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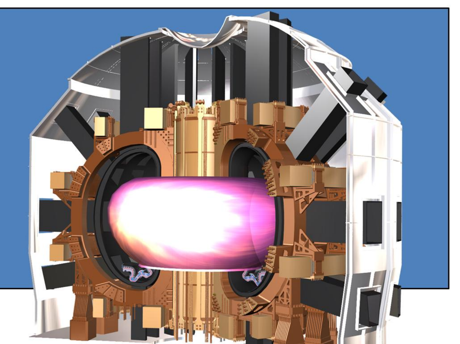
DTT Divertor Tokamak Test facility



Magneto-structural calculations and design study of the DTT central solenoid

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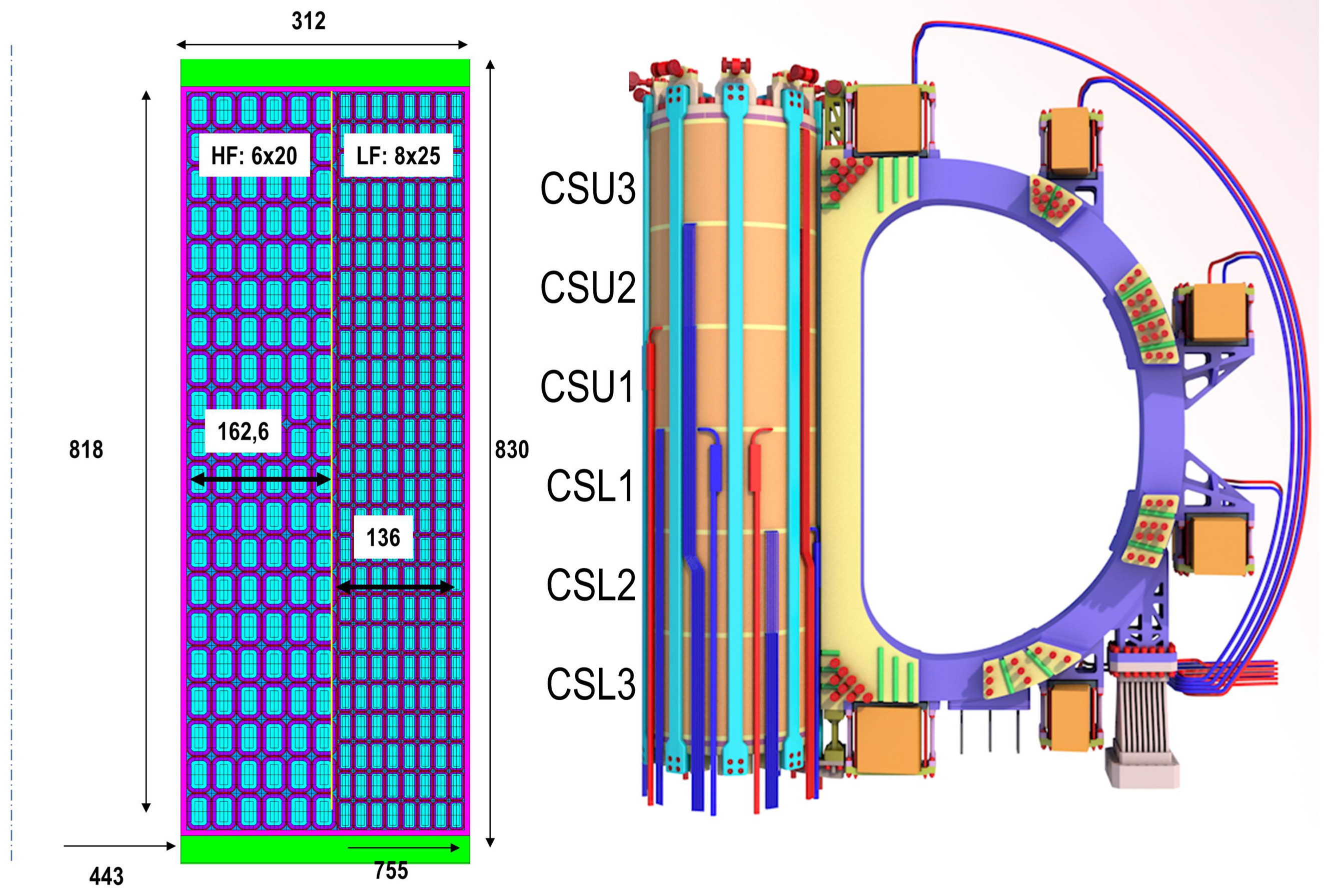
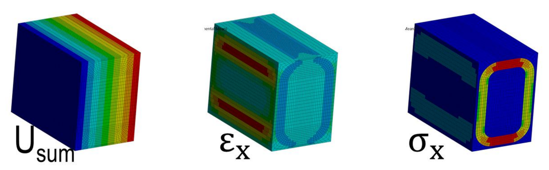
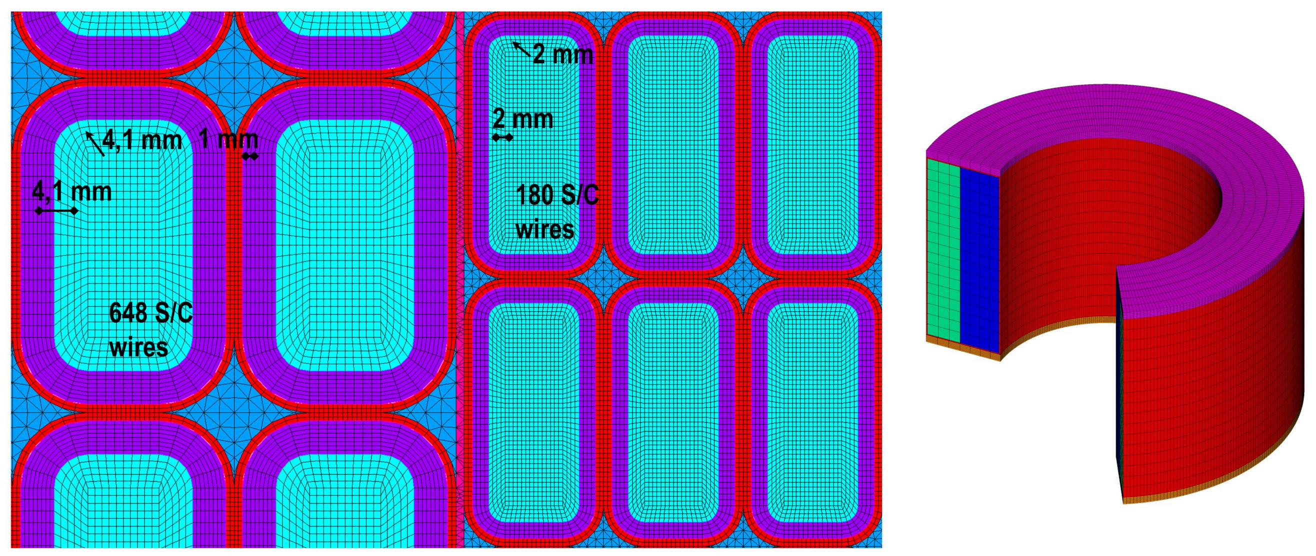
INTRODUCTION : The "Divertor Tokamak Test" is a project of an experimental reactor to be built in Italy. This work presents the magnetic and structural assessment of the central solenoid. This magnet is composed of a stack of six layer-wound independently energized modules, comprised of Nb3Sn CICCs, and generates the needed flux density of 16.4 Wb with an operative current of 29.04 kA/cable. To optimise the amount of superconducting material, each module is divided into two submodules: the innermost (HF) operates in a range of 10/14 T, while the outer one (LF) at 6/10 T. To asses this structure, 2D and 3D FEM models have been implemented and analysed.



