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The structure analysis of ITER cryostat based on the finite element method☆

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ABSTRACT

In the ITER project the cryostat is one of the most important components. Cryostat shall transfer all the loads that derive from the TOKAMAK inner basic machine, and from the cryostat itself, to the floor of the TOKAMAK pit (during the normal and off-normal operational regimes, and at specified accidental conditions). This paper researches the dynamic structure strength of the ITER cryostat during the operation of TOKAMAK. Firstly the paper introduces the types of loads and the importance of every type load to the research. Then it gives out the method of building model and principle of simplified model, boundary conditions and the way of applying loads on the cryostat. Finally the author discussed the analysis result and the strength questions of cryostat, also, the author pointed out the opinions according to the analysis results.

1. Introduction

In the ITER project the cryostat is one of the most important components. The ITER cryostat consists of four parts: top lid (dome shell), upper cylinder, lower cylinder and basement, top lid is 4.193 m high, upper cylinder is 9.035 m high, lower cylinder is 10.127 m high and basement is 5.767 m high, as well as shown in Fig. 1. The four different parts are welded or bolted together so that inner components can be assembled strongly. Firstly cryostat provides vacuum environment for the thermal insulation to superconducting TOKAMAK systems and envelops the entire basic systems. Secondly the cylinder structure is designed to withstand in particular external pressure loads and also it shall transfer all the loads that derive from the TOKAMAK inner basic machine, and from the cryostat itself, to the floor of the TOKAMAK pit during the normal and off-normal operational regimes, and at specified accidental conditions. So the paper will study the dynamic structure strength of cryostat under some kinds of loads using finite element (FE) method, and those are different from Refs. [1,2].

2. Loads description on the cryostat

In previous studies, various possible loads acting on the cryostat have been investigated that you can find in Table 1. In the table two kinds of the loads are particularly important in this research: inertial force and pressure loads. Inertial force includes dead weight and seismic force. External pressure load is air pressure. Thermal loads are considered to cause negligible secondary stresses on the cryostat because of little temperature gradient across the section of thickness. Vertical displacement event (VDE) loads on the cryostat occur on the pedestal ring due to reaction forces from VV and TF coil supports. These reaction forces are equal opposite and apply smaller net loads on the cryostat [4,5]. The effect of the other electromagnetic (EM) loads on the cryostat is little through the estimation although studies have shown that it has an important influence on the inner components, so all EM loads and thermal loads are dislodged from the cryostat structure analysis, and the detail is discussed in Ref. [3,4].

The seismic force is a special load case in this loads case combination which can lead to so devastating result that we have to calculate it. An earthquake consists of an oscillatory movement of the earth's surface. The ground acceleration can be both in the horizontal and the vertical direction. There are two different ways to evaluate the result of seismic force: the response spectra analysis and transient analysis. The paper only chooses the transient analysis way to analyze the structure strength of cryostat. As you know earthquake is so rare that any data records about its intensity and acceleration wave is different and single. In order to solve the problem, the ITER organization has attempted to collect the earthquake data of the past several hundred years about Cadarache (a French

☆ Chinese 973 supporting project of ITER.

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Table 1
Loads on the cryostat.

		Pressure loads	Thermal loads	EM loads	Inertial force
1	VDE loads		√	√	
2	Plasma disruption		√	√	
3	Magnet quenching			√	
4	Plasma discharge			√	
5	Earthquake				√
6	Atmosphere	√			
7	Dead weight				√
	Total loads	√			√

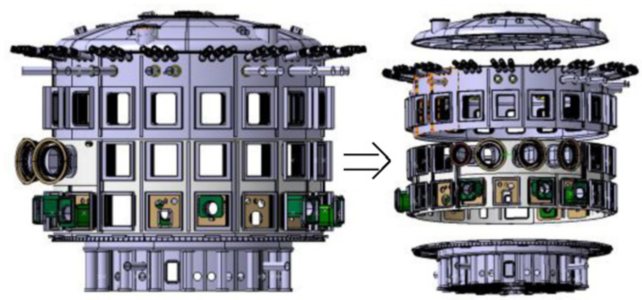

Fig. 1. ITER cryostat.

city), and designed artificial seismic wave shown in Fig. 2 (see [3,4]). Also according to ITER structural design criteria, case combination is:

$$P + D + E$$

where, P equals the external atmospheric pressure (1 bar); D equals the dead weight; E equals the seismic loads.

