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ITER LIMITER FIRST WALL 3-D THERMO-MECHANICAL ANALYSIS

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ABSTRACT

This paper describes, in part, the design activity related to the ITER limiter first wall (FW). The limiter is needed to protect the reactor FW during plasma startup and shutdown. Steady state heat fluxes of 0.5 MW/m^2 are expected with short duration excursions to 5 MW/m^2 during startup/shutdown. A 3-D finite element model has been created to represent the beryllium-copper-steel layered construction of the limiter FW. The model takes advantage of the design symmetry, and the large aspect ratio of the limiter which helps in optimizing the finite element model by assuming infinite extent in the poloidal direction. Different options with various boundary conditions are investigated to optimize the limiter FW design and to simulate as close as possible, actual conditions in the limiter. The model is that of a 10 mm diameter hole running poloidally in a Cu block made of GlidCop Al25 which is 1.9 cm thick, and the spacing between the hole centers is 2.2 cm in the toroidal direction. The Cu block has a 1 cm thick castellated layer of Be facing the plasma and itself is attached to a cooled SS backing. Each block is discrete with a 1 mm groove separating it from the adjacent block. The interface between the various layers assumes no inter-layer compositions and thus has a singularity due to different material properties. For this preliminary analysis the value of 3.0 MW/m^2 heat flux is chosen for reference case. Furthermore, the analysis is elastic, not allowing any plastic deformation. These two rather severe assumptions tend to give higher stresses at the Cu/Be interface. One of the aspects investigated is the depth of the groove in the Cu between the coolant tube blocks. Analysis has shown that when this groove is deeper than 6 mm, the additional effect on the stress at the Cu/Be interface is negligible, the maximum stress in the Cu is reduced, leveling off at a depth of 13 mm. The maximum Be temperature is 552°C and 866°C at the 3 MW/m^2 and 5 MW/m^2 heat fluxes, respectively. The maximum von Mises stresses at the Cu/Be interface corners are 354 MPa and 679 MPa for the 3 MW/m^2 and 5 MW/m^2 heat fluxes respectively. These stresses are superficially high due to the stress singularity at the interface and the assumption of no plastic deformation.

I. INTRODUCTION

The International Thermonuclear Experimental Reactor (ITER) is a tokamak reactor that would be built to demonstrate the controlled ignition and extended burn of DT plasmas, and also to prove the reliability and maintainability of different reactor systems. The limiter is needed to protect the reactor FW during plasma startup and shutdown. The primary difference between the limiter FW and the rest of the reactor is that it must be able to accommodate up to 5 MW/m^2 in steady state compared with 0.5 MW/m^2 for the reactor FW. In addition, the limiter is a likely target for large off-normal heat loads due to Vertical Displacement Events (VDE's). VDE's can result in extensive surface melting and vaporization plus possible burnout of the cooling channels. The first wall is composed of a beryllium tile attached to 1.9 cm thick DS Cu Al25 with 1 mm slots cut poloidally between the coolant channels. The coolant channel is a 10 mm diameter hole running poloidally and the spacing between the hole centers is 2.2 cm in the toroidal direction. This work describes in part, the design activity related to the first wall (FW) for the ITER limiter. The main objective of this analysis is to determine the effect of the groove depth in the Cu on the limiter first-wall stress field. Steady state heat fluxes of 0.5 MW/m^2 are expected during the burn with

TABLE I

Boundary Conditions Used in the Model

Surface	Point (m)	Boundary Condition
X-Y	Z = 0	No deformation in any direction $\Delta x = \Delta y = \Delta z = 0$. It is bonded to SS at $T = 140°$C, same as zero stress temperature.
Y-Z	X = 0	Plane of symmetry, $\Delta x = 0$.
Y-Z	X = 0.01	Groove depth is parameterized between 0.0 and 19 mm.
X-Z	Y = 0	Plane of symmetry, $\Delta y = 0$.
X-Z	Y = 0.01	Free (it should be between free and constrained).

short duration (50 s) excursions to 5 MW/m^2 during startup/shutdown, and the water coolant pressure in the channels is 4 MPa.

