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Thermo-mechanical Design Methodology for ITER Cryo-distribution cold boxes

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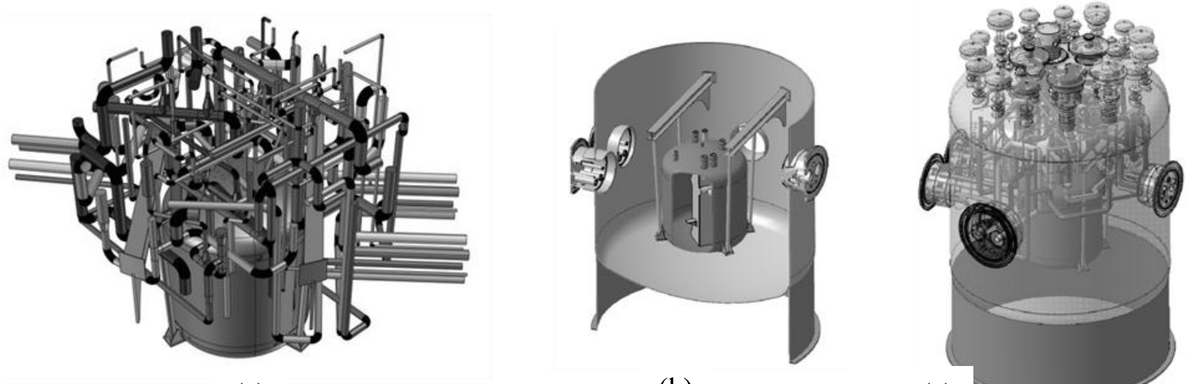
Abstract. The ITER cryo-distribution (CD) system is in charge of proper distribution of the cryogen at required mass flow rate, pressure and temperature level to the users; namely the superconducting (SC) magnets and cryopumps (CPs). The CD system is also capable to use the magnet structures as a thermal buffer in order to operate the cryo-plant as much as possible at a steady state condition. A typical CD cold box is equipped with mainly liquid helium (LHe) bath, heat exchangers (HX's), cryogenic valves, filter, heaters, cold circulator, cold compressor and process piping. The various load combinations which are likely to occur during the life cycle of the CD cold boxes are imposed on the representative model and impacts on the system are analyzed. This study shows that break of insulation vacuum during nominal operation (NO) along with seismic event (Seismic Level-2) is the most stringent load combination having maximum stress of 224 MPa. However, NO+SMHV (Séismes Maximaux Historiquement Vraisemblables = Maximum Historically Probable Earthquakes) load combination is having the least safety margin and will lead the basis of the design of the CD system and its sub components. This paper presents and compares the results of different load combinations which are likely to occur on a typical CD cold box.

1. Introduction

During the intended life time of ITER , several loads are envisaged on the CD system [1], which are, gravity/assembly loads, interface loads, nominal pressure/temperature, test pressure/temperature, purge pressure, thermo-mechanical loads due to break of insulation vacuum (BIV), transport acceleration and seismic loads (SL). Single loads or combinations of them can act on the CD system and on its sub systems; therefore, it is very important to analyze the integrity of the system and components under their influence. A typical CD cold box, i.e. Auxiliary Cold Box (ACB) for the CPs which includes most of the components and largest in size is chosen for the study, and load combinations have been applied on it in order to understand their impacts. A complete 3-D model of ACB-CP [2] is developed in CATIA along with its internal piping, cryogenic control valves and internal components as shown in figure 1. This paper focuses on the understanding of the nature of the loads or their combinations for the ITER CD system as well as their impacts on the design.



(a) (b) (c)

Figure 1. (a) 3D model of ACB-CP with internal piping routing, (b) liquid helium bath arrangement and outer vacuum jacket (OVJ) of ACB-CP.

2. Configuration of a typical CD cold box

ACB-CP is equipped with LHe bath with two submerged HX's, cryogenic control valves, cold circulator and process piping in order to supply the supercritical helium (SHe) at the required mass flow rate, pressure and temperature level. The cold circulator generates the required pressure head for the supply of the SHe to application. The thermal shield, surrounding the 4 K components in order to reduce the radiation heat load, is provided with 80 K gaseous helium (GHe).

