HEAT TRANSFER SIMULATION OF A-FRAME ASSEMBLY TO SUPPORT ALCATOR C-MOD OUTER DIVERTER UPGRADE

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ABSTRACT
To design the Alcator C-Mod outer divertor to operate at 600°C and determine its effect on the surrounding vessel and diagnostics, heat transfer analysis must be used. This paper describes the analysis and the results of heat transfer simulations of the outer divertor tiles, tile-mounting plate, support structure, and current shunt. Using Comsol, commercial FEA software package, a 3D wedge model that exploits the cyclic symmetry of the divertor, is created. By adjusting the power level of each of the 7 heaters used to elevate and control the divertor temperature, a uniform poloidal temperature distribution is achieved and the power requirements for the heaters are determined. The temperature of each component in the assembly is calculated, and results are used for further design changes. Additionally, radiation simulation on thermal shields is presented, which is used as ambient temperature for the heat transfer of the A-frame assembly. Furthermore, a full model of the entire outer divertor ring is presented with its toroidal temperature distribution. Finally, thermal stress of the plate is analyzed based on analytical calculation of the maximum allowable temperature gradient.

7. CONCLUSIONS
Due to the cyclic symmetry of the new outer divertor and the same structure of left A-frame and right A-frame within the maximum temperature rise is 25°C, the design is deemed to be feasible. To adjust the power for each of the 7 heaters, the high-temperature pressure can be heated up to 600°C with toroidal variation within tolerable range. A uniform poloidal temperature distribution is achieved, and the power required is determined.

With use of 1 mm thick Molybdenum thermal shields with 5 mm space apart and 0.1 mm straps between shields simulating impurities on the shield, it turns out that 15 layers is sufficient to meet the design criteria of maintaining the vacuum vessel wall temperature below 150°C.

A further stress analysis for the tile-mounting plate reveals that the maximum Von Mises stress of the plate is 115 MPa and smaller than the yield strength of the material (Inconel 625).

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1. INTRODUCTION


2. MODEL DESCRIPTION

2.1 Geometry
There are 10 modules in the whole outer divertor, due to the cyclic symmetry, 1/10 of the full divertor model can be used in the FEA simulation. As left and right A-frame within the 1/10 module are the same, for purpose of simulation, 1/100 of the whole divertor (18° wedge) is modeled for this study.

2.2 Material property

2.3 Boundary condition for heat transfer analysis
The heat source is the heaters. For illustration of the numbering of the heaters, refer to Fig. 4. The power for each heater is listed in Table II. Except the bottom surface of the vessel floor is fixed as 35°C (the general vacuum vessel), all surfaces radiate to the ambient.

Three different ambient temperatures are used for the different components to radiator to: For tungsten tiles (lower 4 rows) which radiate to the EF1 area, the ambient temperature is 20°C (Ref. 3); for TZM tiles (upper 4 rows) and top surface of plates, the ambient temperature radiated to (the general vacuum vessel) is 35°C; and the back the divertor radiates to an ambient temperature at the EF2 area of 500°C based on simulations radiation of thermal shields.

2.4 Boundary condition for structural analysis
A structural analysis of the plate is also performed to check the maximum thermal stress. Two symmetry planes are used for left and right side of the symmetry divertor model. No translation of the bottom surface of the plate is allowed along normal direction.

3. RESULTS AND DISCUSSION

3.1 Temperature of A-frame assembly

To record the temperature of each tile, a table is made. The first part shows the original temperature, and the second part shows the temperature after subtracting 600°C. The temperature variation along toroidal direction is about 45°C, and the temperature variation along vertical direction is about 25°C.

3.2 Temperature of spherical bearings
Three spherical bearings, one on the top and two on the bottom of the A-frame enable the divertor to expand radially when the divertor is heated. The one on the top has a temperature of 600°C, and the two on the bottom has temperature of 310°C.

3.3 Heater power

3.4 Radiation simulation of thermal shields

Assuming the outer divertor is 600°C, thermal shields are Molybdenum with emissivity 0.2. With the following parameters, the thickness of the first and last shield material has the thickness of the first and last shield material is 0.05 inches. The strips between the layers, simulating the ripple on the thermal shields, has the width of 0.1 inch. If the temperature of the bottom layer is 310°C. With consideration of factors not taken into account, a temperature of 300°C is used as the ambient temperature during the heat transfer calculation of the A-frame assembly.

3.5 Structural analysis of the plate

The stress from heat transfer simulation of the plate ranges within 77°C. The maximum Von Mises stress of the plate is 115 MPa and smaller than the allowable stress of the material (Inconel 625).

REFERENCES

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