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Status of the DEMO blanket attachment system and tackling the outstanding challenges

Z. Vizvary[1*], M. L. Richiusa[1], C. Bachmann[2], C. Vorpahl[2]

[1] *CCFE, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK*
[2] *EUROfusion – Programme Management Unit, Boltzmannstrasse 2, 85748 Garching, Germany*

The DEMO blanket attachment concept is challenging due to several factors: the harsh radiation environment, the thermal expansion, the electro-magnetic loads, the remote maintenance feasibility, and the accurate control of the alignment of the breeding blanket first wall during operation. There are two inboard and three outboard blanket segments per vacuum vessel sector to be installed and extracted by remotely controlled tools through a single upper vertical port. The design of the fixations of the blanket segments to the VV complies with the strategy to avoid the need for front side access for engagement and release. The attachment system has been designed for the numerous critical load cases, including normal operation, dwell between pulses, plasma disruptions, fast discharge of the magnet coils, and accidental conditions such as loss of blanket coolant. At the same time the attachments must guarantee the stresses in the blanket segments not to exceed limits.

This paper introduces the attachment concept and describes the finite element model that has been built to assess the blanket attachment system. The model represents one sector of the DEMO machine. The results focus on the reaction forces transmitted at individual attachment locations to define these interfaces and guide the design of the individual supports.

Keywords: DEMO, Blanket attachment concept, FEM

1. Introduction

The blanket attachment system has to cope with various loading conditions: Gravity, thermal expansion, static magnetic forces during operation on the ferritic blanket steel, transient electro-magnetic forces during central disruptions (major disruption, MD) and vertical displacement events (VDE) toroidal field coil fast discharge (TFCFD), and loss of coolant accidents (LOCA).

The principle approach of the integration of in-vessel components in DEMO is based on avoiding the need for engagement/release of mechanical supports, pipe connections or electrical straps from the front and through the first wall (FW). This is to avoid remote maintenance (RM) tools operating on a regular basis in the very high gamma radiation environment in the plasma chamber. The basic blanket attachment concept is introduced in [1].

The model described in this paper is a shell element-based model of one 22.5° sector for the DEMO vacuum vessel (VV), thus reducing the number of nodes and elements in the model. It was developed to assess the structural behaviour and deformation of the blanket segments inside the VV and to determine the forces transmitted through individual mechanical supports.

2. Attachment system description

2.1 Basic concept

The attachment system needs to support the blanket against very large electromagnetic (EM) loads, in particular radial forces and moments about the radial axis. At the same time the supports need to allow for the significant thermal deformation of the blanket, which reaches more than 500°C in operation, and must maintain good alignment of the FW of adjacent blankets; charged particles following the, mainly toroidal, magnetic field lines would otherwise cause excessive local incident heat loads [2]. The choice was therefore made to support the blankets on the top and on the bottom, see figure. This choice allows also reducing and better controlling the displacements of the feeding pipe interfaces on the blanket backside due to VV and blanket thermal expansion. This concept however does not allow for free blanket thermal expansion and it is essential to verify that reaction forces on its vertical supports do not become excessive in any condition. The accidental loss of active blanket cooling is expected the worst scenario in this respect.

In addition to radial/vertical supports each blanket segment has toroidal shear keys that engage into corresponding slots in the VV. These shear keys react the large radial moments acting on the blanket during the fast plasma current quench that occurs during a disruption. The inboard segments have two shear keys, one at the bottom and one at the top, providing a statically determined support condition. The outboard segments were found too long and flexible for only two toroidal shear keys to suffice. Hence a third toroidal support has been implemented at the outboard side of the upper port (Fig. 1).

author's email: zsolt.vizvary@ukaea.uk

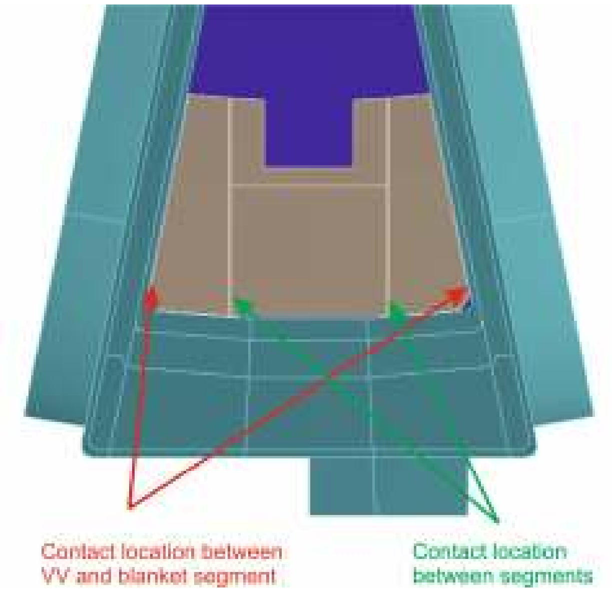


Figure.1. Toroidal support locations between the VV and lateral segments and the COB and lateral segments.