Full detail and Homogenised model:

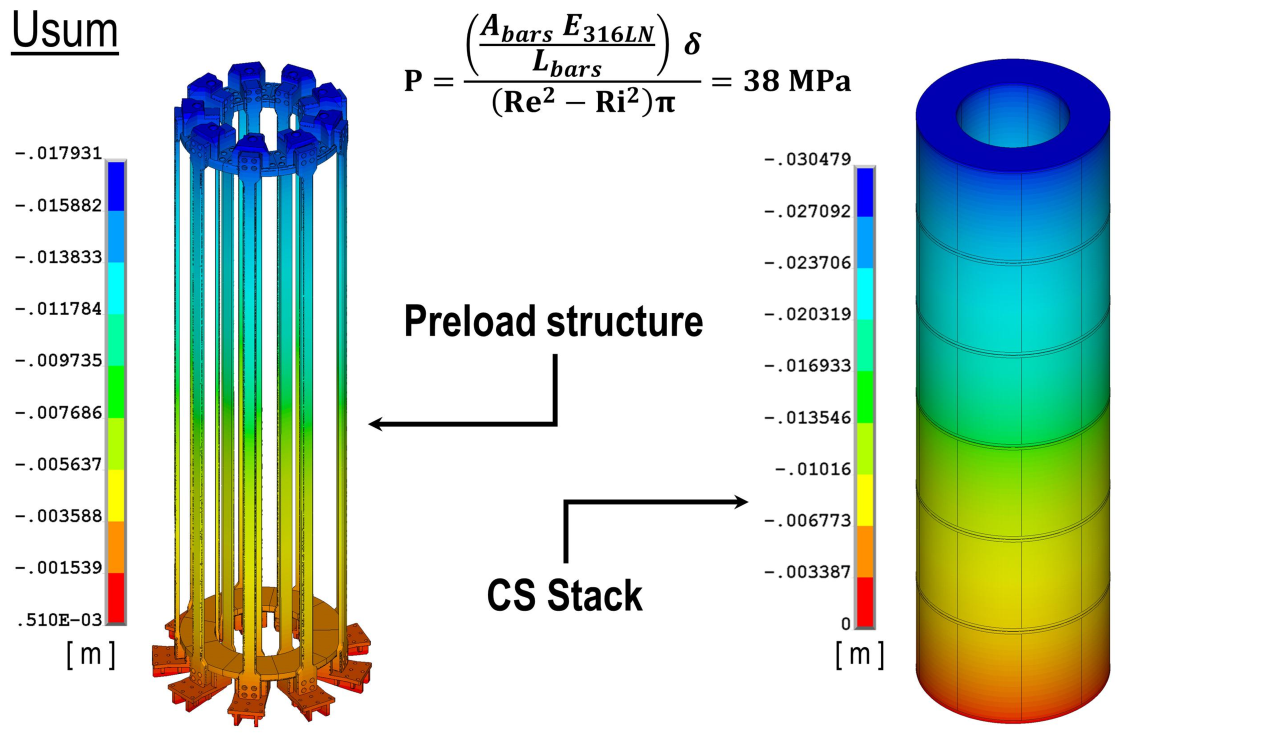
$$C_{11}=\frac{\langle\sigma_x\rangle}{\langle\varepsilon_x\rangle}\quad \langle\varepsilon_x\rangle=\frac{1}{V}\sum_{i=1}^{N}\varepsilon_{x,i}V_i\quad \langle\sigma_x\rangle=\frac{1}{V}\sum_{i=1}^{N}\sigma_{x,i}V_i$$

