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Structural analysis of the Passive Magnetic Shield for the ITER Heating Neutral Beam Injector system

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ABSTRACT

The ITER Passive Magnetic Shield (PMS) main function is to protect the Neutral Beam Injector (NBI) from the external magnetic field coming from the tokamak, and to shield the NB cell from the radiation coming from all activated components. The shielding from the external magnetic field is performed in association with the Active Compensation Cooled Correction Coils (ACCC). The Bushing and Transmission Line (TL) PMS also provides structural support for HV bushing, allowing its maintenance and providing air sealing function between NBI cell and High Voltage deck room.

The paper summarizes the structural analyses performed in order to evaluate the mechanical behaviour of the HNB PMS under operation combined with seismic event. The RCC-MR Code is used to validate the design, assuming creep is negligible, since the structure is expected to be at room temperature. P-type damage is assessed.

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1. Introduction

The Heating Neutral Beam (HNB) Passive Magnetic Shield (PMS) is an assembly of S235 low carbon steel plates (Fig. 1) which works in conjunction with the active compensation/correction (ACC) coils to limit the magnetic field in its interior [1]. This is needed to the correct operation of the HNB system.

The HNB PMS is divided in three sub-assemblies:

- The Vessel PMS, which includes the Beam Line Vessel (BLV) and the Beam Source Vessel (BSV).
- The High Voltage Bushing (HVB) PMS
- The Transmission Line (TL) PMS.

In addition to its magnetic shielding function, the PMS provides structural support for the BLV, BSV, HVB and ACC coils. It also acts as neutronic shield allowing to limit radiation levels in the NB cell during maintenance.

The Vessel PMS rests on the ground of the NBI cell and supports the HNB Vessel. The HVB PMS is attached to the Level 3 floor and supports the HVB itself and the TL PMS.

2. Structural analysis

The aim of the current structural analysis is to verify that the preliminary design of the Vessel, HVB and TL Passive Magnetic Shield fulfils RCC-MR code requirements during normal operation and NB pulse.

As there is no connection between the Vessel PMS and the Bushing and TL PMS both components have been analyzed independently: On the one hand, the vessel PMS and on the other hand the Bushing and TL PMS.

The following analyses have been performed for each component:

a) Modal analysis to determine the main natural frequencies.
b) Equivalent static analysis according to the ITER documentation [2] to simulate the response in case of different magnitudes of seismic events during normal operation and NB pulse.

3. Numerical model

3.1. Vessel PMS model

The Vessel PMS (Fig. 2) consist of a group of plates (panels) connected by a steel structure (grid). The model used for the equivalent static analysis differs slightly from the one used in the modal analysis. The PMS model used for the static structural analysis includes a simplified model of the internal vessel which consists of a box with

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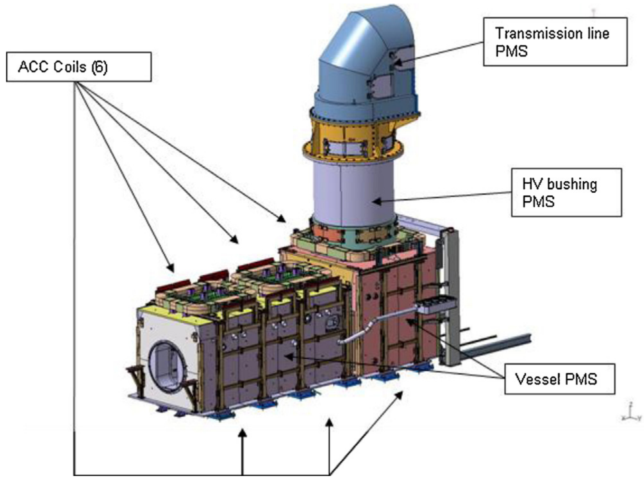

Fig. 1. Heating Neutral Beam (HNB) Passive Magnetic Shield (PMS).