III. 3-D THERMAL/STRESS ANALYSIS OF LIMITER FIRST-WALL

A. The Model

The model is based on a preliminary design provided by the ITER Joint Central Team (JCT) in Garching on June 8, 1995. Figure 1 illustrates the geometry of limiter #14. The properties used for the materials are temperature dependent and were taken from the ITER materials handbook.[1] The limiter first wall (Be tile on a copper block) was modeled. A 3-D finite element model has been created to represent the beryllium-copper-steel layered construction of the limiter FW. The model takes advantage of the design symmetry, and the large aspect ratio of the limiter which helps in optimizing the finite element model by assuming infinite extent in the poloidal direction. Different options with various boundary conditions are investigated to optimize the FW design and to simulate as close as possible the actual conditions in the limiter. The model is that of a 10 mm diameter hole running poloidally in a Cu block which is 1.9 cm thick made of DS Cu Al25, and the spacing between the hole centers is 2.2 cm in the toroidal direction. A groove is located in the Cu blocks midway between the coolant channels. One aspect of this investigation is to determine the optimum depth of this groove for reducing the stresses. The finite element software used for the analysis is ANSYS 5.0A running on a HP 9000 computer.[2] The 3-D geometry of the model is shown in Fig. 2 and the boundary conditions used for the analysis are given in Table I. This analysis assumes no plastic deformation and no intermediate layer between the Cu and Be. The resulting singularity at this interface results in high stresses.

B. Results and Discussion

Figure 3 shows the temperature and von Mises stress distribution in the finite element model for the 3 MW/m^2 surface heat load case. The maximum temperature of 552°C occurs at the surface of the Be and the maximum stress of 290 MPa occurs at the corner of the interface between the Cu and Be. These results are for a groove depth of 13 mm. Figure 4 summarizes the stress variation as a function of groove depth in the Cu. It should be noted that the temperature profiles are not affected by the groove depth since the heat path is parallel to the grooves and the grooves are centered between the coolant tubes. The depth of the grooves, however, have a major impact on the Be stresses and a somewhat lower impact on the Cu. A gradual reduction in the maximum von Mises stresses in the Cu occurs with groove depth, leveling off at $\sim$ 115 MPa at a depth of 13 mm. The stresses in the Be are more sensitive to the groove depth than those in the Cu. There is a precipitous reduction in the stresses with groove depth of 0-4 mm, eventually leveling off to $\sim$ 290 MPa at 13 mm. The dip in the curve between 3-6 mm can be rationalized by recognizing that the von Mises stress is the combination of axial and shear stresses. It is entirely possible that the combination of these stresses gives a minimum in the Be at a depth of 4 mm and thereafter levels off at $>$ 6 mm. However, the logical groove depth to use would be 13 mm where the Cu stresses are at their lowest and the Be stresses are slightly higher than at 4 mm.

The case of the 5 MW/m^2 heat flux was also investigated. At the same groove depth of 13 mm in the Cu, the maximum temperature at the Be surface was 866°C, and the stresses were 2400 MPa and 810 MPa in the Be and the Cu respectively. To investigate the effect of an intermediate compliant layer between the Cu and Be, the model was modified to include 1 mm of a fictitious material with physical

