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ARTICLE

Research on Temperature Field of the Support Structure for the Independent LNG Tank

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ABSTRACT

The independent LNG (Liquified Nature Gas) containment is widely used for small or medium-sized LNG carrier and ship using LNG as fuels. The common tank pattern includes single-spherical-cylindrical tank and double-spherical-cylindrical tank, which is the key to design the hull structure and its support. The support is designed to connect the hull structure and LNG tank. Its main functions are heat transferring and force loading. This paper focus on the temperature field distribution of hull and its support structure. The thermal boundary conditions are simulated according to the heat transfer action, such as thermal convection, heat conduction and thermal radiation. The method on how to carry out thermal analysis is presented for an independent LNG containment. The case study is carried out with two typical independent LNG tanks. One is a tank with double spherical cylindrical in the LNG carrier, and the other is a tank with single spherical cylindrical on the deck of the ship using LNG as fuels. The result shows the method presented in this paper is a good reference for the structural design with independent LNG containment.

1. Introduction

The independent LNG carrier (see Figure 1) has great market share and development prospects in the field of LNG carriers. The independent LNG carrier has the technical advantages of low technical difficulty, great safety performance and low cost, which can achieve the demand of the LNG transportation for the short distance. Small or medium-sized LNG carriers take the main role in this field.

The support structure of independent LNG cargo containment is the main component in this type of ships [1,2]. It is designed for the connection of the hull structure and LNG containment to implement the transmission of force, deformation, and heat [3]. The temperature field of the support structure not only determines the choice of structural materials [4,5], but also affects the local thermal stress distribution [6].

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(a) The independent LNG cargo containment

(b) The deck tank

Figure 1. The independent LNG carrier

This field is one of the key factors to the design of the independent LNG containment, and many former researchers focused on it. Liu [7] takes the 170 000 m3 LNG carrier with type B independent liquid tank as the study object, the steady temperature field analysis on the liquid tank is carried out. Jiang [8] reports that a LNG carrier with type C tank is taken as the example to compare the calculation results under the extreme conditions respectively from the simplified method and the 3D finite element method. It is found that 3D finite element method can provide the temperature field variations of each region inside the cargo hold. Ma [9] studies the temperature field of the LNG carrier with SPB type tank though the unique structural design different from the membrane design makes it difficult to do so. Li [10] reports that the ambient temperature has great effect on heat leakage of tank wall, ambient wind velocity has great influence on heat leakage of tank roof, liquid level has some influence on heat leakage of tank wall and tank bottom, and ambient wind velocity has little effect on heat leakage of the whole tank. Zeng [11] reports that liquid cargo tank is in a low temperature and is supported by a saddle connected to the hull so that a low temperature zone and a temperature gradient are formed on the entire cargo area, especially the saddle and its nearby hull.

Taking the current common application scenarios of the independent LNG tank into consideration, simulating the heat transfer method of the ship and studying on the establishment of the temperature field analysis method for the support structure can be the technical reference for designing the support structure of small and medium-sized LNG carriers and LNG-powered vessels.

2. Heat Transfer of Support Structure

The support structure of the independent LNG containment is between the hull and the containment, which implement the transmission of force and heat. Heat transfer always occurs from a region of high temperature to another region of lower temperature, ignoring the radiation heat transfer between the structures.

Taking the support structure as the research object, it mainly has three aspects of heat transfer [12]: heat conduction of the hull to the support structure, thermal convection of the ambient to the support structure and heat conduction of the tank to the support structure.

The temperature of the hull structure can be obtained by the hull temperature field analysis method, and the heat conduction can be completed by the model automatically; the thermal convection of the ambient to the support structure requires the adoption of the thermal convection boundary conditions of thermal analysis, and corresponding fluid temperature and the thermal convection coefficient. The temperature of the boundary of independent LNG containment is as the same as the temperature of LNG, and the containment structure can be set to a fixed temperature boundary condition or a corresponding thermal convection boundary condition.

