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Study of dynamic amplification factor of DEMO blanket caused by a gap at the supporting key

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HIGHLIGHTS

- With the preliminary hypothesis established, the dynamic displacements are not so high and the state of stress (not reported) does not exhibit large region with plastic strain.
- The dynamic displacements show a certain dependency from the mesh adopted, and the geometry chosen.
- The energy (kinetic or strain) of the whole structure gives useful information about the key behavior during impact.
- In order to better understand the overall phenomenon other details (non-linear material, better evaluation of damping, other disruption rise-times and so on.

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ABSTRACT

Among the design activities of the in vessel components for DEMO promoted by European Fusion Development Agreement (EFDA) organization, this work deals with the gap required at the supporting keys of the blanket. Due to its higher operating temperatures compared to the vacuum vessel (VV) ones, this gap will increase during operation.

The electro magnetic (EM) loads due to fast disruptions occur on a short time and might accelerate the blanket significantly before it touches the supporting keys, causing an impact of the blanket itself onto the keys. Depending on their stiffness, the EM loads with their short time scale could excite the structure's natural frequencies, causing dynamic amplification. Both phenomena (impact and dynamic amplification) can cause stresses in the structure significantly higher than the static ones.

This work develops a finite element model of DEMO blanket to study its non-linear transient dynamic behavior under impact loadings. A VV sector, the ribs between the inner and outer VV, the backward manifolds and the supporting keys of the blanket have been modeled. The analyses have been performed with Abaqus [1] and Ansys [2] FEM codes focused on the displacements of the keys in their housing on the blanket. The dynamic amplification factor has been evaluated as the ratio of dynamic to static displacements in meaningful points of the structure for a growing gap till 5 mm.

1. Introduction

This paper deals with a set of numerical analyses that would study the dynamic behavior of the blanket of DEMO tokamak loaded by the EM forces arising from a fast disruption. A gap between the keys supported on the VV's inner surface and the blanket's frames is required during the assembly phase. Because of the blanket higher operating temperatures compared to the VV's ones, this gap will increase during operation. For closing this type of gap during exercise, a movable element would be required, which complicates the function of the keys during installation, and during operations.

EM loads due to fast disruptions occur on a short rise-time and might accelerate the blanket before contact happens at the supporting keys, causing an impact of the blanket onto the keys. Depending on the stiffness of the blanket and its supports, the structure's natural periods might be similar to the time scale of the EM load, causing dynamic amplification.

This study can be carried on by relating the dynamic displacements exhibited during disruptions to the static ones in some meaningful blanket's regions: this will indicate how the blanket attachments can be designed.

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So it is worth to estimate the dynamic amplification factor caused by the radial moment (the most meaningful component of the EM forces arising from a disruption) acting on the blanket vertical segments due to a gap at the supporting keys.

The whole work has been engaged in two independent FEM analyses: one with the Abaqus code, and one with the Ansys code. Two independent ways have been chosen because the results obtained in this way can indicate helpful suggestions each other. The load absolute values and the gap extent have been varied and during post-process some values about the energy involved in the impact's region have been extracted.

2. Abaqus analysis: solid model and mesh

The solid model has been extracted from the EFDA database [3]: the CATIA model has been updated to accept the instructions included in the task's technical specifications. The main geometric dimensions used in the analyses have been:

- Key toroidal width: 150 mm;
- Key poloidal height: 400 mm;
- VV inner and outer shell thickness: 60 mm;
- Thickness of ribs between VV shell: 40 mm;
- Radial length of key's contact area: 100 mm.

In Fig. 1 there is a schematic view of the inboard and outboard blanket's segments and a VV sector. Only a half of a sector has been modeled. The local modeling of the keys and their contact areas arises from the EFDA database [1,3].