The blanket and its attachments have to be compatible with RM requirements. The first disengagement movement should e.g. progressively increase the gap between VV and blanket to avoid locking/jamming. Sliding movements should be avoided to prevent seizing and damage. The envisaged blanket removal kinematics is shown on Fig.2. In addition, to reduce the actions required by RH tools bolts, pins or other locking components requiring release prior to blanket removal were avoided. Instead we rely on the large and constant radial ferromagnetic force acting on the ferritic blanket steel to induce a preload pushing the blanket against its supports closing assembly gaps and providing electrical contact. Electrical straps to guarantee electrical contact between blankets and VV are not required. Temporary supports will likely be required during maintenance fixing in particular the inboard blankets to the upper port.

The simplicity of the individual blanket supports and the absences of bolts or other mechanisms do not allow individual position control as possible in the attachment concept of the ITER blanket [3]. To ensure co-centricity of the VV supports with the toroidal field these are designed to allow for on-site custom machining. Similarly, counter pads on the blanket backside will be custom machined to ensure the correct distance between VV and FW. Manufacturing imperfections of the inboard blanket causing radial deviations of the inboard blanket poloidal shape will be corrected to some degree by the ferromagnetic radial force “bending the blanket straight”. Manufacturing imperfections of the outboard blanket poloidal shape cannot be corrected. The presence of plasma limiters on the outboard is however expected to reduce the alignment requirements of the FW on the outboard. The assessment of the effective alignment tolerances of the BB FW to be expected in different locations is yet incomplete.

2.2 Blanket supports inside upper port

Inside the upper port the blankets cannot be supported on the VV inner shell, instead they need to be supported on the inside of the port wall and by the port plugs, which are inserted into the port after the installation of the blankets is complete. Three port plugs are envisaged in the upper port, see Fig. 6. In some of the upper ports the central port plug will include a plasma limiter replacing the upper part of the central outboard segment (COB). The COB in these sectors will therefore be shorter and will be supported vertically and radially by the central port plug [3].

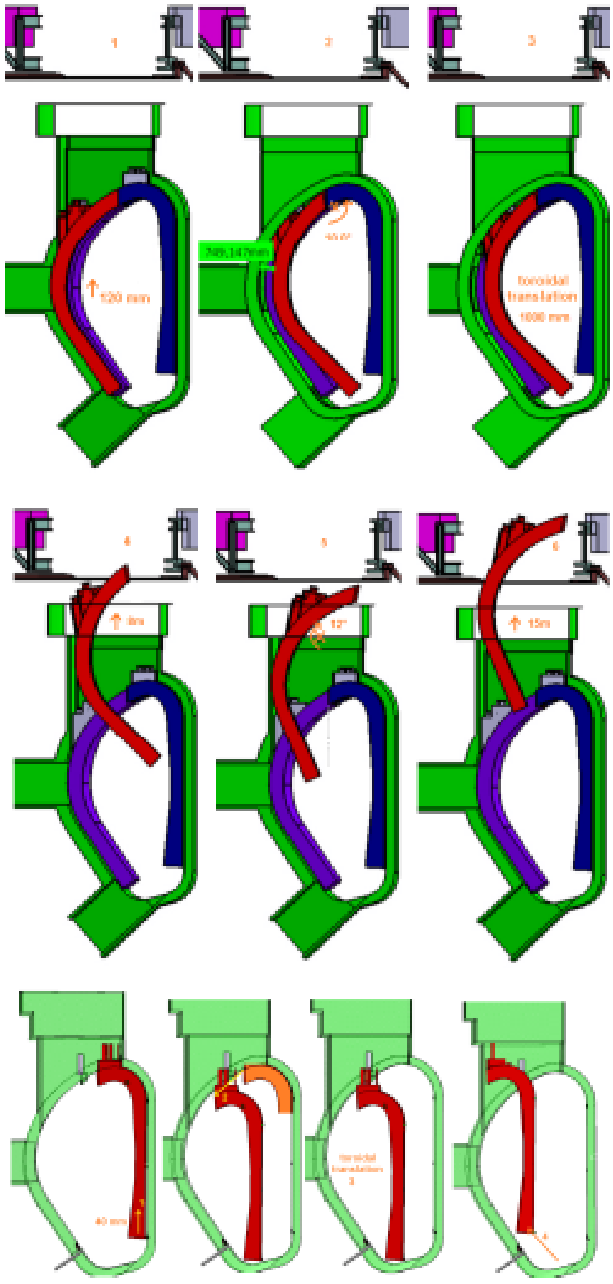


Figure.2. Blanket kinematics.

2.3 Inboard blanket supports

The inboard blanket is located on the high field side where the toroidal field is as high as ~7T causing very large EM forces due to induced currents. Furthermore, the toroidal circumference on the inboard the current density of poloidal currents is higher as compared to the outboard. This causes increased current densities in case of poloidal currents that occur in the blanket either due to a TFCFD of due to vertical displacement events [4]. Together with the ferromagnetic force these loads, which may occur simultaneously [refer to same paper on loads], cause a very large, vertically distributed radial force on the inboard blanket. Radial supports have been defined at four vertical levels and on both lateral side of the inboard blankets providing support also against vertical moments. The vertical levels were chosen carefully based on FE analyses in order to minimize bending stressed in the blanket and to avoid uneven load distribution overloading single supports, see results.

