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TRANSIENT ELECTROMAGNETIC ANALYSIS OF BLANKET MODULES 14 AND 15 IN DIFFERENT SECTORS OF THE ITER BLANKET SYSTEM DUE TO PLASMA DISRUPTION

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The ITER blanket system provides shielding of the plasma controlling field coils and vacuum vessel from the plasma heat flux as well as nuclear heating from the plasma. In addition to the thermal requirements the blanket module attachment scheme must withstand the electromagnetic forces that occur during possible plasma disruption events. During a plasma disruption event eddy currents are induced in the blanket module (first wall and shield block) and interact with the large magnetic fields to produce forces which could potentially cause mechanical failure. For this reason the design and qualification of the ITER blanket system requires appropriate high-fidelity electromagnetic simulations that capture the physics of these disruption scenarios.

The key features of the analysis procedure will be described including the modeling of the geometry of the blanket modules and the plasma current during disruption.

The electromagnetic calculations are performed using the Opera-3d software. This software solves the transient 3D finite element problem from which the eddy currents are calculated. The electromagnetic loads due to these eddy currents are then calculated and translated to the local coordinate system of the blanket module of interest.

I. INTRODUCTION

The ITER blanket system provides shielding for the plasma controlling field coils and vacuum vessel from the plasma heat flux as well as nuclear heating from the plasma. The blanket system is comprised of a number of blanket modules which in general consist of a first wall and shield block. In addition to the thermal and neutronic requirements, the blanket module attachment scheme must withstand the electromagnetic forces that occur during plasma disruption. In addition the individual components that comprise a blanket module must remain intact.

During a plasma disruption event eddy currents are induced in the blanket modules (BM) which then interact with the large magnetic fields to produce forces in the blanket module which could potentially cause mechanical failure in the first wall, shield block, or vacuum vessel. High-fidelity electromagnetic simulations help capture the physics of these disruption scenarios and enable an accurate prediction of the electromagnetic loads experienced by the blanket modules and their components. These high-fidelity simulations have a twofold purpose. The first is to predict the total forces and torque that are experienced by the blanket module and its components. The second is to assess the stress on the components that are calculated from the force distribution within the blanket module. There have been a number of analyses by different domestic agencies of the ITER team that considered these electromagnetic loads on different blanket modules and different disruption events (Refs. 1, 2, 3, and 4).

The blanket modules considered in this paper surround the NBI region of the machine and are unique in their design in comparison to previously considered blanket modules. Specifically, blanket modules 14 and 15 will be analyzed in different sectors of the machine.

II. MODELING CONSIDERATIONS

II.A. Machine Definitions

All of the force and torque calculations are projected onto the local coordinate systems of each blanket module. The three coordinate directions are the radial, poliodal, and toroidal. The radial direction points toward the plasma and the toroidal direction is in the direction of the plasma current flow (clockwise when looking down the axis of symmetry of the machine). The poloidal direction is then defined as toroidal cross the radial unit vectors. The origin of the local system is defined to be the centroid of the intersection points of the flexible mounts of the blanket module of interest

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II.A. Blanket Module Models

As stated in the introduction the blanket modules in this region of the machine have different designs dependent on which sector of the machine they are located in. A brief description of the different models considered will be now be described. Note that in each of the blanket modules considered cooling channels were included in the model to give the proper force distribution within the blanket module.

II.A.1. Model 1

The overall model for the sector, where the different BMs 15 (NBI region) are located, is more complicated due to lack of symmetry. For this reason a twenty degree sector of the machine could not be used and so a forty degree sector was modeled and is shown in Fig. 1. The inner and outer vacuum vessels were included but not shown in the Figure. The design of blanket modules 14 and 15 vary with respect to their location to the NBI ports.

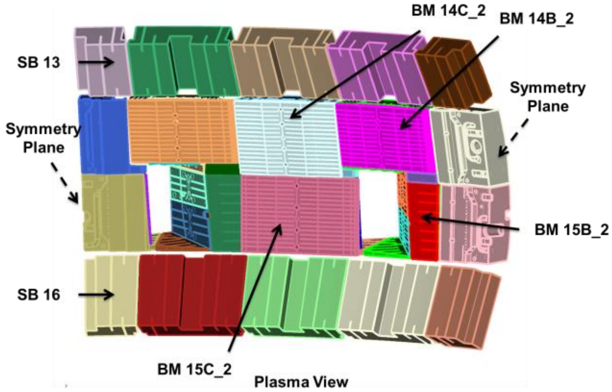

Fig. 1. Solid model 1 for the electromagnetic analysis.

A standard blanket module consists of beryllium (Be) tiles, copper (CuCrZr) fingers, stainless steel (SS 316) fingers, a stainless steel (SS 316) beam, and a stainless steel (SS 316) shield block. To simplify the model the Be tiles are not included. The blanket modules around the NBI ports have a different configuration. In reference to Fig. 1 module BM15B_2 consists of a stainless steel block with copper plates. BM15C_2 comprises the standard blanket module components described above with additional copper plates. BM15C_2 is shown in Fig. 2. To help reduce the mesh count of the overall simulation the first walls were not included on the modules that intersect the symmetry planes.

