Thermal-Hydraulic Analysis of KSTAR Inboard Limiter and NB Armor

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1. Introduction

The KSTAR (Korea Superconducting Tokamak Advanced Research) PFC (plasma facing components) consists of divertor, inboard limiter, poloidal limiter, passive stabilizer and neutral beam armor [1,2]. In 2007, the KSTAR had been constructed, and established successful commissioning operation with partial inboard limiter [3] in 2008. Furthermore, the KSTAR has a plan to reinforce the inboard limiter and NB (neutral beam) armor in 2009. In this study, computational analyses were performed to investigate the thermal hydraulic characteristics of temperature increase and cooling capability of inboard limiter and NB armor to validate satisfaction of the design criteria under the plasma operation condition.

2. Inboard Limiter and NB Armor

The inboard limiter is designed to protect the vacuum vessel inner wall and to define the inner boundary of operating plasma. The inboard limiter is divided into normal sector and neutral beam hitting sector. The graphite tiles are assembled for the normal sector and carbon fiber composite (CFC) tiles are assembled for the neutral beam hitting sector, which is exposed by higher heat flux compared to normal sector. Figure 1 shows the inboard limiter region and its installation in vacuum vessel.

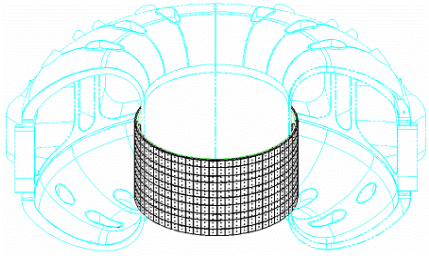


Fig. 1. KSTAR inboard limiter

The NB armor classifies into neutral beam entrance port protector and neutral beam shine-through armor, and the graphite tiles are attached for that. The NB armor is for protection the vacuum vessel port from the particles occurring by collision between neutral particle beam and residual gas. Therefore, the NB armor is designed to prohibit the surface damage. Figure 2 shows the NB armor region and its installation in vacuum vessel.

Basically, the KSTAR inboard limiter neutral beam hitting sector and NB armor are designed for the baseline operation characterized by 20 sec of plasma pulse discharge with 16 MW input power and 1180 sec shutdown for each duty cycle. However, the inboard limiter normal sector is designed for upgrade operation mode of 300 sec pulse discharge with 28 MW of input power and 3300 sec shutdown for each duty cycle. The PFCs should be maintained that the surface temperatures of the graphite and CFC tiles are below 600°C and 1200°C, respectively.

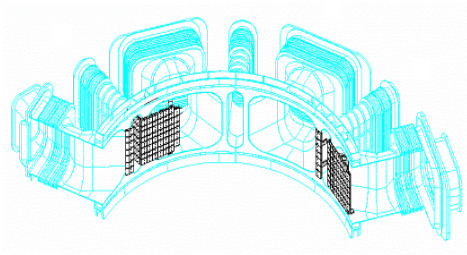
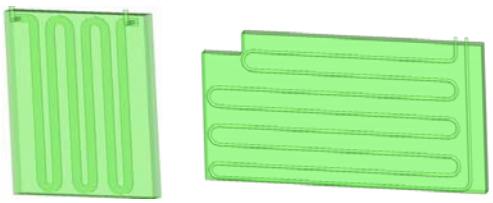


Fig. 2. KSTAR NB armor

3. Calculation Domain and Modeling

3.1 Calculation Domain

The inboard limiter and NB armor consist of backplate of STS316LN, tiles of graphite or CFC and carbon sheet inserted between backplate and tile. In this study, calculation domains as shown in Fig. 3 are 3-dimensional geometries drawn using 3-D CAD. The mesh generations were done by ANSYS ICEM tool.



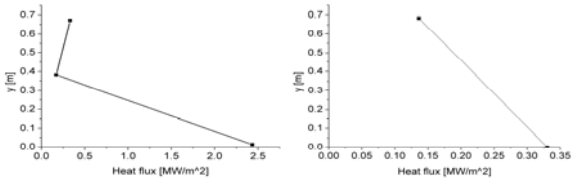
(a) Inboard Limiter (b) NB armor

Fig. 3. 3-Dimensional calculation geometry

3.2 Boundary and Initial Conditions

During the plasma operation time, large amount of heat is loaded on the front surfaces of tile region of PFCs. These heat loads are different for each location of PFC in the vacuum vessel. Fig. 4 and 5 show the heat flux conditions on the tile surfaces of inboard limiter and NB armor, respectively. Initial temperature of 35°C was applied to the inboard limiter and NB armor. The PFC structures were assumed to be cooled by forced water convection. Initial temperature of

coolant is 35°C, and flow rate of 0.45 kg/sec and 3 bar pressure conditions were applied for coolant region. The physical properties of each material were applied as a function of temperature. Fig. 4 and 5 present the heat flux conditions of front surfaces of inboard limiter and NB armor for each position.