3. FE model

The model includes one sector of the VV and the corresponding five blanket segments. It uses shell elements to reduce the degrees of freedom; it therefore adequately simulated the stiffness and deformation of the components; local stress results are however unreliable.

The blanket segments have internal shells representing the back-supporting structure (BSS), the manifold and the modules/breeding zones. There is also an internal shell that can represent the stiffness of the internals (Fig. 3). Currently, all the blanket segments are assumed to be Eurofer 97, but the material properties and the shell thicknesses can be adjusted so that the model can be matched to the developments of the detailed BB design. This representation expected to be adequate to current Helium Cooled Pebble Bed (HCPB) and Water Cooled Lithium Lead (WCLL) designs [5-6]. The density of the material properties of the inboard (IB) and outboard (OB) segments have already been modified so that they mass of the segments is close to that of the estimated values. The model can be setup both as single-module segment (SMS) and multi-module segment (MMS), the latter by de-activating the elements linking the modules together.

Figure.3. Blanket segment internal structure in the FE model.

Nonlinear springs were implemented in the model at each blanket attachment to allow the study of the impact of assembly gaps. In particular, the vertical assembly gaps at the top supports need to be chosen carefully. During maintenance when the blanket is cold assembly gaps are required. In addition, some of the thermal expansion difference between the BB segment and the VV needs to be free to avoid excessive levels of thermal stresses. At the same time the blanket needs to be in contact with its VV supports on the top in order to control the location of the FW in the upper part of the blanket.

The latest upper port configuration [7] with the shield plug split into three separate components has also been implemented (Fig. 4).

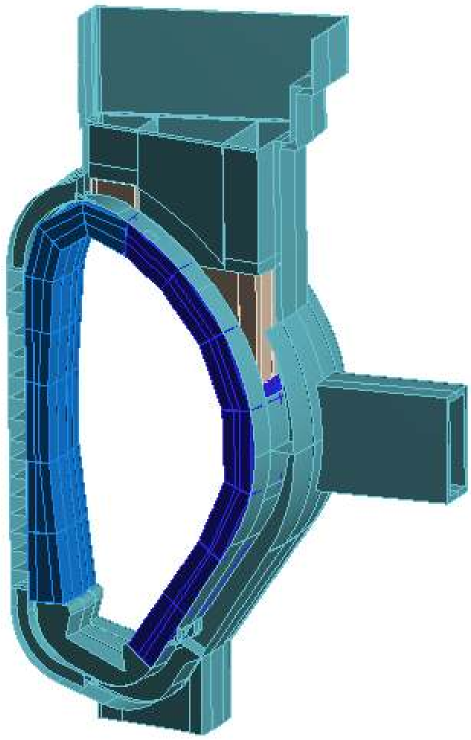


Figure.4. DEMO sector model with VV toroidal side removed to show internal ribs and upper port. Three upper port shield plugs (cyan) on top of five blanket segments (blue) with pipe connection locations “chimneys” (brown).

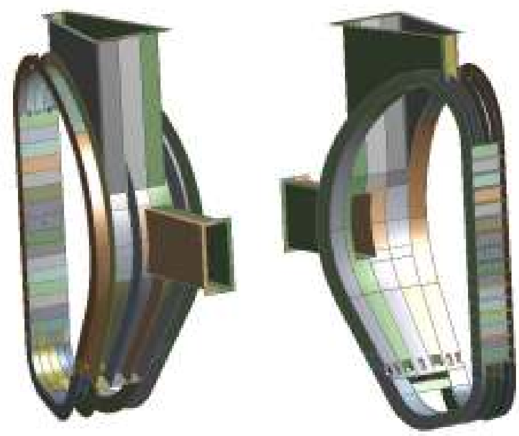


Figure.5. Vacuum vessel inner shell and stiffener ribs.

Table 1: Implemented gaps/stops.

Attachment point	Direction		
	X [mm]	Y [mm]	Z [mm]
IB bot	± 3	-	0/100
IB low	-	± 1	-
IB equa	5/50	-	-
IB high	5/50	± 1	-
IB top	20/100	-	66/100
OB bot	± 3	± 1	0/50
OB port	-	± 1	-
LOB/ROB top	0.1/10	4/100 (both sides)	131/300
COB top	0.1/10	-	101/300
OB port left/right	-	4/100	-

4. Load cases

Applying the gravity and thermal conditions are quite straightforward, although so far the operating temperature regime is only defined as a radial variation along the blanket thickness (Fig. 8). The VV temperature is set at 40 °C, the plasma facing side of the BB is 527 °C, the back is 300 °C (linear distribution applied). The divertor is set to uniform 40 °C in the model as well as the shield plug (same as VV). Although the divertor temperature will be much higher it is not considered to affect the principles of the attachment system concept.

The temperature distribution in the BB during LOCA is also only function of the distance from the plasma facing side currently, with the front face set to 700 °C.

Electromagnetic analysis results for the 2017 baseline model are not available yet. Results for the 2015 baseline have been used [8-9] for the static ferromagnetic forces during operation, although as the BB segments volumes are larger they are also expected to be higher. The calculations will be updated once the EM results are available, also the loads due to major disruptions will be considered only then.