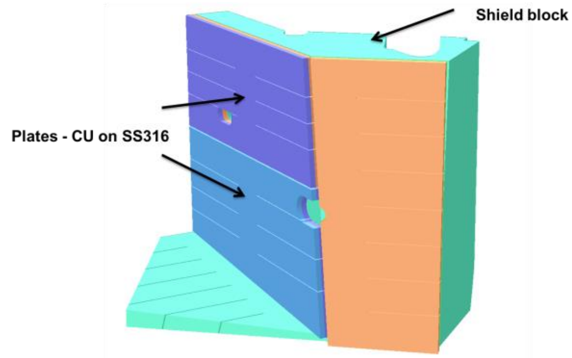

Fig. 2. Close-up view of BM15C_2 shows the plates on this unique module.

II.A.2. Model 2

The second model focuses on a different sector of the machine and is shown in Fig. 3.

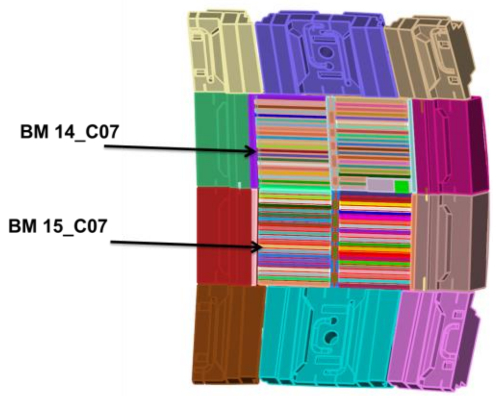

Fig. 3.Solid model 2 for the electromagnetic analysis.

The angular width of the model for this sector is twenty degrees and the key differences of these modules are their physical extent in the toroidal direction. In addition module BM 14_C07 has a diagnostic cover in one corner of the module.

II.B. Plasma Disruption Modeling

There are two categories of disruptions and include major disruptions (MD) and vertical displacement events (VDE). There are normally three stages of a disruption – thermal quench, current quench, and loss of vertical position. The order of these stages determines the type of disruption. During current quench the reduction of the total plasma current induces eddy currents in the blanket system that interact with the magnetic fields present in the device producing electromagnetic loads. In addition the plasma centroid can move either up or down and the plasma current can decay linearly or exponentially. A plasma disruption event MD_UP_LIN represents a major disruption, upward moving, with a linear plasma current decay. This shortened nomenclature will be used to describe a plasma disruption event. The two events to be considered in this analysis will be MD_UP_LIN and MD_DW_LIN.

The disruption events are modeled using the DINA code (Ref. 5). This code can be described as a nonlinear magneto-hydro-dynamic code that assumes the plasma is axisymmetric and takes into account the electromagnetic interactions with the conducting walls and external coils. The plasma current in DINA is modeled by a number of filaments that vary in time and position during the disruption event.

To model these plasma currents in a manner suitable for finite element analysis axisymmetric coils are introduced containing a finite cross-section. These are fixed in space but the time dependence is calculated to accurately model the total plasma current and the effective rate of change of the flux density that each module would experience during plasma disruption. The number of plasma coils used for the simulation of the plasma disruption is 64 and are located near the blanket modules.

II.C. Overall Model

The final step in model preparation is the generation of a finite element model with appropriate boundary conditions. Symmetry planes were used on the toroidal edges of the geometry for both models considered. The mesh count for the 20 and 40 degree models were 19 and 35 million elements, respectively.

The plasma currents described previously were combined with the central solenoid coils, poloidal field coils, and the toroidal field coil. The toroidal field coil is modeled as a line source on the machine axis that produces a magnetic flux density of 5.3T at a distance of 6.2m from the machine axis.

The solutions are computed using the Opera-3d software which has been used previously with great success (Ref. 6). This software can be used with symmetry and also is based on the reduced potential formulation. This formulation decouples the currents from the mesh which allows different current modeling be used on the same mesh. In addition the force distribution within any component of a blanket module results can be exported for stress analysis if desired in the Opera suite of codes or other mechanical analysis packages.

III. RESULTS

Some representative results for the different models and disruption events will now be presented. The focus of the results will be the torque and specifically the radial torque,

III.A. Model 1 Results

The two disruption events considered for this model revealed very similar results for the different blanket modules contained in this model. Some representative results for the different models and disruption events will now be presented. The focus of the results will be the torque and specifically the radial torque.