(a) NB Hitting Sector (b) Normal Sector

Fig. 4. Inboard Limiter heat flux condition

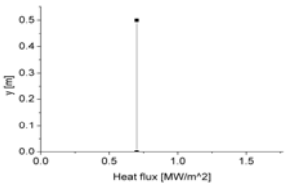


Fig. 5. NB Armor heat flux condition

4. Calculation Results

Computational Calculations were performed for transient conditions by using CFX 11 code [4]. Table 1 presents each design criteria of duty cycle and plasma operation duration time for inboard limiter and NB armor.

Table 1. Design criteria of PFC

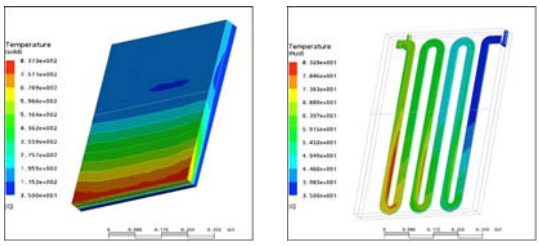
PFC	Duty Cycle (sec)	Plasma On (sec)	Plasma Off (sec)
Inboard limiter NB hitting sector	1200	20	1180
Inboard limiter normal sector	3600	300	3300
NB armor	1200	20	1180

4.1 Inboard Limiter

Fig. 6 presents the temperature distributions of solid structure (tile and backplate) and coolant region of inboard limiter NB hitting sector at the end time of 20 sec plasma operation. The CFC tile of inboard limiter NB hitting sector should be maintained below 1200 °C according to design criteria. In this calculation, the maximum temperature is 837°C in local area of tile region and the coolant maximum temperature is 83°C. This presents that it is confirmed to satisfy the design criteria. Fig. 7 presents the temperature distributions of inboard limiter normal sector at the end time of 300 sec plasma operation. The graphite tile of inboard limiter normal sector should be maintained below 600°C according to design criteria. In this calculation, the maximum temperature is 722°C in local area of the tile region and the coolant maximum temperature is 85°C. The region to be in excess 600°C is very limited in the corner area, so it could be overcome easily by design or manufacturing simple modification

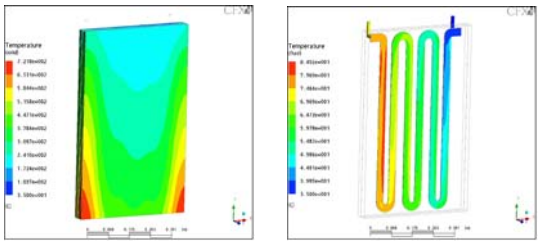
4.2 NB armor

Fig. 8 presents the temperature distributions of solid structure (tile and backplate) and coolant region of NB armor at the end time of 20 sec plasma operation. In this calculation, the maximum temperature is 319 °C in local area of tile region and the coolant maximum temperature is 42°C. This means that it is confirmed to satisfy the design criteria.



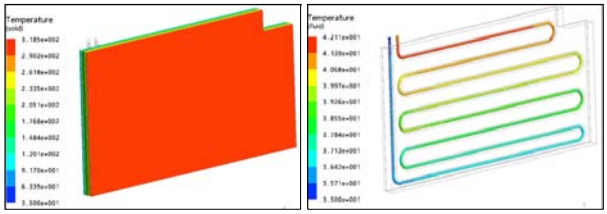
(a) Solid region (b) Coolant region

Fig. 6. Temperature distribution of Inboard limiter NB hitting sector at 20 sec



(a) Solid region (b) Coolant region

Fig. 7. Temperature distribution of Inboard limiter normal sector at 300 sec



(a) Solid region (b) Coolant region

Fig. 8. Temperature distribution of NB armor at 20 sec

5. Conclusions

Commercial Computational Fluid Dynamics (CFD) code was used to calculate the thermal-hydraulic analyses for KSTAR inboard limiter and NB armor with forced water convection cooling condition. The inboard limiter and NB armor were confirmed to satisfy the maximum temperature requirement according to the design criteria in this study.

REFERENCES

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