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Structural analysis of the back supporting structure of the DEMO WCLL outboard blanket

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Within the framework of EUROfusion R&D activities an intense research campaign has been carried out at the University of Palermo, in close cooperation with ENEA Brasimone, in order to investigate the thermo-mechanical performances of the outboard segment Back-Supporting Structure (BSS) of the DEMO Water-Cooled Lithium Lead breeding blanket (WCLL). In particular, the configuration of the outboard segment BSS, purposely set-up by the WCLL project team during 2015 according to the blanket "multi-module system" concept, has been taken into account in order to study its steady state thermo-mechanical behaviour, paying attention to the simulation of both modules-BSS and BSS-vacuum vessel attachment strategies and concepts.

The research campaign has been mainly intended to investigate the thermo-mechanical performances of the outboard segment BSS when subjected to both the thermo-mechanical and electro-magnetic loads it is foreseen to undergo under particularly critical steady state loading conditions.

A theoretical-numerical approach, based on the Finite Element Method (FEM), has been followed and the qualified ABAQUS v. 6.14 commercial FEM code has been adopted.

The thermo-mechanical behaviour of the BSS has been assessed in order to verify its compliance with the design criteria foreseen for the structural material. To this purpose, a stress linearization procedure has been performed along the most critical paths located within the highly stressed BSS regions, in order to check the fulfilment of the rules prescribed by the SDC-IC safety code.

Results obtained are herewith presented and critically discussed, highlighting the open issues and suggesting the pertinent modifications to the BSS geometric design aimed to obtain the complete fulfilment of the prescribed safety criteria.

Keywords: DEMO reactor; WCLL Blanket; BSS, thermo-mechanics.

1. Introduction

Within the framework of the DEMO R&D activities envisaged by the Breeding Blanket Working Package of the EUROfusion action [1], a research campaign has been carried out at the University of Palermo [2 - 7] to investigate the steady state thermo-mechanical performances of the Outboard Segment (OB) Back-Supporting Structure (BSS) of the DEMO Water-Cooled Lithium Lead breeding blanket (WCLL).

To this purpose, attention has been focused on the configuration of the OB BSS, purposely set-up by the WCLL project team during 2015 according to the blanket "multi-module system" concept [8], paying attention to the simulation of both modules-BSS and BSS-vacuum vessel attachment strategies and concepts (fig. 1).

The research campaign has been aimed to the investigation of the thermo-mechanical performances of the OB BSS when subjected to both the thermo-mechanical and electro-magnetic loads it is foreseen to undergo under particularly critical steady state loading conditions.

A numerical approach, based on the finite element method (FEM) has been followed and the qualified FEM code ABAQUS v. 6.14 has been adopted.

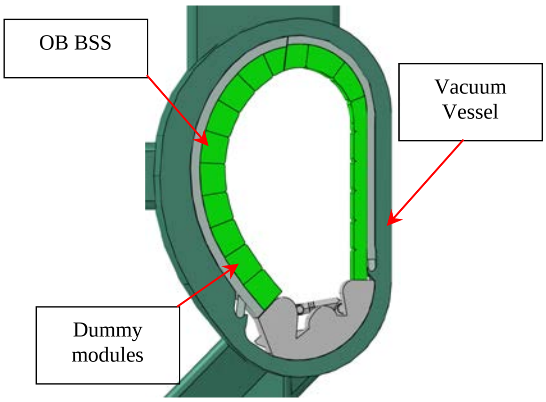

Fig. 1. Isometric view of a DEMO blanket sector.

The thermo-mechanical performances of the BSS have been assessed in order to verify their compliance with the design criteria foreseen for the structural material.

To this purpose, a stress linearization procedure has been performed along the most critical paths located within the highly stressed BSS regions, in order to check the fulfilment of the rules prescribed by the SDC-IC safety code [9].

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2. BSS FEM model

A reinforced version of the BSS of the OB, in which ribs have been lengthened up to the module Back-plates, has been taken into account. The OB modules, modelled by means of a dummy geometry, have been considered as welded to the central ribs of the BSS. A mesh composed of ~$4.4 \cdot 10^5$ nodes connected in ~$8.9 \cdot 10^5$ both tetrahedral and hexahedral elements has been set up (fig. 2).

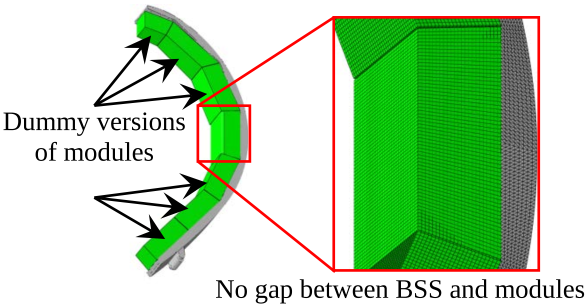

Fig. 2. 3D FEM model of the OB BSS with dummy modules.