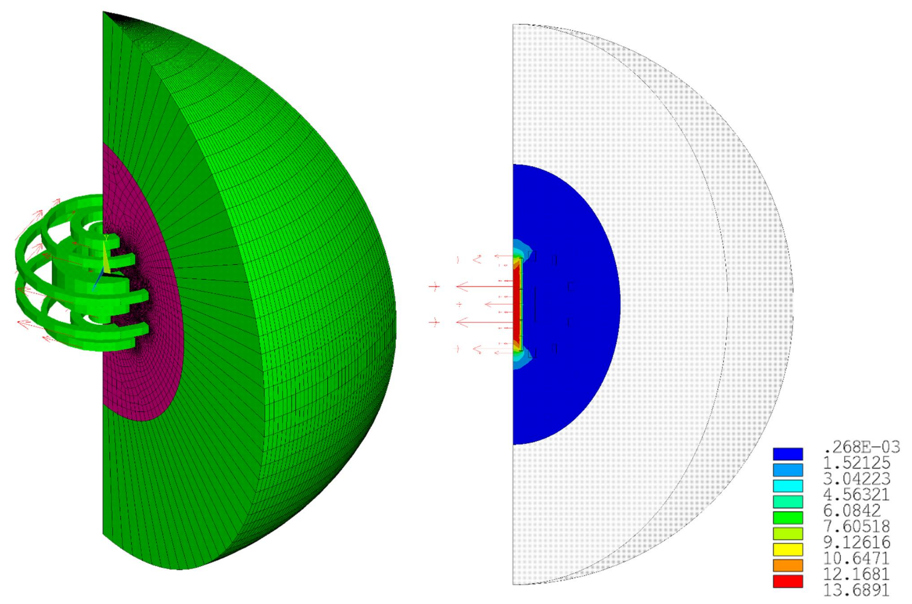




Preload study: the force necessary to withstand the axial repulsion of the modules has been calculated considering the contraction of the preload structure (**-16,8 mm**) and the CS stack (**-30,4 mm**) during the cooldown and the energisation phases. The gap (**δ**) generated between the two structures has been translated into a force through the axial stiffness of the preload bars.

$$P=\frac{\left(\frac{A_{bars}E_{316LN}}{L_{bars}}\right)\delta}{(Re^2-Ri^2)\pi}=38\ \text{MPa}$$