3. Inputs and assumptions

3-D model of ACB-CP is developed in CATIA® [3] and taken as input for study of the load combinations. Thermal shields, internal components inside LHe bath i.e. heat exchangers, heaters have not been analysed individually but their gravity loads have been considered during the analysis. Forces and moments coming from the piping over the nozzles of LHe bath and on vacuum barriers are calculated from pipe stress software CAESAR® and are given as boundary condition to finite element software ANSYS® [4]. Process pipes at the interface position with the cryolines are anchored at vacuum barrier location which has to sustain the generated forces and moments. Detailed analysis of the vacuum barrier is not performed in the present study. Heat flux of 0.5 W/m^2 is given to 4.5 K components as a radiation heat load. Titanium alloy material, having high strength and low thermal conductivity, is taken for the tie rods used to support the LHe bath from OVJ. During the BIV-2 event the minimum temperature of the OVJ is calculated considering OVJ as lumped mass. The minimum temperature of OVJ is calculated as 136 K, considering breakage of LHe bath itself, and applied on OVJ during the analysis; however, there can be spatial distribution of temperature over OVJ. Transport acceleration, lifting and handling loads are not considered in this study. The relevant single loads [3] which are applicable to each expected modes of the ITER CD system are summarized below.

3.1. Nominal operating condition (NO)

Operating pressure (NP) and operating temperature (NT) is considered for the analysis during nominal operation. The OVJ of ACB-CP is kept under vacuum thereby exposed to a pressure difference of 0.1 MPa.

3.2. Test condition

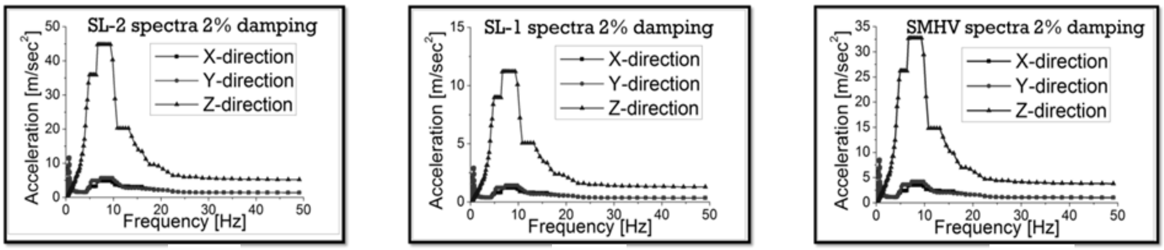
All pressure equipment covered under the European Pressure Equipment Directive (PED) Essential Safety Requirements (ESR) are subjected to a pneumatic test pressure (TP) to be performed at room temperature (RT) in agreement with the safety French regulations. Test pressure, which is 1.43 times the design pressure, is applied.

3.3. BIV-1
BIV-1 is an accidental case due to a major air leak in the CD cold box cryostats during nominal operation. For this case, the pressure loads in the process components are considered equal to their maximum allowable working pressure and internal pressure of the CD cold box cryostats is equal to the atmospheric pressure (0.1 MPa).

3.4. BIV-2
BIV-2 is an accidental case due to a rupture of internal process piping/component during nominal operation. For this case, the pressure loads in the process components shall be considered equal to their maximum allowable working pressure and internal pressure of the CD cold box cryostats equal to 0.14 MPa (absolute value, corresponding to the opening pressure of the safety protection devices of the CD cold box cryostats).

3.5. Incidental confinement pressure (ICP)
As ACB-CP is located on level 3 of the Tokamak building, where maximum possible external pressure of 0.12 MPa on the OVJ is considered for the design.

3.6. Seismic level 1/2/SMHV
The basement of the ITER Tokamak building is constructed on seismic isolators which will have a particular response to a seismic event. For an SL-2 event, acceleration spectra [6] as shown in figure 2 are provided. SL-1 acceleration spectra are derived by dividing the SL-2 values by 4. To take into account the different location inside the Tokamak building, a conservative spectrum taking the envelope of the different nodes is considered for the analysis. The seismic response to SMHV event is obtained by multiplying the results from SL-2 by 0.73. 2% damping is considered for response spectrum analysis for each direction X, Y and Z. For simplicity full SL-1 analysis is not performed and results are obtained dividing the results from SL-2 by a factor of 3.



(a) (b) (c)

Figure 2. (a) Acceleration spectra for SL-2, (b) SL-1 and (c) for SMHV.