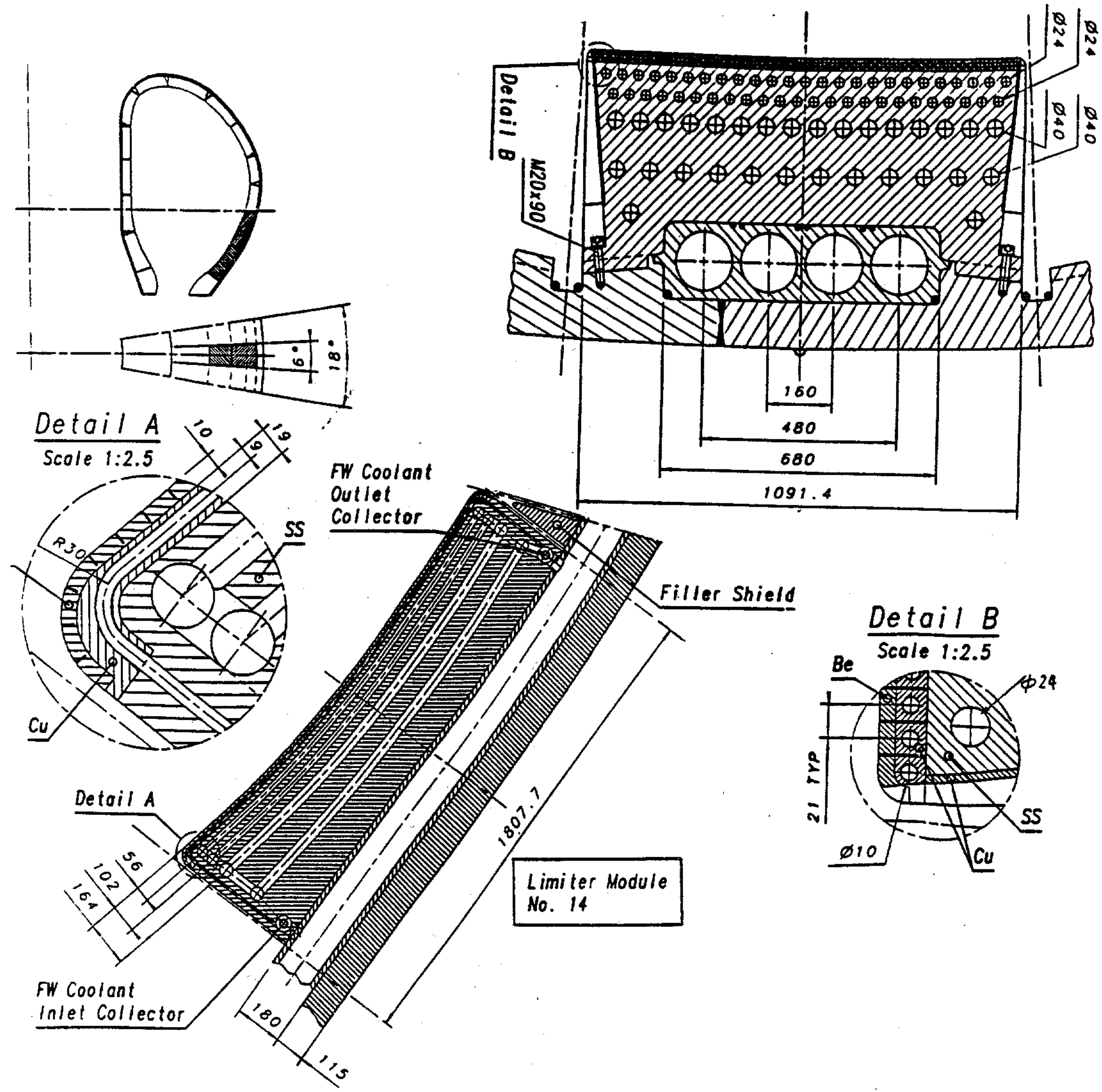

Fig. 1. The geometry of limiter #14.

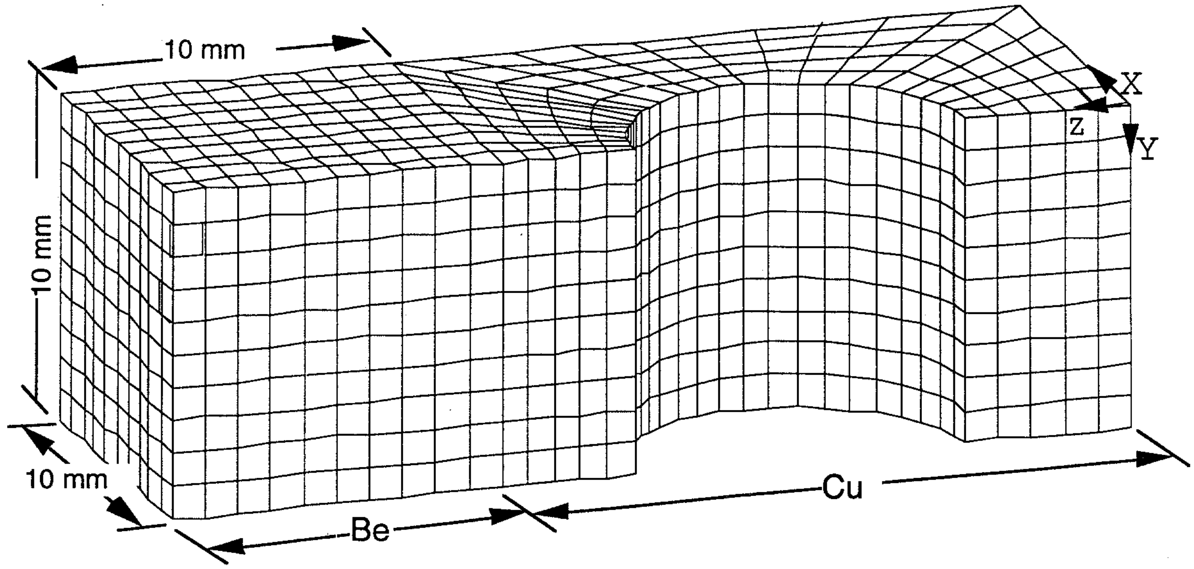

Fig. 2. The 3-D finite element geometry of the model.