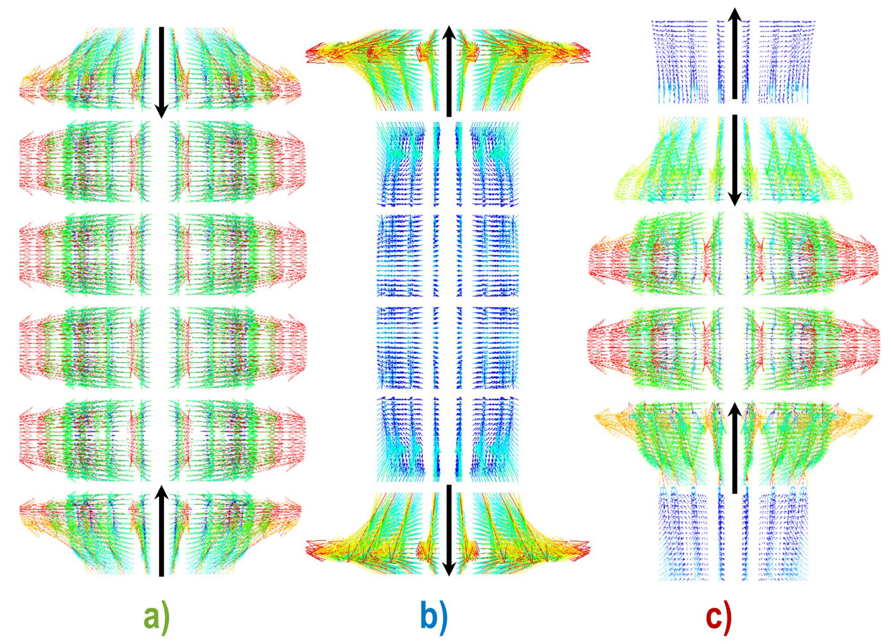


3D homogenised electromagnetic model:

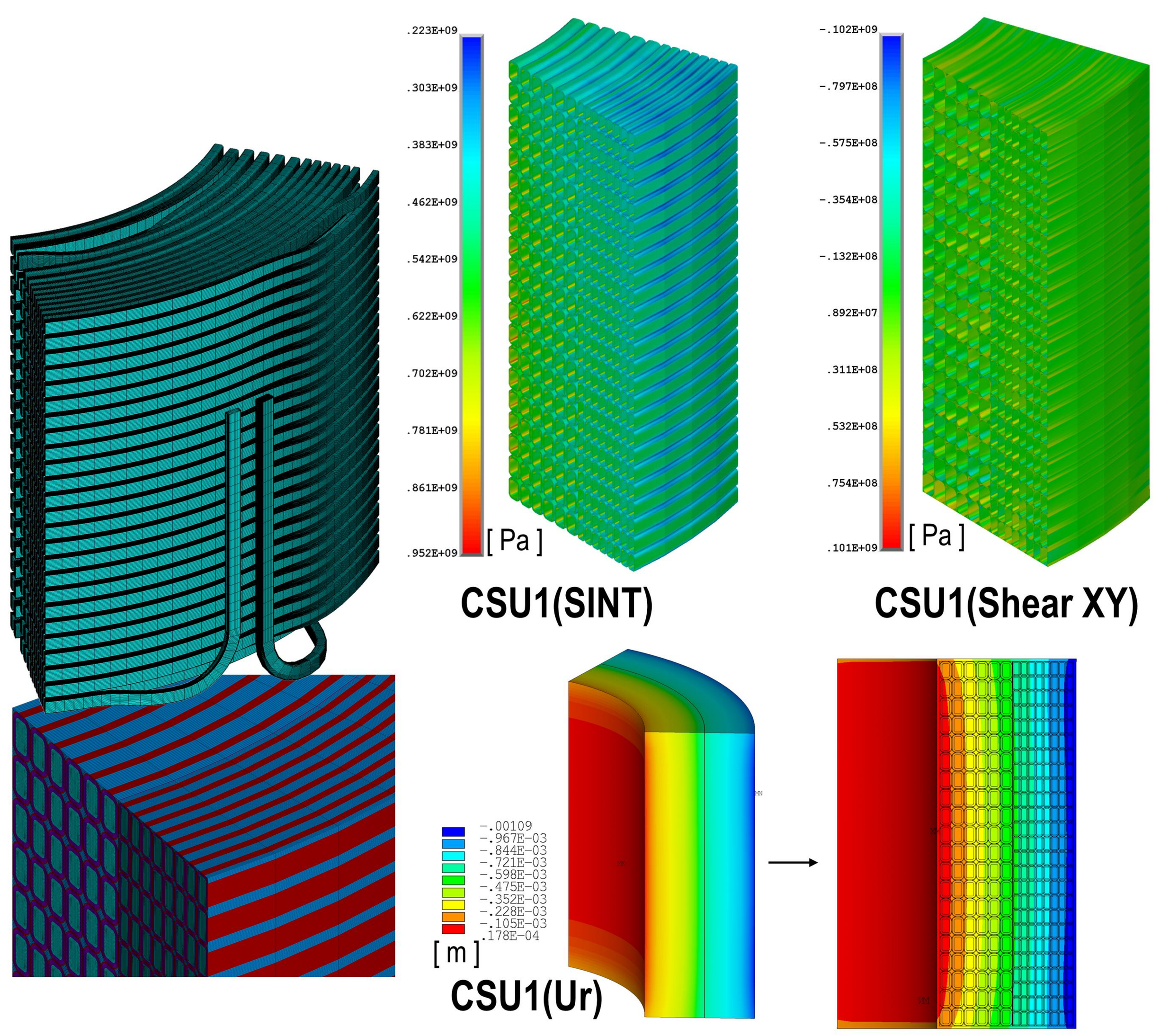
a) SN t = 0 s: Maximum hoop action (**250 MN**) and compression between modules CSU3(**-50 MN**) and CSL3 (**50 MN**);

b) DN t = 93,7 s: Maximum repulsion between extremal modules CSU3 (**30 MN**) and CSL3 (**30 MN**);