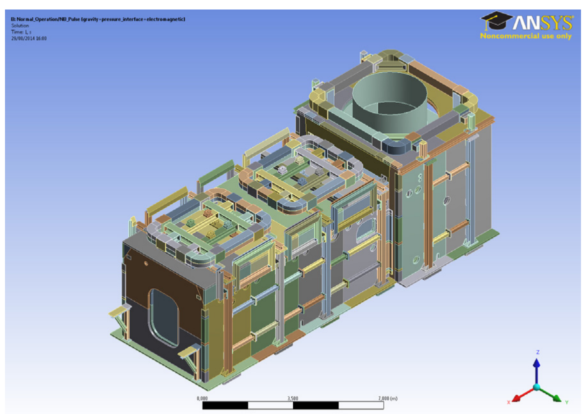

Fig. 2. Vessel PMS Model.

internal reinforcements to give rigidity, and with the thickness necessary to get a model mass that is similar to the real internal vessel (Fig. 3 left). This simplified model for the vessel has been used in the structural static analysis in order to introduce the gravity load and the stiffness of the internal vessel transmitted to the PMS bottom panels. However, when this simplified model is used in the modal analysis, additional modes appear due to the simplifications introduced in the internal vessel model, which are not real modes. Therefore, in the modal analysis two mass elements were used to substitute the internal vessel components (Fig. 3, right).

The static structural model includes frictional contacts between all the PMS panels, between the grid and the panels and between the coils and their supports. However, since non-linear contacts are not permitted in modal analysis, the model used for the modal analysis considers the panels free to move; the only contacts defined for the PMS panels in this case are the bonded contacts between

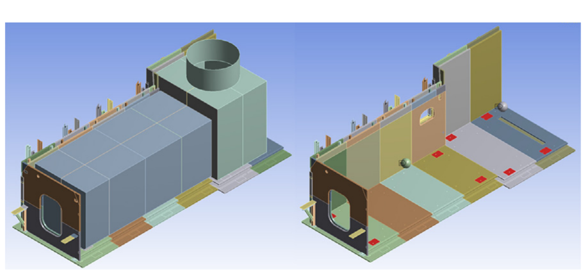

Fig. 3. Internal vessel simplified model for structural analysis (left) and for modal analysis (right).

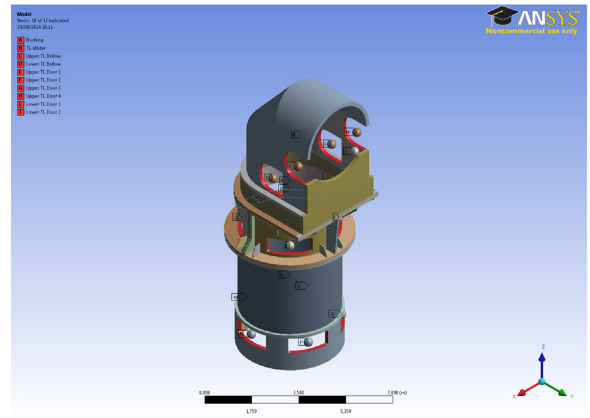

Fig. 4. Mass elements representing the doors, bushing, TL and bellows.

the horizontal panels and the corresponding side panels, used for limiting the vertical displacement (avoiding geometrical interferences). Bonded contacts have been used to simulate every bolted or welded connection in both models.

The total mass, including the internal vessel and the Upper ACC Coils, adds up to 676 tonnes, resulting in a model of ~300 k elements and ~900 k nodes. The mesh of the lateral panels is relatively coarse, since high stresses are not foreseen, but the mesh of the beam structure, coils and bottom panels is stress quality.

The Vessel PMS is attached to the ground through twelve lower supports, located at the bottom of each bottom PMS panel, and aligned with the vertical beams attached to side panels that support the weight of the top panels and coils. This attachment is simulated by applying the fixed support boundary condition.

3.2. *Bushing and TL PMS model*

To assess the structural performance of the Bushing and TL PMS models of the complete assembly have been created except the maintenance doors which were simulated with point masses to simplify the model. There are 5 bushing PMS doors and 8 TL PMS doors.

Four additional mass elements were included in the model to simulate the dead weight of the bushing, the TL and the two bellows connecting bushing and TL. These masses are supported by the flange on the inner side of the bushing PMS cylinder, just above the doors (Fig. 4).

The total mass of the model, including the mass elements, adds up 267,750 kg, resulting in a model of ~65 k elements and ~293 k nodes.

The Bushing and TL PMS is fixed to the HV deck room floor (level 3 of tokamak building). This attachment is simulated by applying the fixed support boundary condition. Bonded contacts have been established to simulate every bolted or welded connection.

4. Design loads

The load combinations analyzed along with the associated applied loads are those included in Table 1 [3].

The following assumptions and simplifications have been made.

- Bolted unions were not modelled in detail.
- Maintenance doors have not been modelled.
- PMS is assumed to be at room temperature.
- Nuclear heating is assumed to be negligible.
- Where the stresses were not significant, linearization was not carried out.

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