Catching the key points in the above heat transfer process, the temperature field calculation and analysis of the support structure in independent LNG containment can accurately simulate the basic law of heat transfer of the support structure, and obtain reliable temperature field calculation results [13]. In this paper, the support structure in the independent LNG containment of two types of ships encountered in engineering practice is taken as the research object, and the research on the temperature field analysis method of support structure is carried out in detail.

3.Thermal Analysis of the Support Structure of Double-spherical-Cylindrical Tank

3.1 Structural Modeling

The purpose of this calculation is to calculate the tempera-

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ture field of the support structure, and the model of the support structure requires to be completely established. The double-spherical-cylindrical tank and hull structure both are boundary conditions. Considering the application of heat transfer boundary conditions [14,15], the longitudinal range of the model should include one web frame spacing in front and back of the support structure. The lateral range includes the full width of the support structure, and the vertical range includes the full height of the support structure, see Figure 2.

Figure 2. Temperature field analysis model of support structure in the independent LNG containment

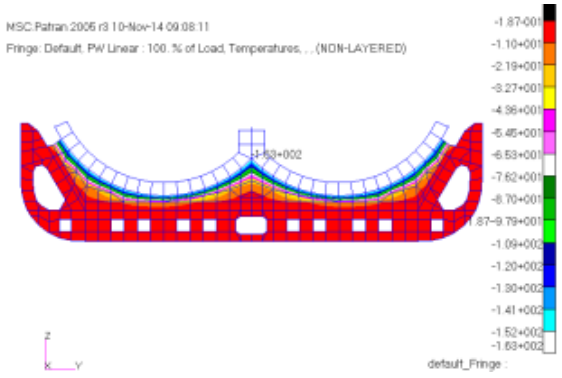
Due to the double-spherical-cylindrical tank, the hull structure and the support structure both are plate structures, the modeling method for the structures above is as the same as the modeling method for the hull structure [16]. The unit size is frame spacing, the unit type is plate and beam element; Laminated wood structure serves as heat shield, the model is established by using hexahedral element.

3.2 Simulation of Thermal Boundary Condition

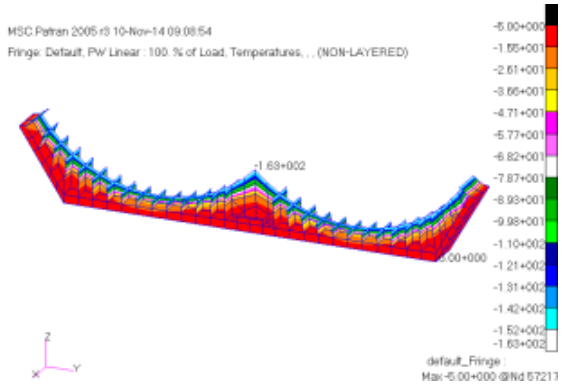
According to the analysis above, four types of boundary conditions are mainly considered in this calculation [12]: the temperature of all nodes in the LNG containment model is set as the temperature of LNG, the hull is subjected to thermal convection of seawater, the internal structure of the hull is subjected to thermal convection of air, the support structure is subjected to thermal convection of air. The thermal boundary conditions are Consistent with the research done by Liu [7].

3.3 Calculation of Temperature Field

According to thermodynamics analysis, the calculation results of the temperature field distribution of the support structure are shown in Figure 3. The calculation results of temperature field of the model are consistent with the previous analysis, such as the Analysis Report for Temperature Distribution by TGE [13]. The temperature field of the hull structure is the highest, and the temperature of the containment is as the same as the cargo's, through the heat transfer of the support structure.