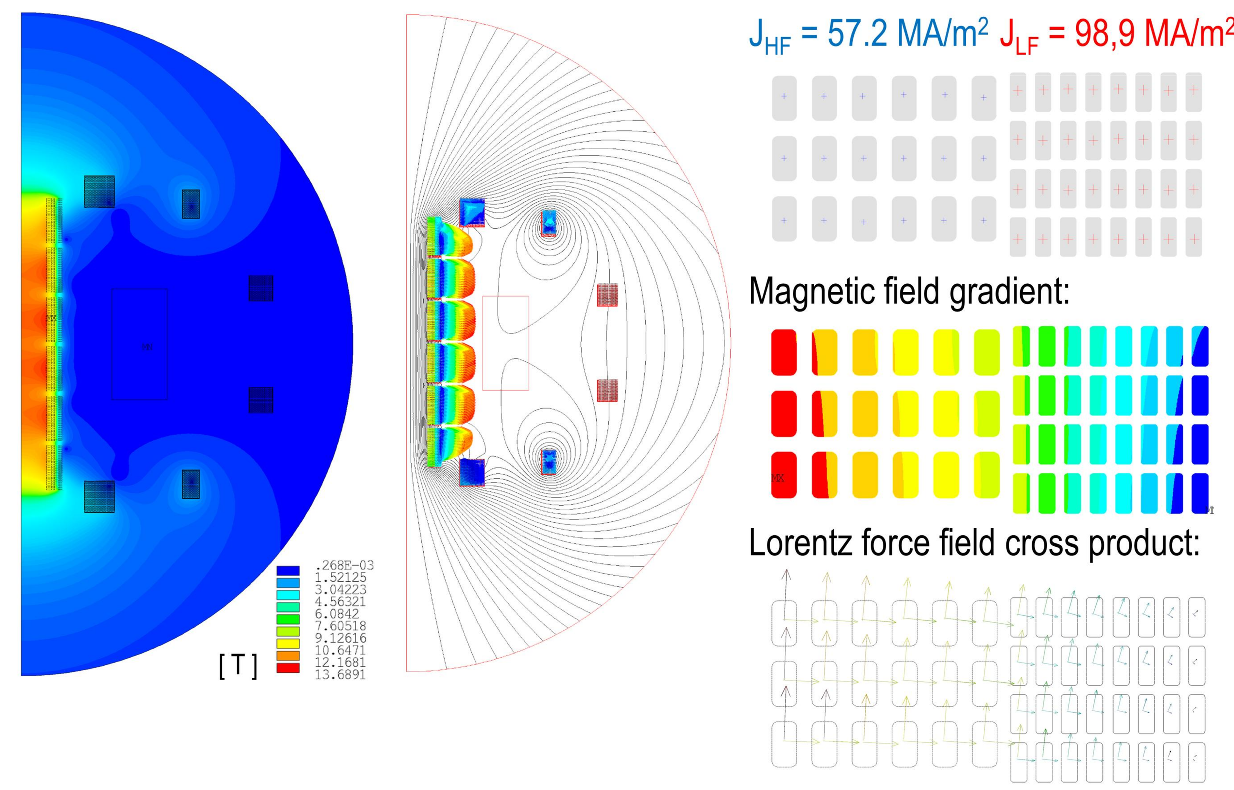
c) SN t = 78,5 s: Net vertical and positive action on CSU3 (**20 MN**) and compression between CSU2 (**-60 MN**) and CSL2 (**60 MN**).