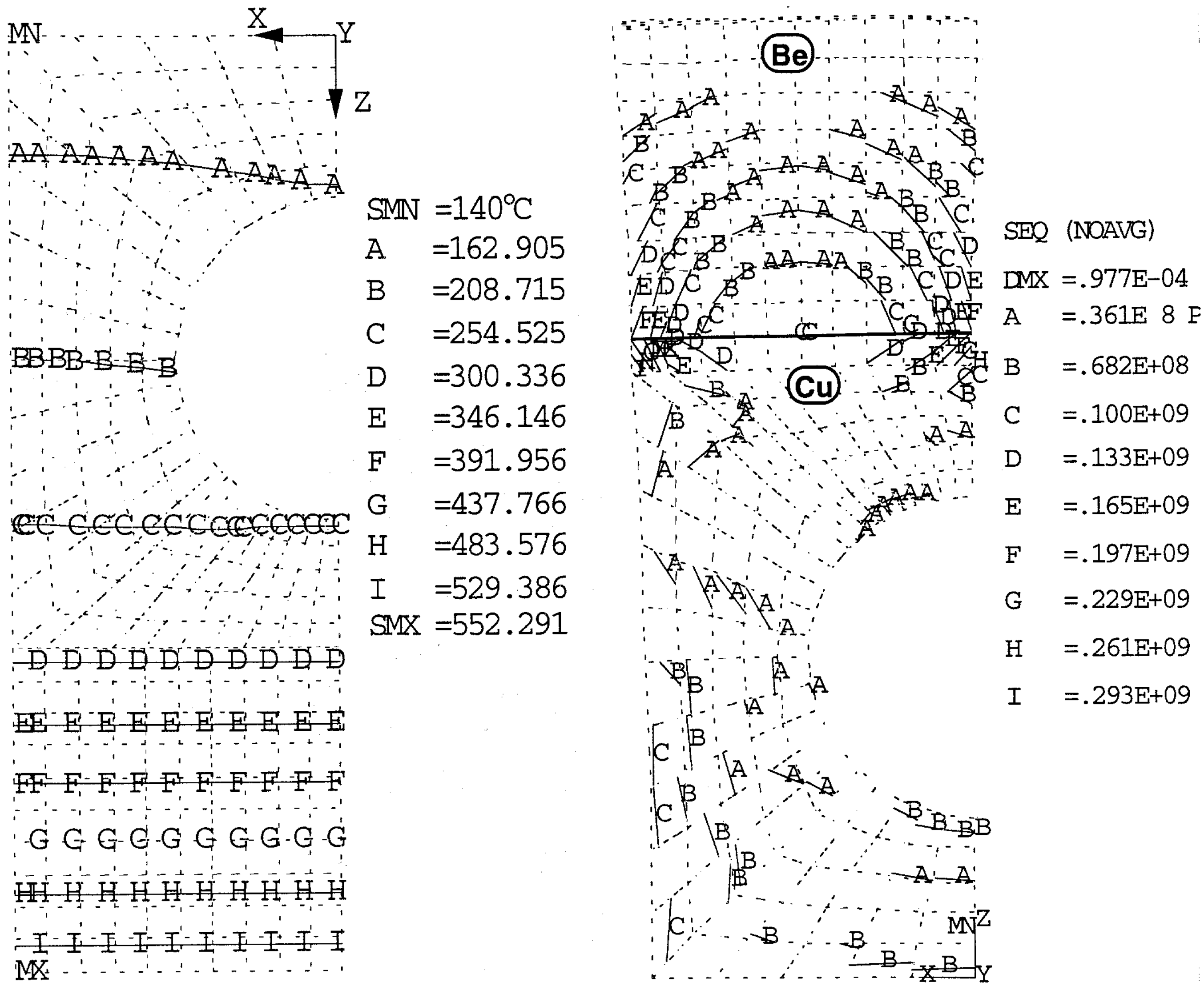

Fig. 3. Temperature and von Mises stress distribution on the X-Z plane for a surface heat flux of 3 MW/m^2, (Cu groove depth of 13 mm); note that the maximum stress occurs at the corner of the interface in Be.

properties which are the linear average between Cu and Be. As might be expected, the temperature profiles remained unchanged, but the stress in both Cu and Be were reduced by a factor of four. However, even this reduction is not sufficient for the case of the 5 MW/m^2 case since the maximum stresses in the Be are still very high at 600 MPa.