2.1. Loads and boundary conditions

EUROFER steel has been considered as structural material for both the BSS and the OB modules. Since OB modules have been modelled by means of a "dummy" geometry, the Young's module of the material they are made of has been reduced to 10% of the EUROFER one in order to take into account their real stiffness.

Mechanical constraints considered are described in the following.

With reference to figure 3, as far as the top of the BSS is concerned, the radial displacements of the highlighted horizontal lines of nodes have been prevented and the toroidal displacements of the small vertical line of nodes have been prevented as well. As far as the bottom of the BSS is concerned, the radial and poloidal displacements of the highlighted horizontal lines of nodes have been prevented and the dotted line of nodes have been constrained in the toroidal direction.

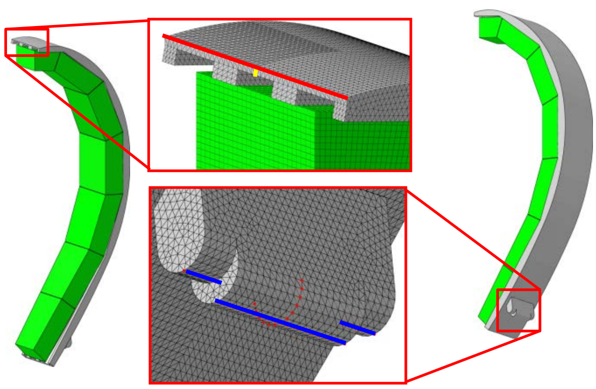

Fig. 3. Mechanical constraints applied to the BSS.

The presence of toroidal keys has been taken into account preventing the toroidal displacements to nodes highlighted in red in figure 4.

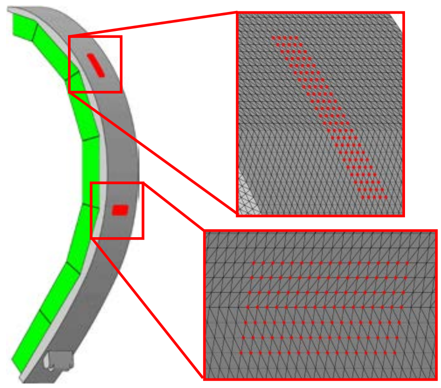

Fig. 4. Nodes reproducing toroidal keys.

As far as Electro-Magnetic (EM) loads acting on BSS and OB modules are concerned they have been calculated in the global coordinate system and applied to its origin [10]. In particular, 14 forces (7 acting on the BSS an 7 on the dummy modules) and 14 moments (7 acting on the BSS an 7 on the dummy modules) have been taken into account. Forces and moments are those calculated in case of a disruption, a severe plasma instability leading to a vertical displacement event, one of the most serious accidents that can occur in fusion power plant [10].

Gravity loads have been taken into account imposing to the dummy OB modules an "effective" density of 10393.6 kg/m^3 while, as to BSS, the EUROFER density has been considered.

As far as thermal loads are concerned, a radial temperature distribution, ranging between 500 °C (on the module First Walls) and 300 °C (on the module Back-Plates), has been imposed to the OB modules. The BSS structure has been considered to be at T= 350 °C (fig. 5) that is a value greater than the Back-Plate module one as it is not directly cooled and it is slightly heated by nuclear particles. The assumption on the thermal loads are deduced from the thermo-mechanical response of an equatorial outboard blanket module shown in [5].

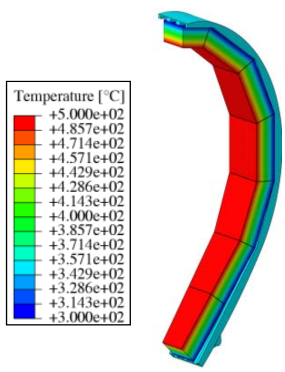

Fig. 5. Thermal field imposed to the system BSS-modules.

3. Results

Initially, the effects of gravity, EM and thermal loads have been investigated individually and finally, the combined effect of the three different loadings has been assessed as well. Figures 6, 7, 8 and 9 show the thermo-mechanical response of the BSS in terms of displacements and stress fields.

Regarding the stress field, the Von Mises equivalent stress is shown highlighting the most critical areas of the structural material where significant paths have been considered for stress linearization procedure.

Concerning the displacement field, it is interesting to note as the effects of the thermal loads limit those of both the EM and gravity loads along the poloidal direction. Moreover, EM loads make the BSS rotate clockwise in the poloidal-toroidal plane.