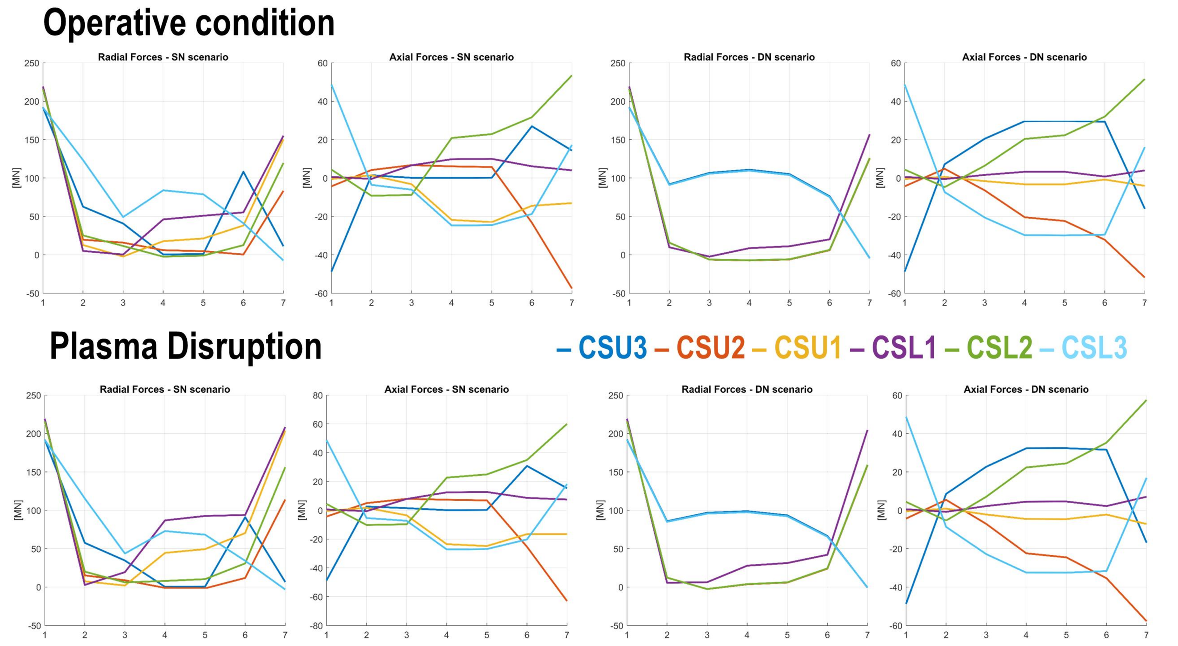
Submodeling procedure: displacements and loads have been transferred respectively from the 3D homogenised model and from the 3D full detail magnetic model to a 3D full detail structural model as boundary condition.