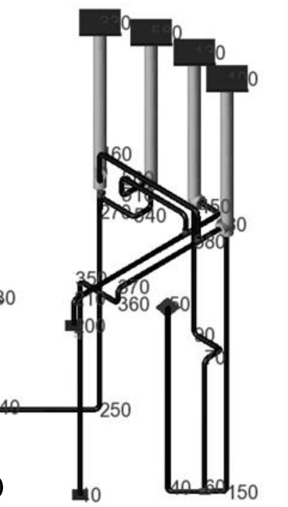
4. Methodology
ACB-CP is modelled in CATIA® [3] to carry out complete thermo-mechanical analysis using Finite Element Method. Internal piping with valves are modelled in CAESAR® software which gives extensive results based on European piping design code EN-13480. Cryogenic valves are modelled by CAESAR® as pipe element with anchoring points on the OVJ location and valve seat location connected with process piping. Internal piping layout inside the cold box is modelled in such a way that maintenance of HXs can be performed easily. LHe bath is supported from the OVJ with the help of two I-beams which cross section is 150×150 mm^2. Piping of the ACB-CP is modelled loop wise as shown in figure 3 and the all load cases are applied on it. Forces and moments at the anchor position are extracted from the pipe stress analysis and given as input for the analysis in finite element software ANSYS® [4]. Different load cases are categorized in different service limits [4] and are subjected to different allowable limits. The forces and moments on the valve seat location obtained from pipe stress

analysis software are applied to FE model of complete ACB-CP. For all the load combinations analysis is performed and allowable stresses are verified.

5. Results and discussion

5.1. CAESAR analysis results

Internal process pipes for ACB-CP are modelled in CAESAR®. Forces and moments at the anchor locations are extracted for all the load combinations. CAESAR® analysis for one loop is shown in figure 3(a). For some of the load combinations forces and moment at anchor locations are given in figure 3(b). The deformation at valve seat location are obtained in order to insure that valve deflection is within the allowable limit (2 mm) generally specified by the valve supplier and stresses in piping layout is within the allowable limits. CAESAR analysis also ensures that there is no clashes are foreseen between process pipes in any load combination.



(a)

Node	130		190		330		580	
	NO	NO+ SL-2	NO	NO+ SL-2	NO	NO+ SL-2	NO	NO+ SL-2
Fx [N]	4	26	-108	513	131	622	-36	169
Fy [N]	-6	73	-90	428	-32	148	-11	52
Fz [N]	498	2362	13	62	-21	102	49	234
Mx [Nm]	-1379	1995	37	56	71	102	-131	189
My [Nm]	-270	390	-70	100	32	45	-23	33
Mz [Nm]	-21	38	-284	411	336	486	-123	183

(b)

Figure 3. (a) CAESAR analysis for loop F and (b) forces and moments at nodes for different load combinations.

5.2. ANSYS® analysis results

Forces and moments extracted from CAESAR are taken as input and suitable boundary conditions i.e. temperature, pressure, gravity, fixed support and heat flux etc. are applied while performing analysis in ANSYS® for each load combination. Steady state thermal, static structural, modal analysis and response spectrum analysis are performed for each load case. Analysis is performed considering all the parts as shell element except tie rods, supporting LHe bath, which are considered as solid element. For all the load combinations analysis is performed in ANSYS® [4] and safety margin is derived for each case. For all load combinations NO+SMHV comes out with least safety margin as 0.06, therefore results shown in this paper are for NO+SMHV load combination only. For the NO+SMHV case the equivalent stress obtained in ANSYS® [4] are shown in figure 4. Maximum stress in LHe bath and its support location is 178 MPa as shown in figure 4(a). For the same case maximum deformation in LHe bath support is 47.6 mm as shown in figure 4(b). Maximum deformation in case of NO+SMHV in the OVJ is 1mm as shown in figure 4(c) and equivalent stress in the OVJ is 141 MPa as shown in figure 4(c). Table 1 given below shows the summary of results, category of the load combinations, allowable limits and available safety margin for all the load cases.