All these outcomes are highlighted in figure 10, where a view of the BSS configuration deformed with an isotropic amplification factor of 15 has been superimposed on the un-deformed one.

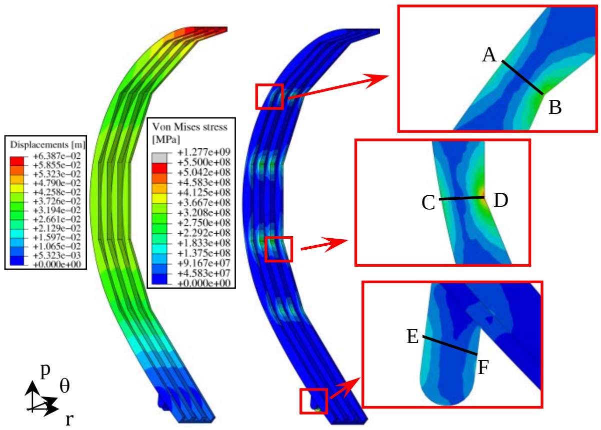

Fig. 6.Thermo-mechanical response to gravity loads.

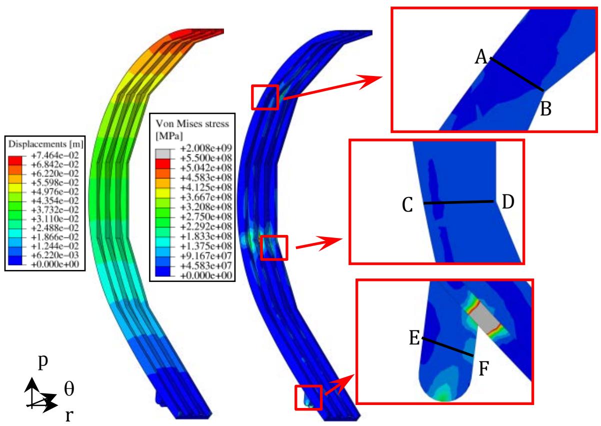

Fig. 7. Thermo-mechanical response to thermal loads.

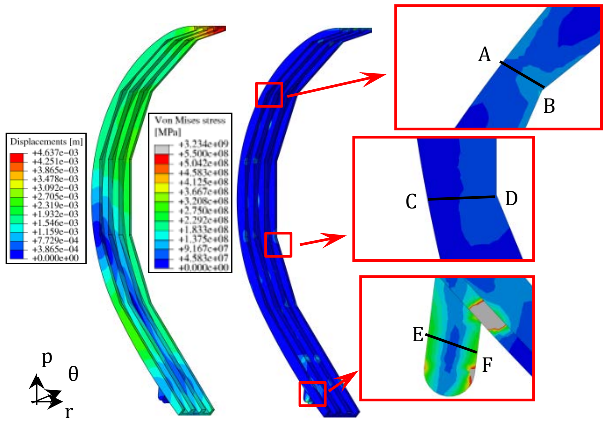

Fig. 8. Thermo-mechanical response to EM loads.

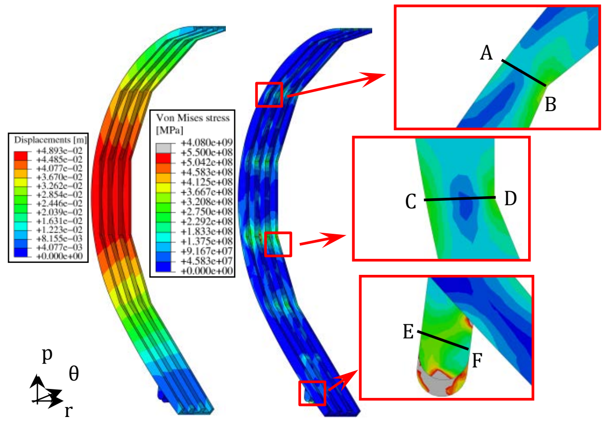

Fig. 9. Thermo-mechanical response to total loads.

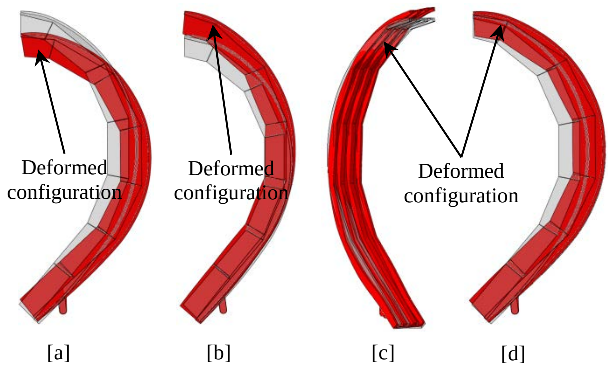

Fig. 10. BSS deformed vs. un-deformed configurations under [a] gravity, [b] thermal, [c] EM and [d] total loads.