The DEMO VV load specifications [10] include the estimated forces due to TF coil fast discharge, and 4 VDE scenarios. These loads are very high and considered to be critical for the system. The TFCFD loads and the worst VDE case have been implemented in the model. These have been uniformly distributed on the BB respective segments. The implemented EM loads are summarised in Table 2.

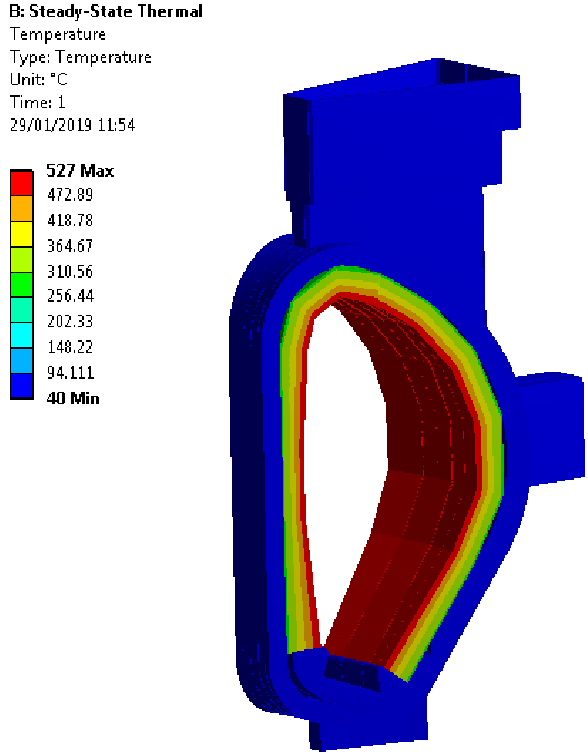


Figure.8.: Implemented temperature distribution for normal operation.

Table 2: Applied EM loads. Positive radial direction is pointing away from the machine centre, positive vertical direction is upwards.

Load case name	Inboard segments	Outboard segments
Radial direction (Fx)		
Static ferromagnetic forces	-7.7 MN	-7.05 MN
TFCFD	-8.5 MN	2.7 MN
VDE slow up	-4.05 MN	1.42 MN
Vertical direction (Fz)		
Static ferromagnetic forces	0	0
TFCFD (only on modules 6-8)	1.6 MN	0
VDE slow up	2.99 MN	0.8 MN

Due to the flexibility of the FE model, each load case can be considered on its own or in combination with others offering which can help understanding the dominating load in critical cases. The analysis is static, but it can be extended to transient later on, if required.

5. Reaction forces

Reaction forces in selected off normal events as well as the operational load case is presented in this section.

In this paper the focus will be on the following load combinations:

- Operational (operational temperature distribution + gravity + static ferromagnetic forces)
- IB LOCA (IB LOCA temperature distribution + gravity + static ferromagnetic forces)
- OB LOCA (OB LOCA temperature distribution + gravity + static ferromagnetic forces)
- TFCFD (operational temperature distribution + gravity + static ferromagnetic forces + TFCFD loads)
- VDE slow up (operational temperature distribution + gravity + static ferromagnetic forces + TFCFD loads + symmetric VDE slow up)
- TFCFD+VDE slow up (operational temperature distribution + gravity + static ferromagnetic forces + TFCFD loads + symmetric VDE slow up)

The dominant load on the blanket segment during normal operation (flat top) is the static ferromagnetic force on the segments. This is a radial force in the magnitude of ~7MN/segment. This force pushes the IB segments against the VV wall, it is distributed by radial pads sufficiently positioned so that the load is shared. The OB segments are also pushed towards the centre of the machine, in the case they are reacted at the bottom and the top of the segments in bridge-like manner [3].

The selected off-normal events in this paper are the TFCFD, VDE slow up and simultaneous TFCFD+VDE slow up will be discussed as they are the most sever load cases. Other load cases are also of interest (ie.: major plasma disruption) and it needs to be confirmed for each case that the attachment system can cope with each of them. However, they will not be discussed in this paper.

The most critical load case was found the TFCFD load case. Where the 8.5 MN radial force (Table 2) acts in addition to the ferromagnetic forces. Regarding the VDEs, the sector model only allows symmetric cases to be considered, and the largest force magnitudes are estimated during the VDE slow up event.

The behaviour of the blanket segments is as expected. The vertical and radial displacement plot (Fig. 9) during operation show how the OB segments are "straightened" by the radial ferromagnetic forces.

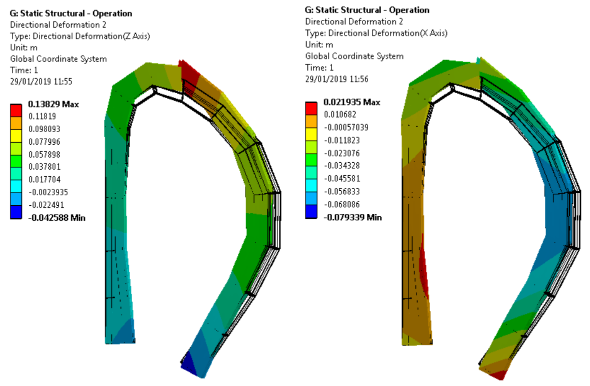


Figure.9.: Vertical and radial displacements during normal operation.

