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Research Paper

Structural assessment on DEMO lower port structure

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ABSTRACT

The present work focuses on structural assessment of DEMO Vacuum Vessel Lower Port structure. Since previous studies have been addressed the structural scheme of the main vessel, this work investigates a feasible layout of vessel supports defining the position of the pumping port cut and different inclinations of the lower port. All design configurations have been analysed according to Design and Construction Rules for Mechanical Components of Nuclear Installations. The structure was checked against a vertical load due to a Vertical Displacement Event in combination with the estimated mass of all components supported by the vessel. The outcome of the assessment gives relevant information about the optimal position of the supports, the impact of the pumping port duct cut and the lower port inclination.

1. Introduction

The DEMO Vacuum Vessel (VV) is a large torus structure that contains and supports the in-vessel components such as breeding blanket [1] and divertor cassette [2]. The VV is part of the primary confinement barrier for the reactor and shall be designed to withstand the electromagnetic loads during plasma disruptions and design basis accidents. The most critical disruption events are the Vertical Displacement Events (VDE) which are uncontrolled vertical motion of the plasma column in tokamaks that brings it in contact with the surrounding structures. The expected vertical load due to a VDE becomes one of the first design load to consider when designing the vacuum vessel of a tokamak.

To verify the structural integrity of the VV according to RCC-MRx code [3], three different types of damages shall be evaluated:

- P type damage
- S type damage
- Buckling (with manufacturing imperfection)

As such as reported in the code, the type P damages are those which can result from the application to a structure of a steadily and regularly increasing loading or a constant loading, while the damages result from repeated application of loadings are identified as Type S damages [3]. In the present study just the “P type damage” has been evaluated. A VDE is indeed an event of Category 3 and the Level C criteria must be applied [3]. An operating conditions of category 3, emergency conditions, corresponding to very low probability of occurrence but which must nonetheless be considered, and which imply shut down and appropriate inspection of the component or of the plant for these kind of events the code provides a level C criteria. The aim of level C criteria is to protect the component against immediate or time-dependent excessive deformation, immediate or time-dependent plastic instability, time-dependent fracture, elastic or elastoplastic instability immediate or time-dependent [3]. According to Design and Construction Rules for Mechanical Components of Nuclear Installations (RCC-MRx) in case of type P damage evaluation, fatigue analyses are not required, while the buckling phenomena will be studied in more detailed design phase. The analysis has been run according to the elastoplastic procedure. Indeed in the elastoplastic analysis procedure the load is applied progressively to the deformed structure up to plastic collapse. Minimum true stress-strain material properties are considered and required collapse load factor is 2.0 (i.e. RCC- MRx RB 3251.12) [3].

Previous studies on DEMO 2014 configuration [5,6] addressed the structural scheme of the main vessel. The aim of the present paper is indeed to provide:

- a structural assessment of the VV structure updated to DEMO 2015 configuration model [7] subjected to a VDE (Fig. 1);
- a structural assessment of different configurations of VV structure in terms of lower port inclination, supports and pumping port cut positions.

The assessment is based on finite element method (FEM) that is being discussed in the next sections. In particular, according to RCC MRx – RB 3242 “Elastoplastic analysis of a structure subjected to a

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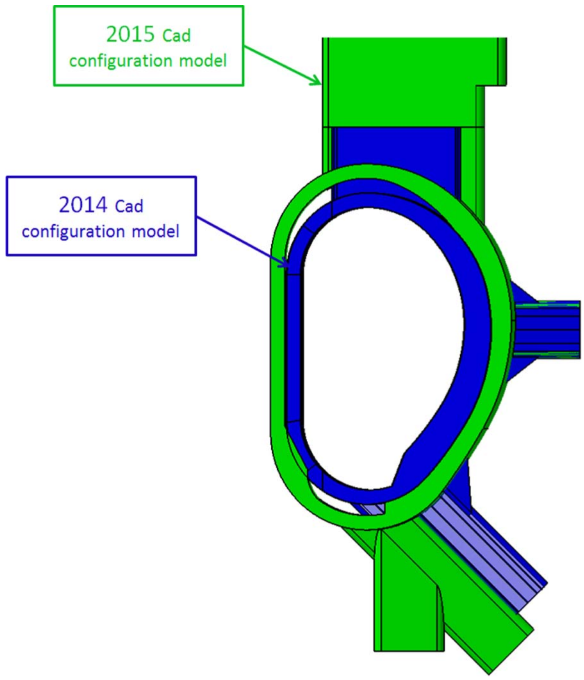

Fig. 1. Comparison between 2014 and 2015 DEMO VV shape.

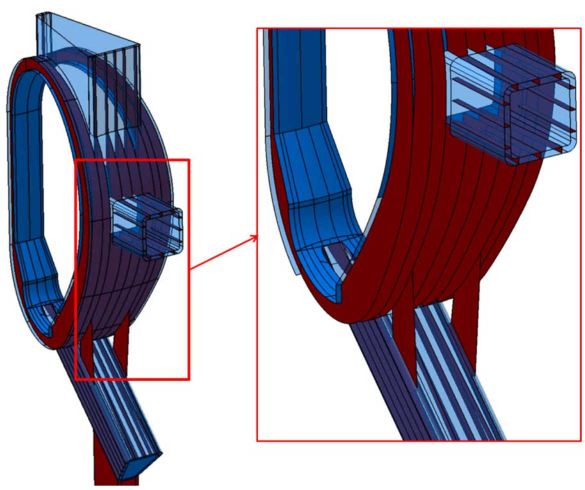

Fig. 2. Surface model of DEMO VV 2015.