As far as stress linearization analysis is concerned, results show that in the most critical paths taken into account, the SDC-IC rules are always verified for each of the three considered loads. When the total load is taken into account all the rules are fulfilled as well, even if with a lower margin above all in the path CD as it is shown in table 1, which gives a summary of the results obtained.

Table 1. Stress linearization.

Criterion	Path		
	AB	**CD**	**EF**
	Gravity loads		
P_m/S_m	0.15	0.14	0.13
$(P_m+P_b)/K_{eff}\ S_m$	0.60	0.69	0.44
	Thermal loads		
$(P+Q)_m/S_e$	0.11	0.28	0.18
	Electro-mechanical loads		
P_m/S_m	0.06	0.27	0.09
$(P_m+P_b)/K_{eff}\ S_m$	0.13	0.27	0.27
	Total loads		
P_m/S_m	0.10	0.41	0.16
$(P_m+P_b)/K_{eff}\ S_m$	0.47	0.96	0.48

4. Conclusions

Within the framework of the DEMO R&D activities a research campaign has been carried out at the University of Palermo to investigate the steady state thermo-mechanical performances of the BSS of the DEMO WCLL outboard breeding blanket with the specific aim to assess its thermal-mechanical behaviour under the envisaged loads and to verify the fulfilment of the prescribed SDC-IC safety rules code.

Results have shown that EM loads make the BSS rotate clockwise in the poloidal-toroidal plane. This occurrence could introduce some problems in the overall configuration of the blanket and should be taken into account in its development.

Safety verifications, according to SDC-IC codes, are totally satisfied as far as each single load is concerned and also when the total load is taken into account, even if with a lower margin.

Acknowledgments

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References

[1] Final Report on Deliverable WCLL DESIGN REPORT 2015, Report IDM reference No EFDA_D_2N6WLQ, WPBB-DEL- BB-3.2.1-T002-D001.

[2] Chiovaro, P., Di Maio, P.A., Giammusso, R., Lupo, Q., et al., Thermal-mechanical and thermal-hydraulic integrated study of the Helium-Cooled Lithium Lead Test Blanket Module, Fusion Engineering and Design, 85, pp. 1147-1153, 2010.

[3] Di Maio, P.A., Arena, P., Boccaccini, L.V., Bongiovì, G., Carloni, D., Chiovaro, P., Giammusso, R., Kecskes, S., Vella, G., On the numerical assessment of the thermo-mechanical performances of the DEMO Helium-Cooled Pebble Bed breeding blanket module. Fusion Engineering and Design, 89, pp. 1411-1416, 2014.

[4] P. Chiovaro, P. Arena, J. Aubert, G. Bongiovì, P.A. Di Maio, R. Giammusso, A. Li Puma, Assessment of the Thermo-mechanical Performances of a DEMO Water-Cooled Liquid Metal Blanket Module. Journal of Fusion Energy, Volume 34, pp 277-292, 2015.

[5] P. Chiovaro, P. Arena, J. Aubert, G. Bongiovì, P.A. Di Maio, R. Giammusso, A. Li Puma, Analysis of the thermo-mechanical behaviour of the DEMO Water-Cooled Lithium Lead breeding blanket module under normal operation steady state conditions, Fusion Engineering and Design, Volume 98-99, pp 1737-1740, 2015.

[6] P. Chiovaro, P.A. Di Maio, P. Arena, G. Bongiovì, R. Forte, S. Garitta, On the optimization of the first wall of the DEMO water-cooled lithium lead outboard breeding blanket equatorial module, Fusion Engineering and Design, in press.

[7] P. Chiovaro, P.A. Di Maio, P. Arena, G. Bongiovì, A. Del Nevo, R. Forte, Optimization of the breeder zone cooling tubes of the DEMO Water-Cooled Lithium Lead breeding blanket, Fusion Engineering and Design, in press.

[8] L.V. Boccaccini, G. Aiello, J. Aubert, C. Bachmann, et al., Objectives and status of EUROfusion DEMO blanket studies, Fusion Engineering and Design (2016), http://dx.doi.org/10.1016/j.fusengdes.2015.12.054P

[9] ITER structural design criteria for in-vessel components (SDCIC) code, G 74 MA 8 01-05-28 W 0.2, September 2012.

[10] Final Report on Deliverable EM Analyses in 2015, Report IDM reference No. EFDA_D_2MXFJL, WPBB-DEL-BB-9.3.1-T002-D001.