This paper uses this loads case combination.

3. The finite element (FE) model and boundary conditions

The 3D model of cryostat was built with Catia V5 shown in Fig. 1. The cryostat is a single walled shell vessel consisting of two cylindrical sections, top dome shape lid and a basement with eighteen pedestal columns. A little port penetrations are not strict symmetry in circumference direction through the 3D model. In contrast with length and height the wall thickness of the cryostat is so little that the model is build with curved surface and the inner/outer face of the 3D model is used as the neutral surface for FE mesh [6]. In order to ensure the precision of analysis the FE model keeps all ribs and the reinforcement plates of all the port penetrations according to the original model of the cryostat. Also in order to simplify the FE model small, nonsymmetric openings are neglected (see Fig. 3).

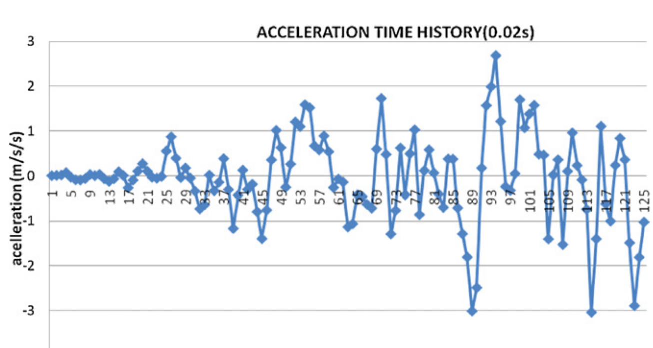

Fig. 2. ITER Cadarache artificial earthquake wave (only 125 points/total 1001 points).

In order to reduce the calculated workload of computer we only choose one sixth of cryostat model which included the weakest part. The paper can give out three reasons to design the analysis model as these:

(1) The ribs distributed on four parts are no difference; one sixth of the model can include all symmetry ribs and port penetrations, and be enough for the FE analysis. This is different from some literatures [1] which have used whole model or one twelfth of model.
(2) Although analysis result with the weakest part is not the precise result of the real model, but result is conservative or safe to all the structure.
(3) The analysis software (ansys13.0) can compensate the result of other not-included-in structure under the symmetric boundary conditions.

Two type's boundary conditions have been applied on the model shown in Fig. 4. The bottoms of the basement are constrained in all degrees of freedom because the cryostat is connected to the building at these points and this is a pretty good approximation. The eighteen pedestal columns (see Fig. 3, pedestal columns) are not part of cryostat but the support of magnet and vacuum vessel. Dead weight of inner components and EM loads act on the support plane then transfer to pedestal columns, finally act on the support ground. In reality, the pedestal columns are bolted to the basement, 18 lugs around the edge of the cryostat is constrained against toroidal movement. So the FE model is designed as Figs. 3 and 4: the pedestal columns are deleted, in the same place, fixed supporting constraints instead of them. Symmetric is a special type constraint

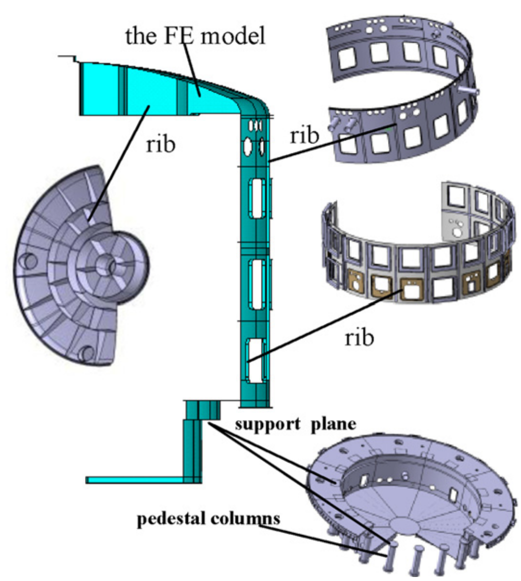

Fig. 3. The FE model and the original model.