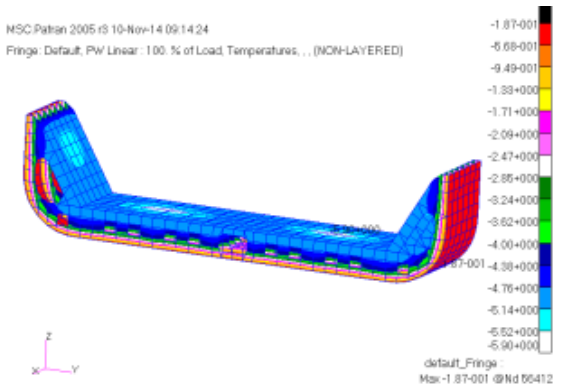


(a) The temperature distribution of the whole model



(b) The temperature distribution of the supporter

(c) The temperature distribution of the laminated wood structure



(d) The temperature distribution of the hull structure

Figure 3. Analysis results of temperature field of the independent LNG containment

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The temperature of the area where the support structure contacts the containment is as the same as the temperature of LNG. Under the action of air convection and heat conduction, the temperature of the support structure rises rapidly and a large temperature gradient is formed. It shows that the support structure is a key factor in heat shielding. The temperature field distribution of the containment is symmetrical along the direction of ship width, and the temperature forms a large temperature gradient along the support structure, and the overall trend is linear, which is consistent with the industry experience. The finite element analysis can better reflect the distribution characteristics of the temperature field, which under the joint action of multiple heat transfer modes. The finite element analysis can reflect the detailed changes in the temperature field of the support structure.

Under the action of air convection and heat conduction, the steel support structure supporting the containment changes rapidly from -163℃ to -5℃ , forming a large temperature gradient. This situation needs to be paid enough attention:

(1) This situation may cause large thermal stress and requires a focus on structural strength;

(2) This situation has a greater impact on steel grades, requiring a focus on material selection.

Laminated wood is placed under the steel support structure with a minimum temperature of -31.3℃ , and the closer to the containment, the lower the temperature becomes, which is consistent with common knowledge in the industry. The finite element method can better reflect the distribution of temperature on the laminated wood, and can describe the characteristics of heat transfer more vividly.

The heat conduction occurs between the hull structure and the support structure. It can be seen from the calculation results that the temperature of the hull structure will decrease. The minimum temperature of the hull structure in the model is about -5.9℃ . The temperature rises rapidly along the support structure and then reach the ambient temperature. The temperature of the containment is as the same as the cargo's, which is -163℃ in the example.

3.4 Analysis of the Calculation Results

The example of the containment shows that the calculation method used in this calculation is reliable and the calculation results are consistent with the current knowledge of the industry. This method can be used as the calculation method for the temperature field analysis of the support structure in independent LNG containment. Using the finite element method, the distribution of temperature field of the support structure can be simulated more accurately, reflecting the temperature transfer law between "containment -support structure-hull".

It can be seen from the calculation results that the distribution of temperature field of the support structure has an important relationship with its design form. The hull structure is in contact with the tank through support structure, it lets the hull structure under low temperature conditions, which needs to be paid enough attention. From the trend of the distribution, and the perspective of simplifying the calculation, the empirical method used in the ship rule can also be used to simulate the distribution of temperature field of the structure.

4. Thermal Analysis of the Support Structure of Single-spherical-cylindrical Tank

4.1 Structural Modeling

The purpose of this calculation is to find out the temperature field of the support structure, and the model of the support structure requires to be completely established.

The deck tank and hull structure are boundary conditions of temperature field [10]. Considering the application of heat transfer boundary conditions, the longitudinal range of the model should include one web frame spacing in front and back of support structure. The lateral range includes the full width of the support structure, and the vertical range includes the full height of the support structure, See Figure 4.

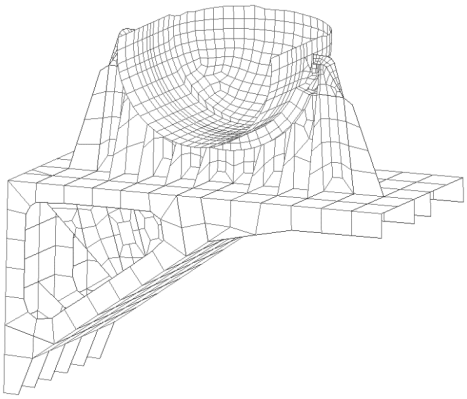

Figure 4. Temperature field analysis model of deck tank

Due to the deck tank, the hull structure and the support structure both are plate structures, the modeling method for the structures above is as the same as the modeling method for the hull structure. The unit size is frame spacing, the unit type is plate and beam element; the laminated wood structure acts as the heat shield. The model is established by using hexahedral element.