IV. SUMMARY AND CONCLUSIONS

Three dimensional finite element analysis of the ITER limiter FW using elastic deformation and no intermetallic layer at the interface between the Cu and the Be has been performed at 3 MW/m^2 and 5 MW/m^2 surface heat loads. The combination of no plastic deformation and the singularity at the Be/Cu interface combines to give high von Mises stresses. The stresses can be lowered by a groove in the Cu blocks between the coolant channels. Parametric analysis has shown that a 13 mm depth groove reduces the stresses in the Be to $\sim$ 290 MPa, which at 552°C are still excessive. At this depth, the stresses in the Cu are reduced to $\sim$ 115 MPa. The higher surface heat load of 5 MW/m^2 increases the stresses by a factor of eight for the 13 mm groove depth. An intermetallic layer 1 mm thick with intermediate properties between Cu and Be reduces the stresses by a factor of four. The recommendations from this study are:

1. Perform the analysis using plastic deformation

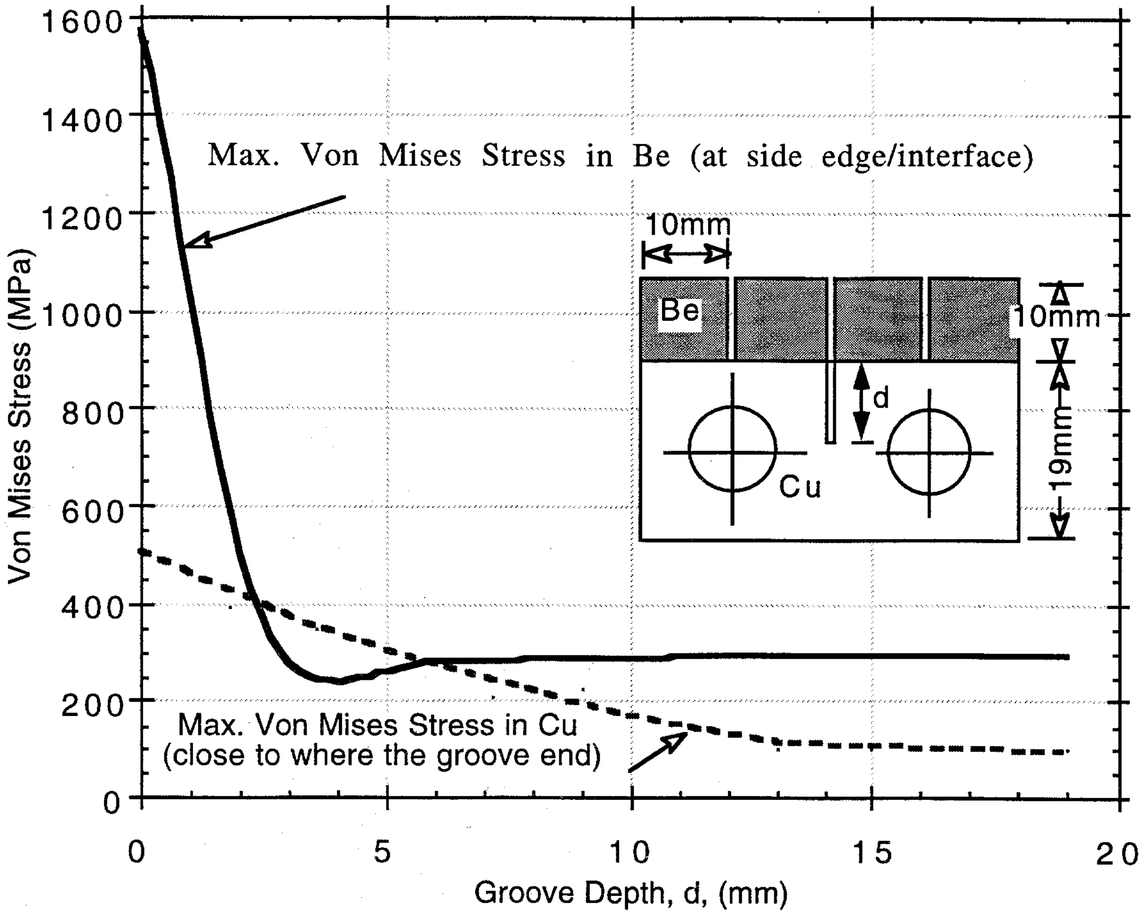

Fig. 4. Summary of the stress analysis for a surface heat flux of 3 MW/m^2.

and include intermediate layers of realistic materials compatible with Cu, Be and the fusion environment.

2. Perform an optimization study to determine the most effective groove depth using the above conditions.

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REFERENCES

1. ITER Materials Properties Handbook, 1995.

2. ANSYS User's Manual for Version 5.0, Upd0 DN-R300:50-1, December 23, 1992, Swanson Analysis Systems, Inc.