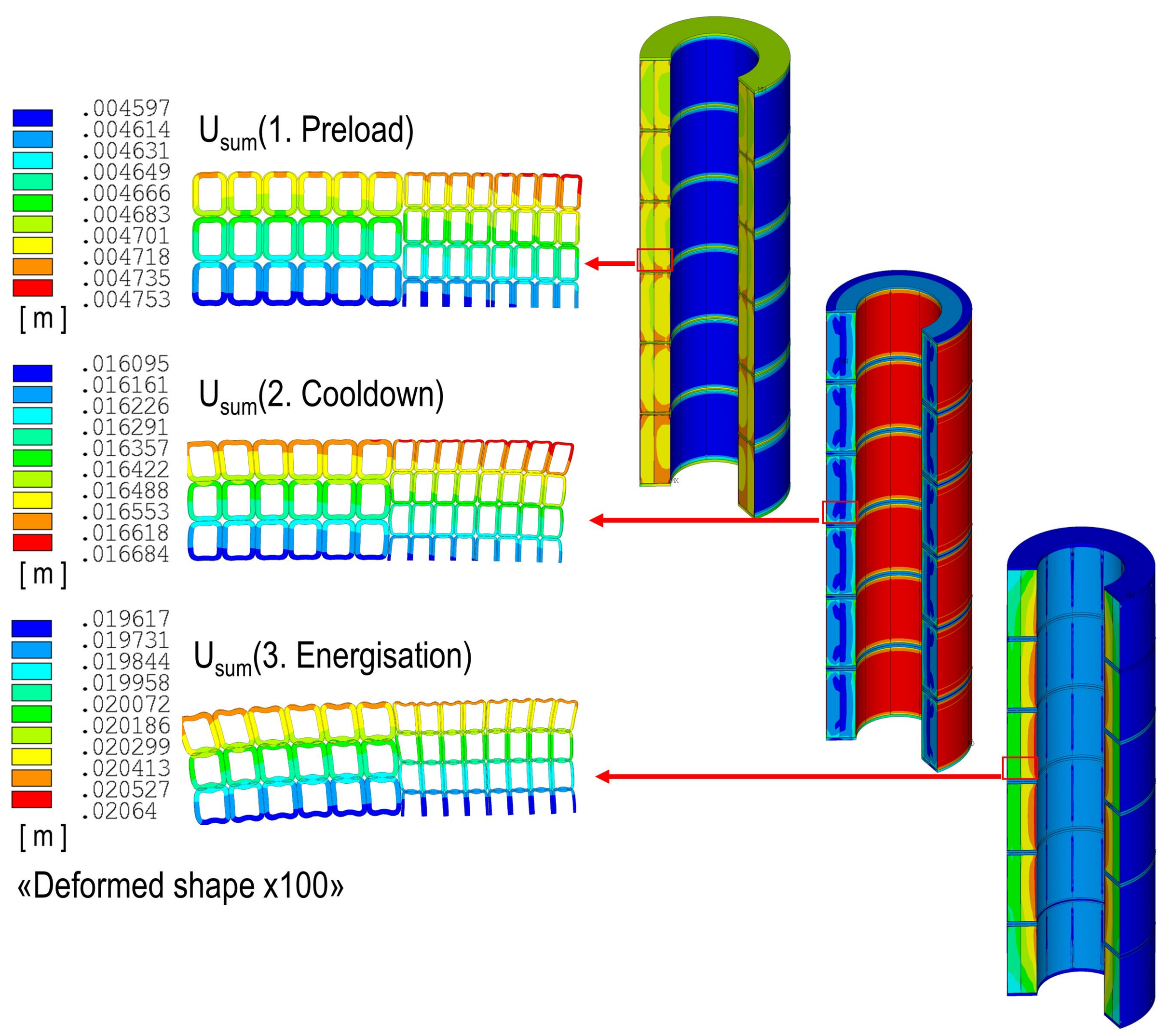
J_{HF} = 57.2 MA/m² J_{LF} = 98,9 MA/m²



2D fully detailed electromagnetic model: from the analyses of the Single Null (**SN**), Double Null (**DN**), Snow Flake (**SF**), Inverse Triangularity (**IT**) and X Divertor (**XD**) scenarios the Lorentz force field has been derived at each instant. The graphs show the behaviour of the radial and the axial components of the force in all normal and off-normal conditions.

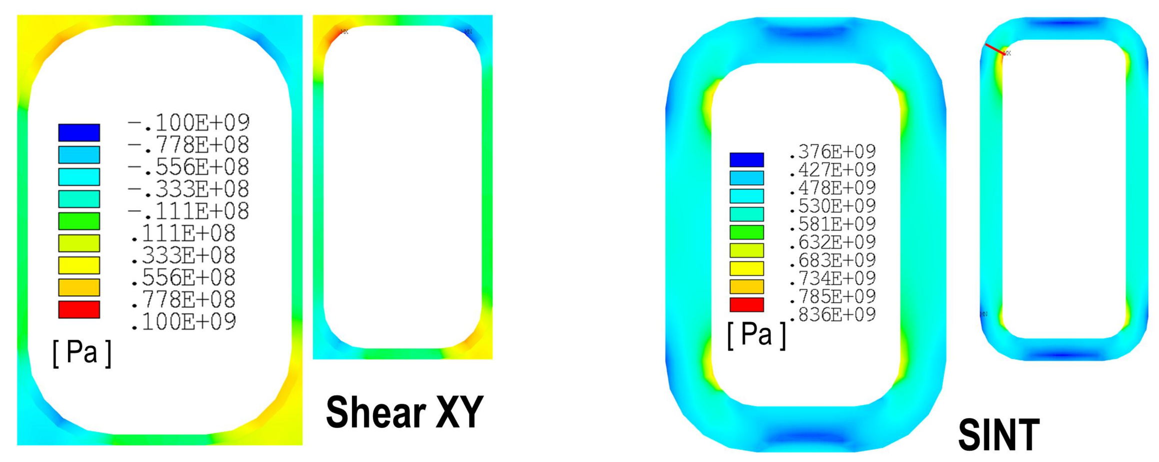


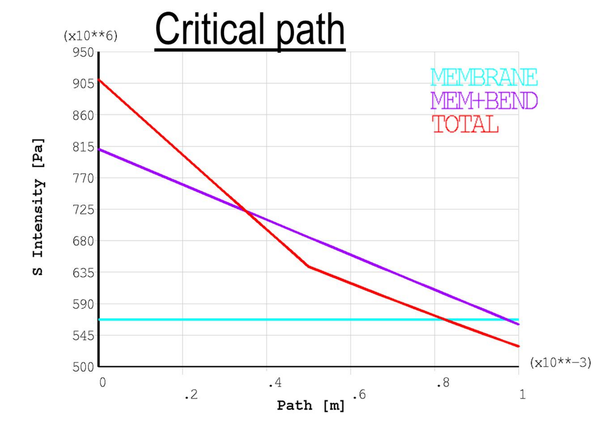
The structural assessment considers the three main load cases:



2D fully detailed structural model: The critical instant for the CS corresponds to the EOF of the SN scenario. The jacket reaches a peak, in terms of eqv. stress intensity, of **836 MPa**. The linearization procedure has been performed filtering the secondary stress out (e.g. thermal load).