4.2 Simulation of Thermal Boundary Condition

According to the analysis above, three types of boundary conditions are mainly considered in this calculation: the

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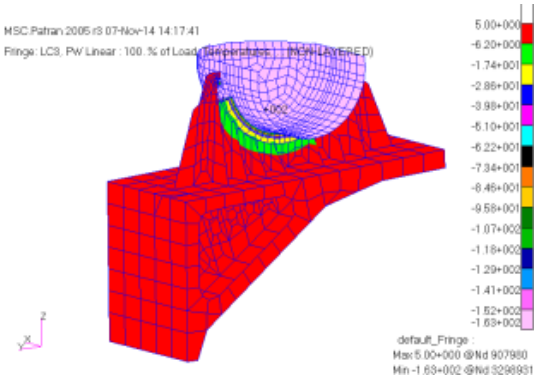
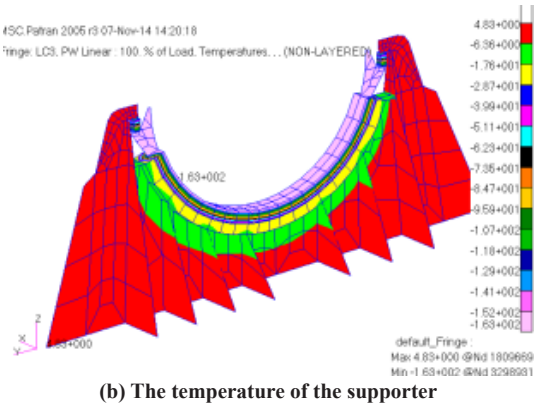
temperature of all nodes in the deck tank model is set as the temperature of LNG, the structure of the hull is subjected to thermal convection of air, and the support structure is subjected to thermal convection of air.

4.3 Calculation of Temperature Field

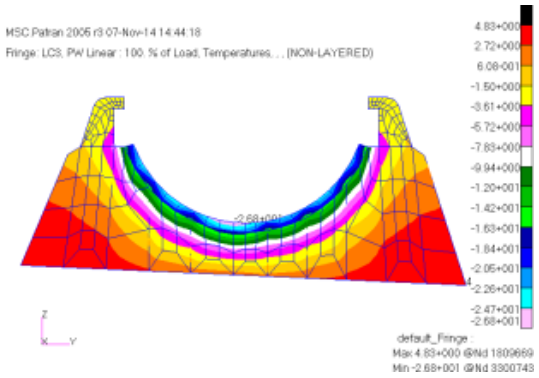
According to thermodynamics analysis, the calculation results of the temperature field distribution of the support structure are shown in Figure 5. The calculation results of temperature field of the model are consistent with the previous analysis. The temperature field of the hull structure is the highest, and the temperature of the deck tank is as the same as the cargo's, through the heat transfer of the support structure. Laminated wood structure serves as heat shield, and it goes through a large temperature gradient.



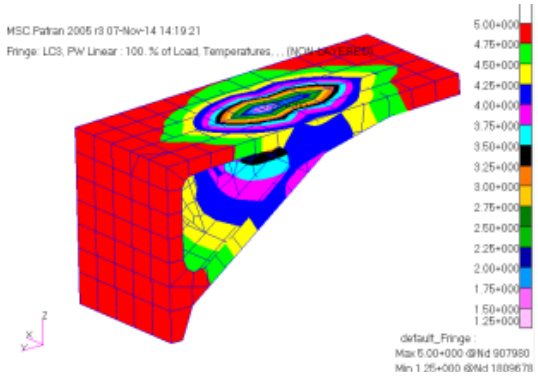
(a) The temperature of the whole model



(b) The temperature of the supporter



(c) The temperature of the hull structure excluding wood structure



(d) The temperature of the hull structure

Figure 5. The calculation results of the temperature field distribution of deck tank