The radial displacement plots during normal operation (Fig. 10-11) show the difference between the central outboard segment and the lateral segments due to the attachment of the COB being further out. The radial displacement difference is ~12 mm in the middle, at the top however it is ~20 mm, although the whole reason of supporting the COB differently is the planned upper limiter, which will be a separate component. The radial displacement difference may be control with the initial gaps defined, if it becomes necessary from the FW alignment point of view.

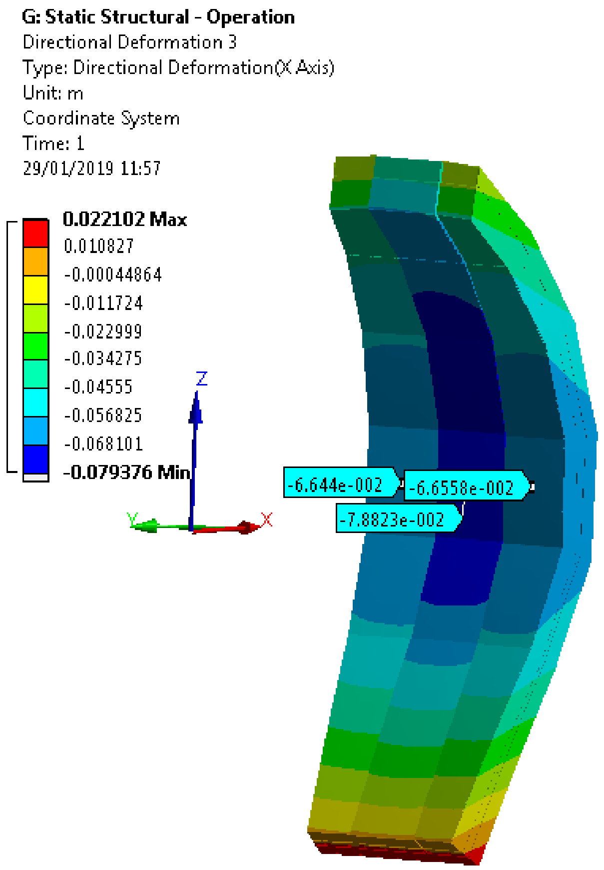


Figure.10.: Radial displacements during normal operation, with values at the centre [m].

It is also important to note, that despite the reaction forces being asymmetric (Table 3-8) the displacements look quite symmetric indicating that there may be displacement differences limited to the local connections between the segments and the VV.

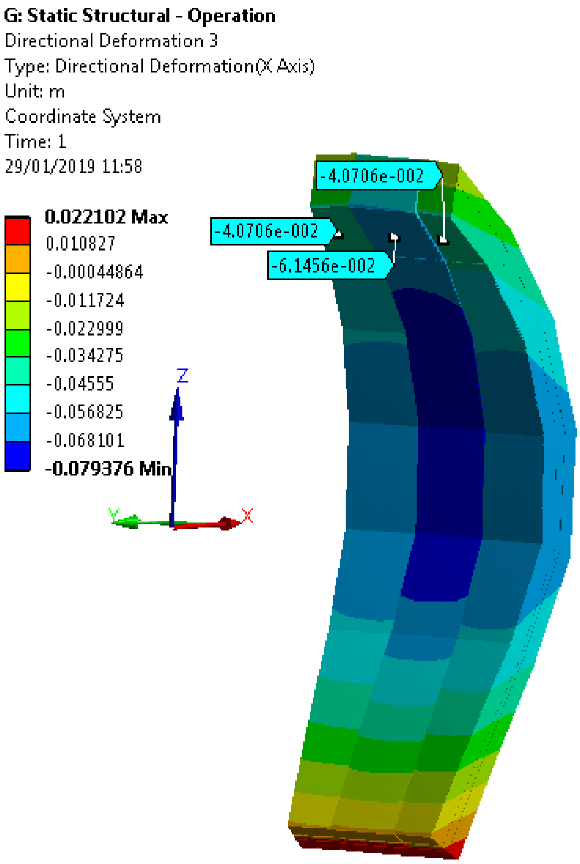
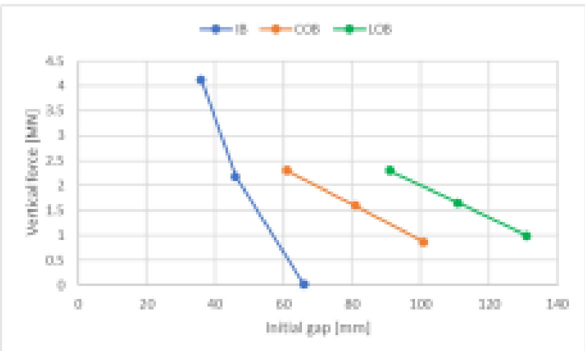


Figure.11.: Radial displacements during normal operation, with values at the top [m].

The average blanket displacements at the top and the average vertical upward force against the VV during flat top operation on the top are listed in figure 12 for different gap sizes at assembly.