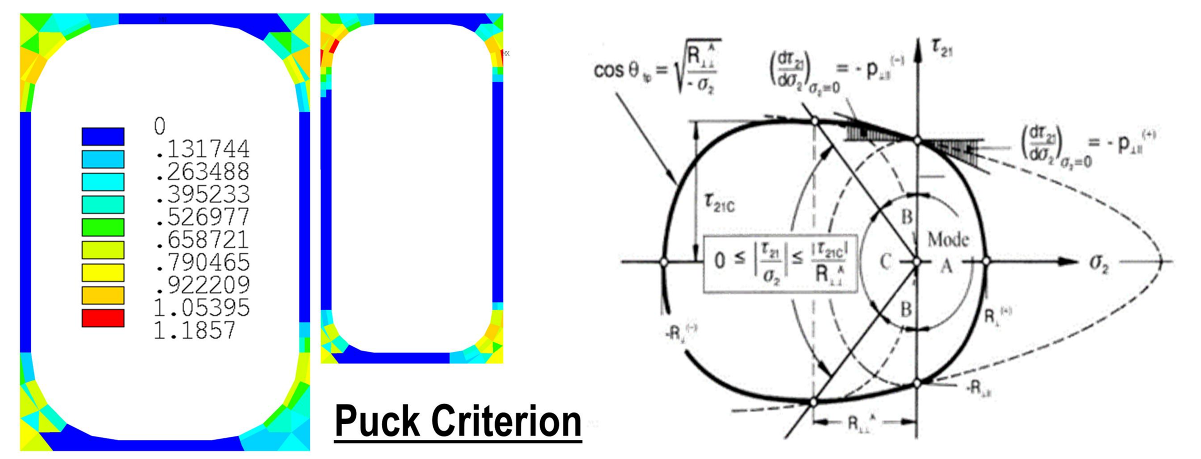
The results show that the stress level is below the allowable limits for both components: **membrane (667 MPa)** and **membrane + bending (867 MPa)**



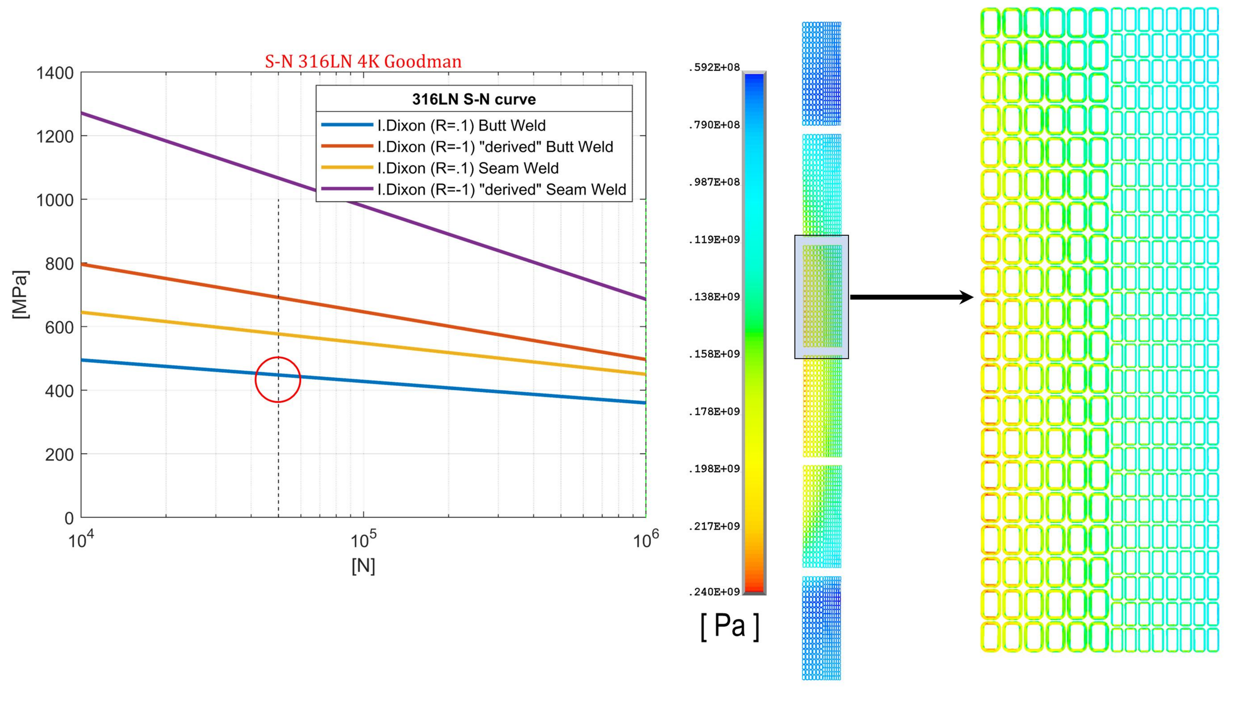


- P_m = 560 MPa < 667 MPa
- P_m+P_b = 815 MPa > 867 MPa

Shear stress on turn insulation: the obtained values are critical. Further studies have been done in order to verify the integrity of the structure and ensure electrical insulation between the cables. In depth analyses have been computed drawing on Puck's criterion. The critical zone remains in the A-zone of the Puck curve, in which the crack is expected to remain interlaminar.



The fatigue assessment: has been done via S-N approach, considering a scheduled operation life of 25k cycles. The critical stress cycle is defined by the instants t=-40s (cooldown phase) and t=78,5 s (EOF) of the SN scenario.



Acknowledgement

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