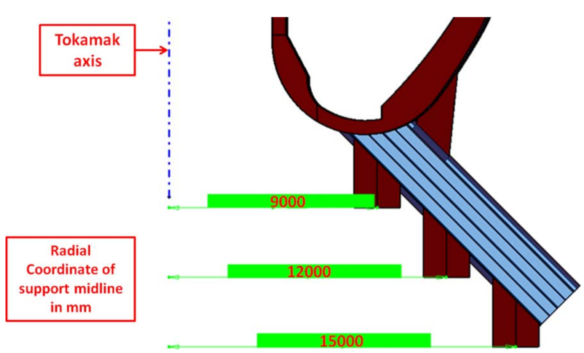

Fig. 3. Vacuum Vessel Supports Layout.

monotonic loading", the VV has to be verified against the maximum vertical load due to a VDE, as well as its own weight. Therefore the weight of all the components that are not modelled is considered as well in the calculation.

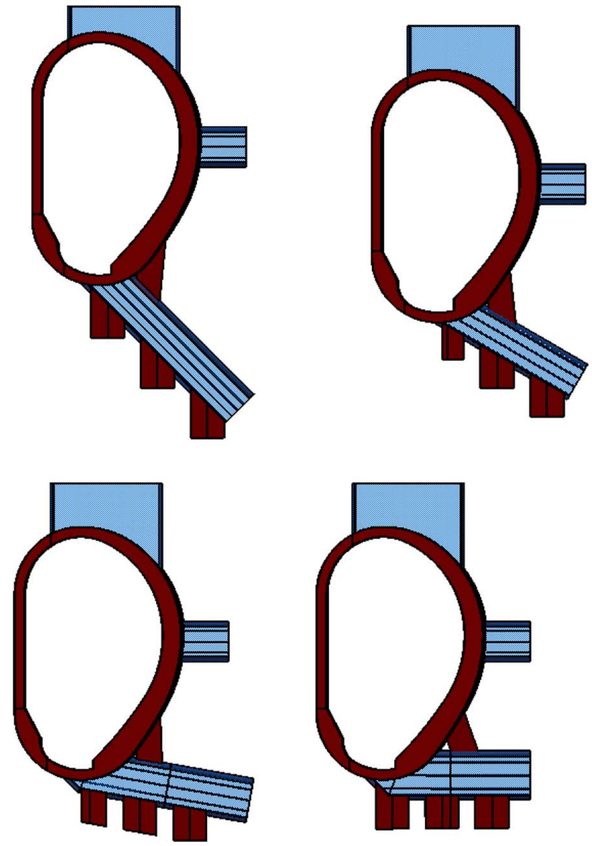

Fig. 4. CAD surface models of DEMO 2015 configurations.

Table 1
ID and characteristics of DEMO VV design configurations.

ID of Demo VV Configurations	Radial Support Location [m]		
	9	12	15
45° – without pumping duct	L9_45	L12_45	L15_45
45° – pumping duct option 1	L9_45_pd_1	L12_45_pd_1	L15_45_pd_1
45° – pumping duct option 2	L9_45_pd_2	L12_45_pd_2	L15_45_pd_2
30° – without pumping duct	L9_30	L12_30	L15_30
30° – pumping duct option 1	L9_30_pd_1	L12_30_pd_1	L15_30_pd_1
30° – pumping duct option 2	L9_30_pd_2	L12_30_pd_2	L15_30_pd_2
10° – without pumping duct	L9_10	L12_10	L15_10
10° – pumping duct option 1	L9_10_pd_1	L12_10_pd_1	L15_10_pd_1
10° – pumping duct option 2	L9_10_pd_2	L12_10_pd_2	L15_10_pd_2
0° – without pumping duct	L9_0	L12_0	L15_0
0° – pumping duct option 1	L9_0_pd_1	L12_0_pd_1	L15_0_pd_1
0° – pumping duct option 2	L9_0_pd_2	L12_0_pd_2	L15_0_pd_2

2. Vacuum vessel structure and design configurations

Since a previous assessment [6] on the structural scheme of the VV confirmed its capability to withstand the loads due to a critical VDE, this scheme has been adopted also in DEMO 2015 design. The DEMO VV is a double-walled structure made from SS 316 L (N). Its overall thickness of 0.60–1.15 m is formed by inner and outer shells, 60 mm in thickness, joined by welded stiffening ribs of 40 mm in thickness. In the current configuration [7] the VV is divided toroidally into 18 sectors (20° for each one) which are joined by field welding. The lower port is joined to the main vessel structure and is reinforced by gusset plates (Fig. 2). The poloidal ribs aligned with the gussets plates are 80 mm in thickness. Since previous studies [6] confirmed that the gussets plates are critical components their thickness is set at 100 mm. This choice guarantees the structural continuity in order that loads can be safely