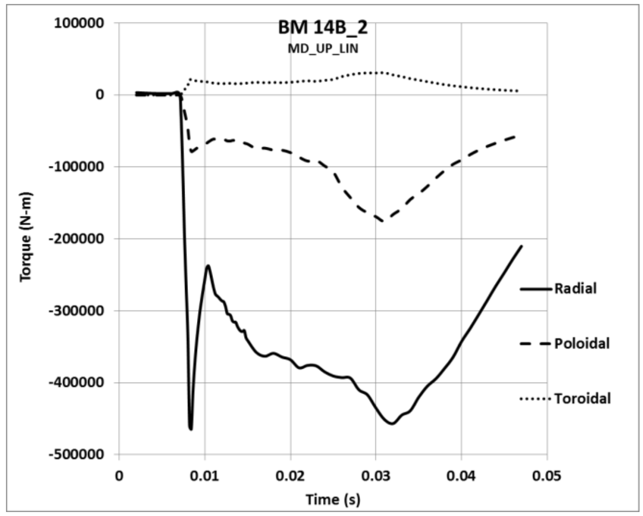

Fig. 4 Computed torque for model 1, BM 14B_2 for MD_UP_LIN.

As can be seen in Fig. 4 the radial torque is the largest and has two peaks, one occurring near thermal quench and the other during current quench. All of the blanket modules analyzed for this sector had very similar behavior. The magnitude of the maxima of the radial torque for the different blanket modules and disruption events are shown in Fig, 5.

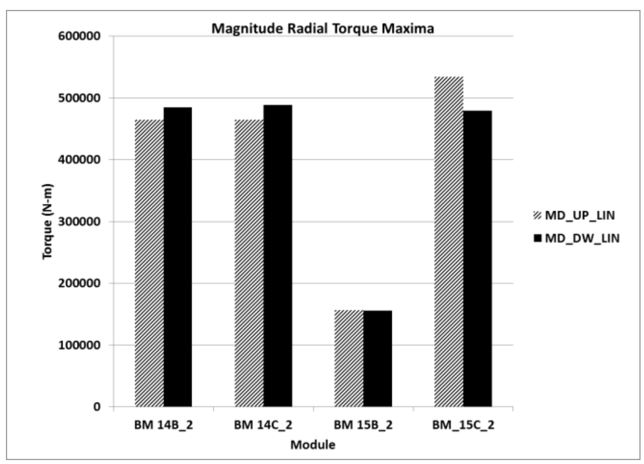

Fig. 5. Radial torque maxima for the blanket modules and disruption events for model 1.

III.B. Model 2 Results

The results for this model are similar to the previously considered model. The radial torque is the largest load and has two peaks – one near thermal quench and the other during current quench. The time variation of the different torque components for blanket module BM 14_C07 are shown in Fig. 6. Figure 7 shows the magnitude of the torque maxima for the different modules and disruption events considered.

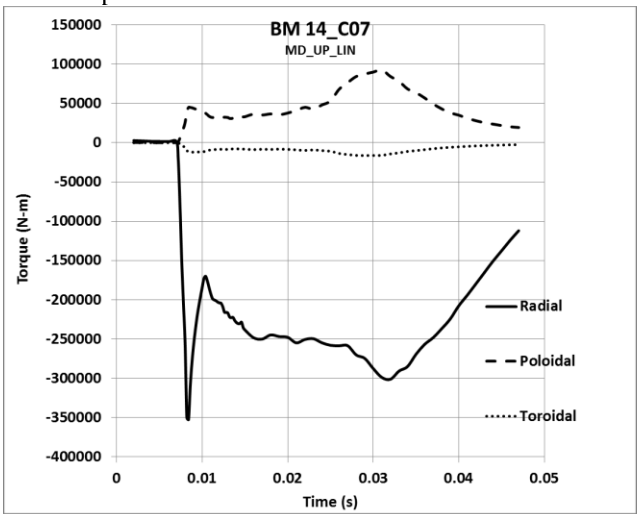

Fig. 6. Computed torque for model 1, BM 14_C07 for MD_UP_LIN.

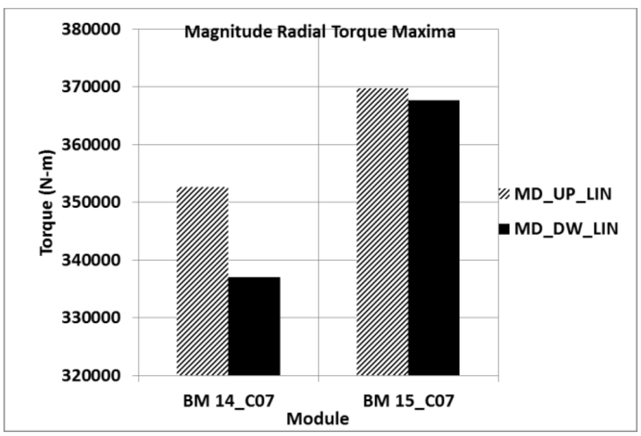

Fig. 7. Radial torque maxima for the blanket modules and disruption events for model 2.

IV. CONCLUSIONS

The key features needed to calculate the electromagnetic forces due to plasma disruption have been described on selected outboard modules of the ITER device. These included the geometric and current modeling necessary for a high-fidelity electromagnetic simulation of a blanket module during plasma disruption.

Attention was focused on the modules near the equatorial ports and the radial torque maxima were shown for two different sectors of the machine and disruption events. The results show for the disruption events considered the radial torque maxima do not show significant variation.

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The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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