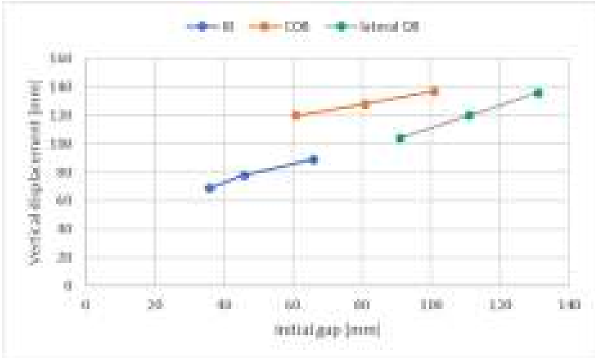


Figure.12.: Effect of initial gap sizes on the vertical reaction forces at the top and the vertical blanket displacements (including VV).

Table 3: Reaction forces due to load during normal operation [MN].

IBL				IBR			OBC				OBL				OBR		
Support name	Fx	Fy	Fz	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Fx	Fy	Fz
Inb. top left	1.92	0.00	-0.01	1.89	0.00	-0.01	Outb. top left	1.65	0.00	-0.82	Outb. top left	1.36	0.00	-0.21	2.18	0.01	-1.99
Inb. top right	1.89	0.00	-0.01	1.92	0.00	-0.01	Outb. top right	1.65	0.00	-0.90	Outb. top right	1.99	0.00	-1.79	1.17	-0.04	-0.01
Inb. high mid`	0.00	0.00	0.00	0.00	0.00	0.00											
Inb. high left	0.42	0.00	0.00	0.40	0.00	0.00											
Inb. high right	0.39	0.00	0.00	0.42	0.00	0.00											
							Outb. tor OBL	0.00	0.00	0.00	Outb. tor VV-BLK	0.00	0.00	0.00	0.00	0.00	0.00
Inb. mid left	0.00	0.00	0.00	0.00	0.00	0.00	Outb. tor OBR	0.00	-0.01	0.00	Outb. tor BLK-OBC	0.00	0.00	0.00	0.00	-0.01	0.00
Inb. mid right	0.00	0.00	0.00	0.00	0.00	0.00											
Inb. low mid	0.00	0.00	0.00	0.00	0.00	0.00	Outb. bot mid	0.00	0.00	0.00	Outb. bot mid	0.00	0.01	0.00	0.00	0.05	0.00
Inb. bot left	1.39	0.00	0.29	1.25	0.00	0.34	Outb. bot left	1.72	0.00	1.30	Outb. bot left	1.45	0.00	0.90	1.78	0.00	1.50
Inb. bot right	1.25	0.00	0.34	1.40	0.00	0.29	Outb. bot right	1.71	0.00	1.33	Outb. bot right	1.90	0.00	1.93	1.58	0.00	1.33
TOTAL	**7.27**	**0.00**	**0.61**	**7.27**	**0.00**	**0.61**	**TOTAL**	**6.74**	**-0.01**	**0.90**	**TOTAL**	**6.70**	**0.00**	**0.83**	**6.70**	**0.02**	**0.84**

Table 4: Reaction forces due to load during IB LOCA [MN].

IBL				IBR			OBC				OBL				OBR		
Support name	Fx	Fy	Fz	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Fx	Fy	Fz
Inb. top left	1.87	0.00	-3.17	1.87	0.00	-0.99	Outb. top left	1.66	0.00	-0.79	Outb. top left	1.39	0.00	-0.13	2.15	0.01	-1.87
Inb. top right	1.87	0.00	-0.99	1.86	0.00	-3.17	Outb. top right	1.66	0.00	-0.87	Outb. top right	1.95	0.00	-1.74	1.18	-0.04	-0.01
Inb. high mid`	0.00	0.10	0.00	0.00	0.10	0.00											
Inb. high left	0.00	0.00	0.00	0.00	0.00	0.00											
Inb. high right	0.00	0.00	0.00	0.00	0.00	0.00											
							Outb. tor OBL	0.00	0.00	0.00	Outb. tor VV-BLK	0.00	0.00	0.00	0.00	0.00	0.00
Inb. mid left	-0.01	0.00	0.00	-0.01	0.00	0.00	Outb. tor OBR	0.00	-0.01	0.00	Outb. tor BLK-OBC	0.00	0.00	0.00	0.00	-0.01	0.00
Inb. mid right	-0.01	0.00	0.00	-0.01	0.00	0.00											
Inb. low mid	0.00	0.10	0.00	0.00	0.10	0.00	Outb. bot mid	0.00	0.00	0.00	Outb. bot mid	0.00	0.01	0.00	0.00	0.05	0.00
Inb. bot left	1.82	0.00	2.30	1.72	0.00	2.46	Outb. bot left	1.71	0.00	1.27	Outb. bot left	1.44	0.00	0.82	1.80	0.00	1.40
Inb. bot right	1.72	0.00	2.46	1.82	0.00	2.31	Outb. bot right	1.71	0.00	1.29	Outb. bot right	1.93	0.00	1.88	1.57	0.00	1.32
TOTAL	**7.26**	**0.21**	**0.61**	**7.26**	**0.20**	**0.61**	**TOTAL**	**6.74**	**-0.01**	**0.90**	**TOTAL**	**6.70**	**0.01**	**0.83**	**6.70**	**0.02**	**0.84**

Table 5: Reaction forces due to load during OB LOCA [MN].