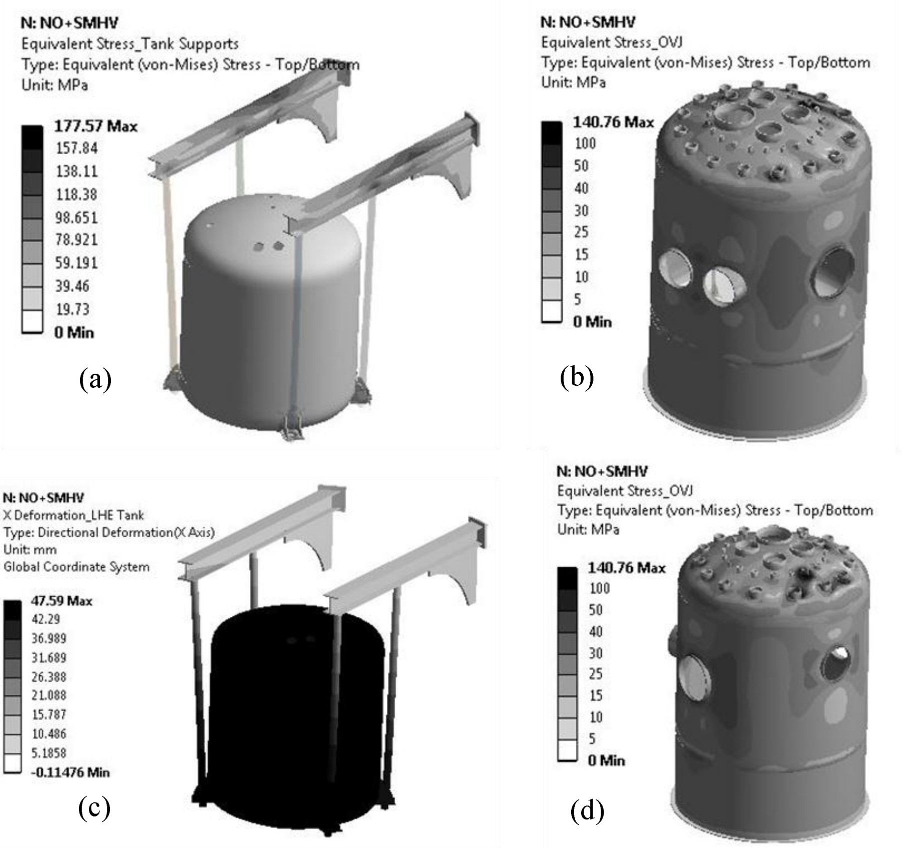


Figure 4. (a) ANSYS® simulation results equivalent stress on LHe support, (b) equivalent stress on OVJ, (c) deformation in LHe support and (d) and deformation in OVJ.

Table 1. Summary of results and available safety margin for all the load cases and their combinations.

Load combinations	Category	Allowable limit [MPa] [7]	Actual stress value [MPa]		Available Safety margin
			Pm	Pm+Pb	
Dead weight (G)	I	Pm<143	40	NA	2.58
TP + TT	I	Pl<172	85	NA	0.68
NP + NT (NO)	I	(Pm or Pl)+Pb <172	84	NA	0.70
NO + ICP	II	Pm<143	89	NA	0.61
TP+TT+SL-1	II	Pl<172	94	NA	0.52
NO+SL-1	II	(Pm or Pl)+Pb <172	92	NA	0.55
TP+TT+SMHV	III	Pm<172	161	175	0.07
BIV-1+SMHV	III	Pl<258	158	177	0.09
NO+SMHV	III	(Pm or Pl)+Pb <258	**163**	**194**	**0.06**
BIV-2+SMHV	III		163	191	0.06
NO + SL-2	IV	Pm<286	214	231	0.34
TP+TT+SL-2	IV	Pl<430	216	229	0.32
BIV-1+SL-2	IV	(Pm or Pl)+Pb <430	224	247	0.28
BIV-2+SL-2	IV		210	245	0.36

6. Conclusion
Present study encapsulates all the loads which are to be borne or likely to be borne by the ACB-CP, and thus establishes a well-defined methodology for the repeated analysis of ACB-CP or analysis for other CD boxes. The thermo-mechanical design and analysis for one representative ACB has revealed the load combinations which are really design drivers, e.g. NO+SMHV. During the design iterations of the ACBs concentration on the design drivers reduces the analysis efforts for the other CD boxes.

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Disclaimer
The views and opinions expressed herein do not necessarily reflect those of the ITER organization.

References
[1] Serio L et al. 2011 *Proceedings of ICEC 23-ICMC* 833
[2] Internal technical report 2011 *Conceptual Design of ACBCP-II-ODA2EC7-v_1_1*
[3] Dassault Systems, 2012. CATIA® Version 5, Vélizy-Villacoublay, France
[4] ANSYS® Version 15, Canonsburg, PA, USA
[5] ITER Document, Loads Specification for ITER CD system-II-IWSX43Q-v_1_0
[6] Tender Design-Tokamak Complex 2012, Generation of the Floor Response Spectra ITER_D_3Z5N6P v1.3
[7] ITER Document, Allowable values and limits in service I_3G3SYJ_v3_1