermo-hydraulic analysis for the TBM-shield. The requirements for the TBM-shield design are the temperature of the structure and the pressure drop of the coolant. For the TBM-shield structure, the temperature is limited to a maximum of 450 degrees. The pressure drop is also related to the design characteristics of the primary heat transfer system of ITER that supplies the coolant to the TBM-shield, which is 1.29 MPa. The maximum temperature formed in the TBM-shield is 293 degrees, which is lower than the maximum design allowable temperature. The pressure drop at the coolant inlet and outlet at the rear of the TBM-shield is 1.15 MPa. This value is lower than the required value of 1.29 MPa for the TBM-shield. The design value can be met by reducing the size of the flow channel inside the TBM-shield and installing obstructions in the cooling water inlet and outlet channels.

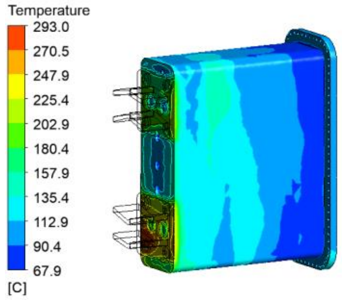


Fig. 4. Temperature distribution on TBM-shield

2.3 Results of Mechanical analysis

Figure 5 shows the stress distribution induced in the TBM-shield structure by thermal, pressure, and weight loads. The maximum stress value is 345 MPa, which is lower than the allowable stress of 363 MPa of the structural material of 316L(N)-IG [8]. The structural integrity evaluation confirms that the structure remains sound for all three loads without any major problems.

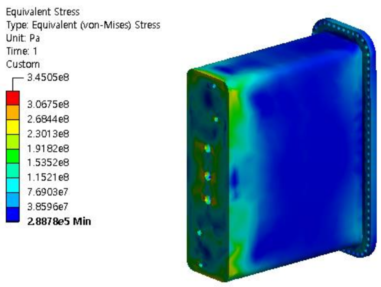


Fig. 5. Stress distribution on TBM-shield

4. Conclusions

It was confirmed that the complicated geometry of the basic TBM shield limited its manufacturing, and to solve this problem, the internal geometry of the TBM shield was simplified to improve manufacturability. The internal design was made in consideration of the cooling characteristics of the TBM-shield and the maintenance of structural integrity, and it was confirmed that the design requirements could be fully satisfied through thermo-hydraulic and structural analysis.

Acknowledgment

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