IBL				IBR			OBC				OBL				OBR		
Support name	Fx	Fy	Fz	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Fx	Fy	Fz
Inb. top left	1.61	0.00	-0.01	1.51	0.00	-0.01	Outb. top left	1.46	0.00	-2.39	Outb. top left	1.73	0.00	-2.30	2.62	0.04	-5.36
Inb. top right	1.50	0.00	-0.01	1.61	0.00	-0.01	Outb. top right	1.45	0.00	-2.52	Outb. top right	2.18	0.00	-4.67	1.27	-0.06	-1.61
Inb. high mid`	0.00	0.00	0.00	0.00	0.00	0.00											
Inb. high left	0.49	0.00	0.00	0.17	0.00	0.00											
Inb. high right	0.16	0.00	0.00	0.49	0.00	0.00											
							Outb. tor OBL	0.00	0.00	0.00	Outb. tor VV-BLK	0.00	0.00	0.00	0.00	0.00	0.00
Inb. mid left	0.00	0.00	0.00	0.00	0.00	0.00	Outb. tor OBR	0.00	-0.01	0.00	Outb. tor BLK-OBC	0.00	0.00	0.00	0.00	-0.01	0.00
Inb. mid right	0.00	0.00	0.00	0.00	0.00	0.00											
Inb. low mid	0.00	0.00	0.00	0.00	0.00	0.00	Outb. bot mid	0.00	0.00	0.00	Outb. bot mid	0.00	0.01	0.00	0.00	0.11	0.00
Inb. bot left	1.46	0.00	0.31	1.25	0.00	0.31	Outb. bot left	1.91	0.00	2.86	Outb. bot left	1.10	0.00	3.25	1.43	0.00	3.72
Inb. bot right	1.25	0.00	0.32	1.46	0.00	0.31	Outb. bot right	1.92	0.00	2.95	Outb. bot right	1.70	0.00	4.56	1.37	0.00	4.10
TOTAL	**6.47**	**-0.01**	**0.61**	**6.48**	**-0.01**	**0.61**	**TOTAL**	**6.74**	**-0.01**	**0.90**	**TOTAL**	**6.70**	**0.01**	**0.83**	**6.69**	**0.08**	**0.84**

Table 6: Reaction forces due to load during TF coil fast discharge [MN].

IBL				IBR			OBC				OBL				OBR		
Support name	Fx	Fy	Fz	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Support name	Fx	Fy	Fz	Fx	Fy	Fz
Inb. top left	2.18	0.00	-0.74	2.25	0.00	-0.01	Outb. top left	1.07	0.00	-0.45	Outb. top left	0.86	0.00	-0.01	1.36	0.01	-0.98
Inb. top right	2.25	0.00	-0.01	2.17	0.00	-0.74	Outb. top right	1.09	0.00	-0.48	Outb. top right	1.28	0.00	-0.97	0.79	-0.01	-0.01
Inb. high mid`	0.00	0.04	0.00	0.00	0.04	0.00											
Inb. high left	3.03	0.00	0.00	2.23	0.00	0.00											
Inb. high right	2.21	0.00	0.00	3.02	0.00	0.00											
							Outb. tor OBL	0.00	0.00	0.00	Outb. tor VV-BLK	0.00	0.00	0.00	0.00	0.00	0.00
Inb. mid left	0.01	0.00	0.00	0.05	0.00	0.00	Outb. tor OBR	0.00	-0.01	0.00	Outb. tor BLK-OBC	0.00	0.00	0.00	0.00	-0.01	0.00
Inb. mid right	0.05	0.00	0.00	0.01	0.00	0.00											
Inb. low mid	0.00	0.04	0.00	0.00	0.04	0.00	Outb. bot mid	0.00	0.00	0.00	Outb. bot mid	0.00	0.00	0.00	0.00	0.02	0.00
Inb. bot left	2.02	0.00	0.00	2.12	0.00	0.00	Outb. bot left	1.13	0.00	0.93	Outb. bot left	0.96	0.00	0.58	1.27	0.00	1.01
Inb. bot right	2.10	0.00	0.00	2.00	0.00	0.00	Outb. bot right	1.12	0.00	0.90	Outb. bot right	1.32	0.00	1.24	1.01	0.00	0.81
TOTAL	**13.84**	**0.08**	**-0.75**	**13.84**	**0.08**	**-0.75**	**TOTAL**	**4.42**	**-0.01**	**0.90**	**TOTAL**	**4.43**	**0.00**	**0.83**	**4.43**	**0.02**	**0.84**

Table 7: Reaction forces due to load during VDE slow up [MN].