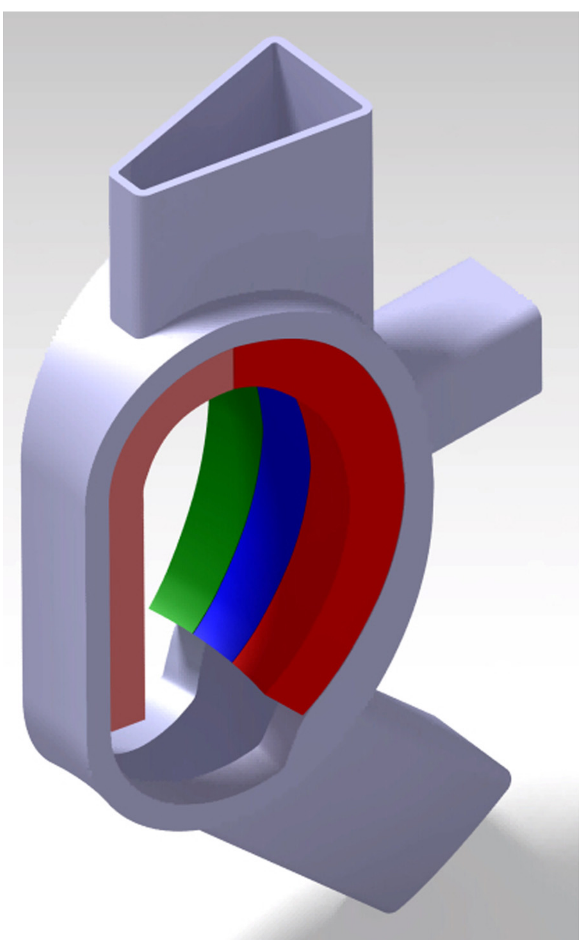

Fig. 1. Catia model of DEMO VV and blanket.

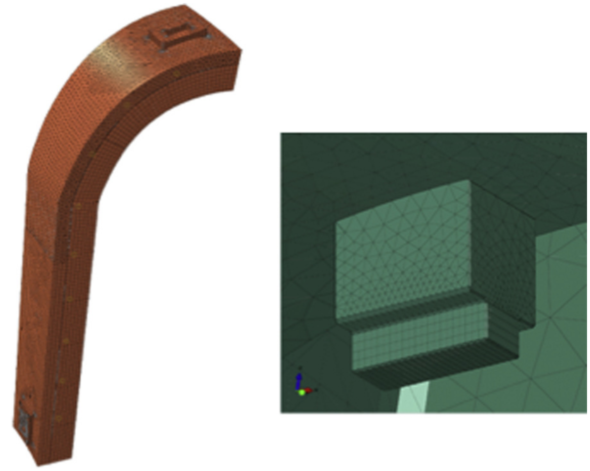

Fig. 2. FEM model of a blanket sector and the upper key.

In Fig. 2 there are the fem model of the blanket sector and a picture (not in scale) of the upper key: its stiffness has been predefined in the same EFDA drawings [3].

2.1. Boundary conditions and loads

Great attention has been paid for the zone between key and frame whose interface has been modeled with contact elements. In all analyses two gaps in toroidal direction have been introduced whose width is 2.5 mm. Assuming that the initial condition in the dynamic case is with one toroidal gap closed, the total toroidal gap under dynamic load has been ranged from 2.5 mm to 5 mm.

For the boundary conditions, the following statements have been adopted:

- the nodes on the equatorial port have been fixed in global coordinate system ($Ux = Uy = Uz = 0$) as the stress in this region are not important for this kind of analysis;
- for toroidal symmetry, the nodes on the border of the VV sector must not exhibit circumferential displacements, so their corresponding degree of freedom has been nullified in a proper cylindrical coordinate system;
- because of the blanket's double curvature geometry, only the rotations about a radial axis of the inboard blanket sector have been allowed.

A particular procedure has been adopted to constrain the rotations of the blanket's sector because the brick elements do not have rotational DOF. A reference point (RP) for each blanket's module have been introduced, then a multi points constraints (MPC) element type has been used to connect the reference point at the nodes on the front surface (the one that directly faces the plasma) of every breeding module (Fig. 3). Then the constraints on rotational DOF and the concentrated moments have been applied only on the reference points and then automatically transferred to the nodes above mentioned surface.

The load component that we have considered is the radial moment due to VDE [4] with maximum amplitude of 30 MNm. First of all this moment has been applied as static and then as dynamic load. The same load has been applied on the blanket sector according to the advices included in [4]. In the dynamic analysis the load amplitude has been modeled (according to the choices made in [5]) as a function of time as: