3-D stress analysis of 'Il Mantello', a solid breeder gas-cooled blanket for NET

L.Anzidei
Associazione EURATOM-ENEA sulla Fusione, C.R.E. Frascati, Rome, Italy
A.Amici
ENEA Guest

1 THE CANISTER STRUCTURE

The finite element codes of the CASTEM system have been used for the 3-D analysis of stresses in the blanket module (the "Canister") of IL MANTELLO, a solid breeder gas-cooled blanket for NET.

The results presented here concern the reference design of IL MANTELLO (see Figure 1). In this design the breeder is contained in tubes which are purged by helium (1st circuit) and assembled to form a bundle in crossflow. On the side facing the plasma and contiguous to the tube bundle, there is an assembly of nested half-cylinders made of multiplier material and separated by proper, coolant flow passages. The helium which, in crossflow, removes the thermal power constitutes the 2nd circuit. All the above components make up the breeding blanket and are installed within a structural container which is a double-walled envelope, independently cooled by a helium flow running between the first and the second wall (3rd circuit) which are joined together by flow channel spaces. With this last helium circuit it is possible to maintain relatively low temperatures in the first wall; whereas in the blanket interior the temperatures should be as high as possible for good efficiency and good tritium recovery. For the helium coolant the pressure is 50 atmospheres, the inlet temperature is 525 °k and the exit temperature is 625 °k.

Stationary analyses have been carried out in elastic field; the loads examined are due to pressure and temperature distribution on the surfaces of the walls and have been considered both separately and together. We have also considered a constant temperature gradient across the thickness of the flow separator and thermal gradients across the walls.

The stress analysis has been made on the canister envelope and on the canister regions which perform structural functions. From the structural point of view, the canisters are essentially pressure vessels with a thin wall which are self-supported in the plasma radial direction by using curved surfaces that act as membranes (while in the toroidal direction and in the inner radial direction, the walls are aided in their structural function by a toroidal stiffener that performs a flow separator function also). In the poloidal direction, however, the canisters have planar surfaces that cannot be used to resist the internal pressure and, therefore, the canisters must be mutually supporting. To provide this mutual support, in the reference design, a number of canisters are assembled in a fixture called an "omega

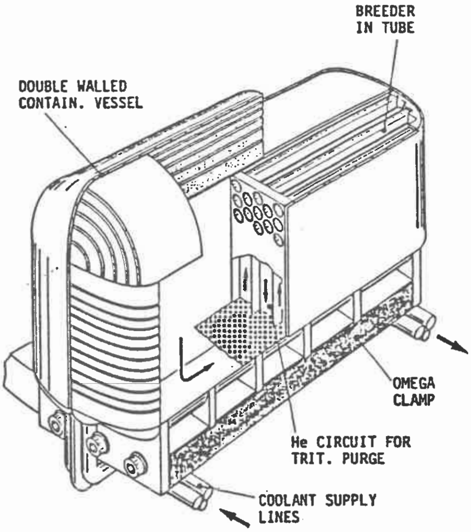


Figure 1. Cutaway view of the complete module.

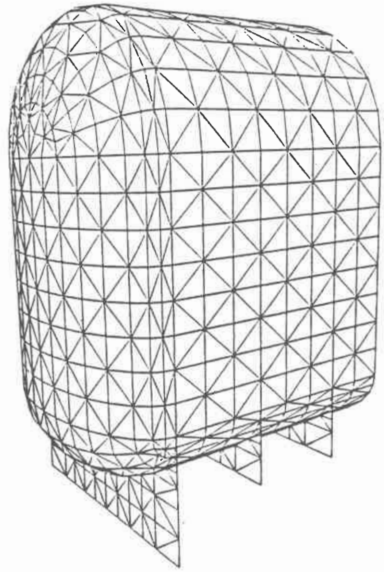


Figure 2. Standard canister mesh.

clamp", and each canister is connected to the clamp by bolts placed on the toroidal end regions.

A standard canister has the following dimensions: 0.65 m height, 1 m toroidal length, 0.2 m radius of the "nose", 0.1 m minor axis of the elliptic back plate (with an elongation of 2), 0.015 m total thickness of the walls. Since the poloidal midplane is a symmetry plane for both the geometry and the loads, the analysis has been made only on half a canister. The structure mesh has been made up using shell elements with three modes. The 3-D mesh of the half-canister analyzed consists of 1580 elements and 821 nodes. The structural material is HT9 at an average temperature of 575 °k and hence with an allowable stress of 200 MPa, to be decreased to 160 MPa because of irradiation.

2 CONSTRAINTS

The poloidal midplane of the canister (see Figure 2) is a symmetry plane for both the canister geometry and the loads; therefore, the analysis may be limited to one half of the canister subjected to the following constraints:

1. The poloidal midplane section is free to move only on its plane.
2. The bolted junction between the omega clamp and the canister is a fixed point.
3. The poloidal walls rest on the planes that divide two adjacent canisters.

As regards the canister fins, two cases have been considered:

1. The fins rest on the omega clamp.
2. The fins are free.

3 LOADS

As far as the pressure load is concerned, it has been uniformly distributed on the shell elements. The thermal loads are due both to the average temperature distribution and to the thermal gradients through the wall thickness. In order to define the design values for the walls thickness of the double-walled envelope and the distance between the walls 1-D thermal-hydraulics and stress analyses of the canister nose have been performed. The resulting average temperatures and thermal gradients have been used as input data for the present 3-D stress analysis. In our case in particular, thermal gradients across the walls are well described by a linear approximation. However, only constant values of the gradients can be considered for the BILBO code of the CASTEM system we have used. To solve this problem, we have approximated the parabolic temperature distribution according to the ASME code criterion (Sect. III - Div. 1 - NB3653) but have used an overestimated value of the average temperature, i.e., $(T_{max.}+T_{min})/2$. Under such an assumption, the ASME code nonlinear contribution to the temperature profile produces only local stresses which can be taken into account at the end of the analysis and the BILBO code can therefore be used. We believe that reasonable values of the stresses are obtained by this procedure. Starting from the nose, linear distributions of the average temperatures and of the thermal gradients have been used along the poloidal toroidal and radial directions.

Figure 3 shows the input data. As far as the flow separator is concerned, it works at a higher temperature as it is cooled by the breeder coolant helium which is 100 °C hotter than the double-walled envelope coolant. A linear average temperature distribution between the hotter centralzone and the cooler boundaries has been chosen. The linear temperature drop through its thickness has been evaluated as 30% of the local main coolant temperature drop, as the remaining 70% is due to the boundary layers.

Figure 4 shows the scheme of the input data for the flow separator.

4 RESULTS

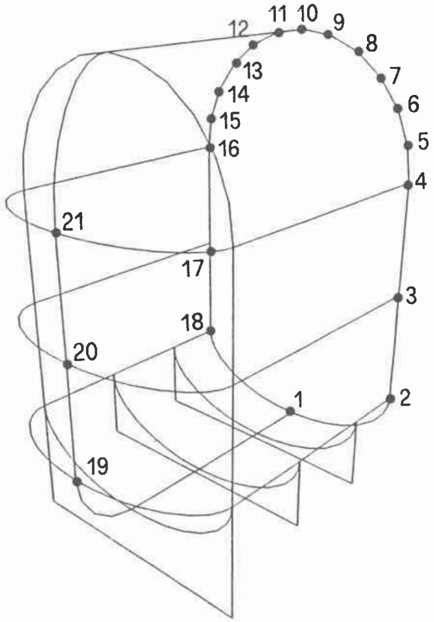
The stress analysis has been carried out separately both for each load and for the combined loads. The influence of the different constraints (fins resting on the Omega clamp or free) has been studied in each case.

4.1 Pressure loads

A maximum displacement of 0.3 mm and a maximum V.M. stress of 120 MPa have been found. As they occur on the toroidal ends, no appreciable variation is found by changing the above constraints.

4.2 Average temperature distribution loads

The prominent role is played by the flow separator which works at a higher temperature than that of the envelope. It acts as a structural stiffener and its own temperature distribution determines a maximum displacement of 0.8 mm in the canister along the radial direction. Its free expansion is partially prevented by the fixed points so that a



1) T=575, ΔT= 0.0	12) T=664, ΔT=33.0
2) T=525, ΔT= 0.0	13) T=657, ΔT=27.0
3) T=543, ΔT=-4.5	14) T=647, ΔT=17.5
4) T=560, ΔT=-8.5	15) T=635, ΔT= 5.5
5) T=577, ΔT= 5.5	16) T=623, ΔT=-8.5
6) T=595, ΔT= 7.5	17) T=624, ΔT=-4.5
7) T=615, ΔT=26.5	18) T=625, ΔT= 0.0
8) T=634, ΔT=33.0	19) T=575, ΔT= 0.0
9) T=650, ΔT=37.0	20) T=583, ΔT=-4.5
10) T=661, ΔT=38.0	21) T=592, ΔT=-8.5
11) T=666, ΔT=37.0	

Figure 3. Temperature map.

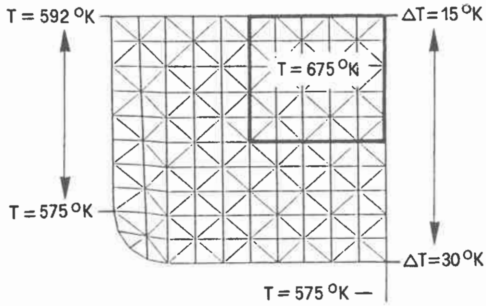
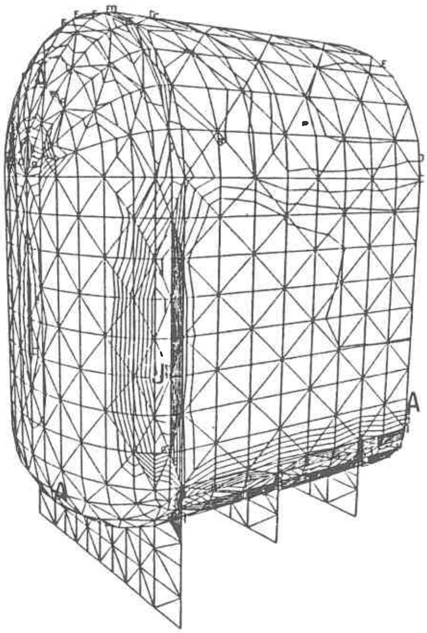


Figure 4. Temperature distribution in the flow separator.

maximum V.M. stress of 70 MPa occurs in the connection between the canister and the omega clamp. The envelope behaves as a flexible and compliant structure so that no effect is produced by changing the constraints.

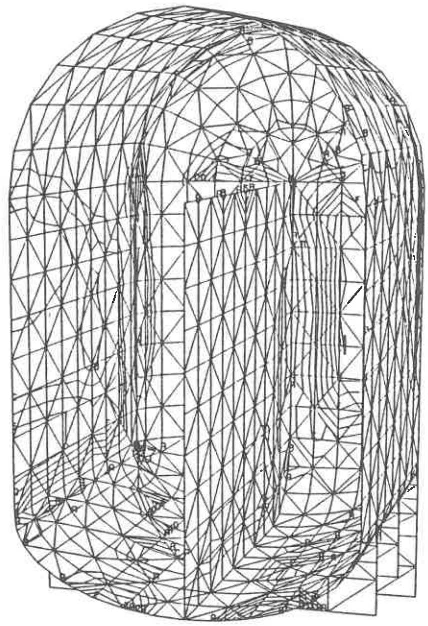
4.3 Thermal gradient loads

As the envelope has a symmetric distribution of thermal gradients with respect to the radial midplane, the canister sections produced by such a plane do not rotate. Furthermore, along the radial direction the thermal gradients reverse; thus, large displacements are prevented (the maximum value being 0.2 mm) and so the induced stresses are due to the local thermal gradient. A maximum V.M. stress of 50 MPa is obtained in the nose where the largest thermal gradients occur. As far as the flow separator is concerned, it is like a plate with three fixed sides. It can move along the fourth side leading to lower stresses but higher displacements (up to 0.8 mm). There is not influence due to the variation of the constraint as the thermal gradient in that zone is almost zero.



A = 50 MPa J = 140 MPa

Figure 5. Distribution of V.M. stresses (membrane - flex).



A = 50 MPa I = 130 MPa

Figure 6. Distribution of V.M. stresses (membrane + flex).

4.4 Combined loads

The main effect is due to the pressure load, which acts as a stiffener for the whole structure. The thermal displacements of the poloidal walls are prevented and the V.M. stress values increases up to 140 MPa in the coldest zone. The same value is reached in the toroidal ends.

As far as the local stresses due to the nonlinear components of the temperature distribution are concerned, a conservative calculation has given a maximum value of 50 MPa. This value occurs in the nose topper region, far away from the maximum stress which is due to the combined loads (see Figures 5 and 6).

The maximum canister displacement is below 0.8 mm and the same value is found for the flow separator in the poloidal direction (Figure 7).

The above stress-strain values are not appreciably affected by constraint variation. Table 1 shows a stress comparison among the load configurations.

5 CONCLUSION

The design solutions appear to be correct. The canister structure is compliant and flexible under thermal loads. A maximum V.M. stress of 140 MPa is compatible with the HT9 maximum allowable stress under irradiation. A maximum displacement value of 0.8 mm occurs in the radial direction where it is acceptable. The stiffeners provided (the flow

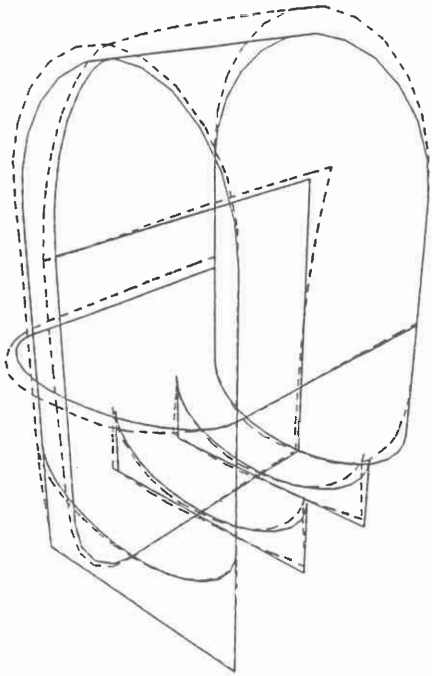


Figure 7. Canister profile (elastic deformation amplified by a factor 50).

Table 1. Stresses comparison

Values (MPa)		Toroidal ends	Poloidal walls	Flow separator	Toroidal constraints
Pressure	Mb+Fl	120	80	<50	<50
	Mb-Fl	110	110	<50	<50
Average temperature distribution	Mb+Fl	60	70	<50	50
	Mb-Fl	70	60	50	<50
Thermal gradients	Mb+Fl	50	50	<50	
	Mb-Fl	50	50	<50	
Combined loads	Mb+Fl	130	90	70	50
	Mb-Fl	140	130	70	60

separator and the fins) act correctly, in spite of the rather high flow separator displacement. The latter problem, however, is well beyond the purpose of the present analysis. The above stress-strain values are rather insensitive to the canister constraints. This means that considering a canister free to expand radially, a remarkable design simplification could be gained.