	IBL			IBR				OBC				OBL			OBR		
Support name	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**	**Support name**	**Fx**	**Fy**	**Fz**	**Support name**	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**
Inb. top left	1.89	0.00	-1.64	1.98	0.00	-0.31	Outb. top left	1.37	0.00	-0.59	Outb. top left	1.13	0.00	-0.04	1.79	0.01	-1.59
Inb. top right	1.98	0.00	-0.30	1.89	0.00	-1.64	Outb. top right	1.38	0.00	-0.65	Outb. top right	1.64	0.00	-1.55	0.98	-0.02	-0.01
Inb. high mid`	0.00	0.07	0.00	0.00	0.07	0.00											
Inb. high left	1.92	0.00	0.00	1.52	0.00	0.00											
Inb. high right	1.51	0.00	0.00	1.91	0.00	0.00											
							Outb. tor OBL	0.00	0.00	0.00	Outb. tor VV-BLK	0.00	0.00	0.00	0.00	0.00	0.00
Inb. mid left	0.00	0.00	0.00	0.00	0.00	0.00	Outb. tor OBR	0.00	-0.01	0.00	Outb. tor BLK-OBC	0.00	0.00	0.00	0.00	-0.01	0.00
Inb. mid right	0.00	0.00	0.00	0.00	0.00	0.00											
Inb. low mid	0.00	0.07	0.00	0.00	0.07	0.00	Outb. bot mid	0.00	0.00	0.00	Outb. bot mid	0.00	0.01	0.00	0.00	0.04	0.00
Inb. bot left	1.60	0.00	0.00	1.70	0.00	0.00	Outb. bot left	1.39	0.00	0.73	Outb. bot left	1.17	0.00	0.39	1.48	0.00	0.98
Inb. bot right	1.69	0.00	0.00	1.59	0.00	0.00	Outb. bot right	1.38	0.00	0.73	Outb. bot right	1.57	0.00	1.35	1.26	0.00	0.79
TOTAL	**10.61**	**0.15**	**-1.94**	**10.61**	**0.15**	**-1.95**	**TOTAL**	**5.52**	**-0.01**	**0.21**	**TOTAL**	**5.51**	**0.00**	**0.16**	**5.50**	**0.02**	**0.16**

Table 8: Reaction forces due to load during simultaneous TF coil fast discharge VDE slow up [MN].

	IBL			IBR				OBC				OBL			OBR		
Support name	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**	**Support name**	**Fx**	**Fy**	**Fz**	**Support name**	**Fx**	**Fy**	**Fz**	**Fx**	**Fy**	**Fz**
Inb. top left	2.13	0.00	-2.26	2.19	0.00	-1.04	Outb. top left	0.79	0.00	-0.28	Outb. top left	0.62	0.00	-0.01	0.98	0.00	-0.56
Inb. top right	2.19	0.00	-1.04	2.12	0.00	-2.26	Outb. top right	0.81	0.00	-0.29	Outb. top right	0.94	0.00	-0.56	0.58	-0.01	-0.01
Inb. high mid`	0.00	0.06	0.00	0.00	0.06	0.00											
Inb. high left	4.38	0.00	0.00	2.70	0.00	0.00											
Inb. high right	2.66	0.00	0.00	4.36	0.00	0.00											
							Outb. tor OBL	0.00	0.00	0.00	Outb. tor VV-BLK	0.00	0.00	0.00	0.00	0.00	0.00
Inb. mid left	0.01	0.00	0.00	0.95	0.00	0.00	Outb. tor OBR	0.00	-0.01	0.00	Outb. tor BLK-OBC	0.00	0.00	0.00	0.00	-0.01	0.00
Inb. mid right	0.96	0.00	0.00	0.01	0.00	0.00											
Inb. low mid	0.00	0.06	0.00	0.00	0.06	0.00	Outb. bot mid	0.00	0.00	0.00	Outb. bot mid	0.00	0.00	0.00	0.00	0.01	0.00
Inb. bot left	2.41	0.00	0.00	2.32	0.00	0.00	Outb. bot left	0.81	0.00	0.41	Outb. bot left	0.68	0.00	0.18	0.96	0.00	0.42
Inb. bot right	2.29	0.00	0.00	2.38	0.00	0.00	Outb. bot right	0.80	0.00	0.37	Outb. bot right	0.98	0.00	0.55	0.71	0.00	0.32
TOTAL	**17.02**	**0.11**	**-3.31**	**17.02**	**0.12**	**-3.31**	**TOTAL**	**3.20**	**-0.01**	**0.21**	**TOTAL**	**3.23**	**0.00**	**0.16**	**3.23**	**0.01**	**0.16**

6. Summary

The reaction forces due to selected off normal events at the blanket attachment points and overall displacements of the blanket segments have been presented using a shell element-based model, which considers gaps and unidirectional constraints. Initial gaps at the top of the blanket segments have been chosen to minimise the thermal stresses in the blanket segments. These details need further refinement and optimisation to make sure that requirements regarding RM and FW alignment are also satisfied.

Initial studies indicate that up to 3-4 MN can be transferred at a single attachment location. However, this may be further limited by the VV or the blanket segment strength.

Based on this, the reaction forces seem to be high in two cases:

- In the TFCFD+VDE slow up case the reaction forces at the inboard at "high" location exceed 4MN on one side (average reaction force between left and right ~3.5 MN), however either further refinement in the high position, distributing the load between "mid" and "high" or splitting "high" into two locations or achieving symmetrical load distribution between the left and right pads of "high" would bring this force under 4 MN.
- In the case of OB LOCA there are reaction forces over 5MN, but this is a result of a very asymmetric load distribution (average reaction force between left and right ~3.5 MN). Either with changing the reaction position, or refining the initial gap sizes, this can be reduced to tolerable levels.

Further investigation may be necessary to identify the reason in the slight asymmetry observed in the reaction forces.

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