The support structure is an important factor in temperature transfer. The temperature of the position where the support structure contacts the deck tank directly is -163℃, and the position where the support structure contacts the hull structure is 4.83℃, which is close to the ambient temperature of 5℃. Laminated wood structure serves as heat shield, and it goes through a large temperature gradient.

The temperature of the steel support structure reaches -26.8℃, which is consistent with the industry experience data. The temperature of the support structure is affected by local components such as brackets, but the overall trend varies linearly, which is consistent with industry experience. The finite element analysis can reflect the detailed changes in the temperature field of the support structure.

From the partial magnifying cloud diagram, the laminated wood is the main factor of heat shielding. The temperature gradient of the laminated wood is very large. The bracket can change the distribution of local temperature field and increase the temperature value of the corresponding position, but the range and the size of influence is very small.

In the aspect of heat shielding, the laminated wood is the key factor. The support steel sheet located in the middle of the laminated wood and the fixed steel sheet around the laminated wood will affect the distribution of temperature field. The finite element analysis effectively describes the details of distribution of temperature field.

The heat conduction occurs between the hull structure and the support structure. It can be seen from the calculation results that the temperature of the hull structure will decrease by several degrees. The minimum temperature of the hull structure in the model is about 1.25℃. The temperature rises rapidly along the support structure and then reach the ambient temperature. The temperature of the deck tank is as the same as the LNG's, which is -163℃ in

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the example.

4.4 Analysis of Results

This example proves that the calculation method is reliable and the calculation results are consistent with the current knowledge of the industry. This method can be used as the calculation method for the temperature field analysis of the support structure for deck tank. The distribution of temperature field can be simulated more accurately with this method. It also can describe the effect of local details (such as brackets, fixed steel sheet, internal support steel sheet, etc.) on the distribution of temperature field of the support structure.

From the trend of temperature field analysis results, it can be concluded that the result is similar to the temperature distribution simulated by the approximation method in the specification, both have their own advantages and disadvantages. The approximation method is easy to gain the general temperature result at the initial stage of LNG tank design. And the FEM method is exact to simulate the detailed temperature distribution for the final design of LNG tank design.

It is more appropriate to retain these two methods in the specification for users to choose:

(1) The finite element method can simulate the temperature field distribution of the support structure accurately, but it needs to do corresponding calculation work;

(2) Simplified linear interpolation can describe the trend of the temperature field distribution of the support structure more conveniently, but it won't reflect the detailed change of the temperature field of the support structure.

5. Conclusions

The independent LNG tank is widely used for the LNG carrier and LNG fuel ship. The ultralow temperature is the most hazard for the safety of the LNG tank. The thermal analysis is the key to gain the temperature field for the design. In this paper, the established method for temperature field analysis of independent support structure is studied, including the modeling method, the model range, the selection of heat transfer mode, and the setting of boundary condition setting, etc., which are verified by examples of real ship and the method have operability. Despite the various forms of the support structure, the heat transfer law is orderly (following the heat transfer law from the hull to the support structure to the containment). When analyses the temperature field, the hull structure and the containment can be taken as the thermal boundary conditions of the support structure. At the same time, it is necessary to consider the influence of air convection on the support structure.

The results of the example show that the minimum temperature of the support structure can reach -30 ℃ , which is consistent with the current general understanding of this problem in the industry, and also consistent with the temperature distribution trend of linear interpolation in the ship specification, further verifying the analysis method for temperature field of the independent LNG containment. The analysis method can more accurately simulate the temperature field distribution trend of the support structure, and is a technical reference for the temperature field analysis of the support structure of the containment for the LNG carrier and the LNG-powered vessels.

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