Strength analysis of LNG tank container for trains under inertial force

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Abstract. As transportable pressure vessel, LNG tank container used in trains bears not only the static load, but also inertial load during transportation. The finite element method is commonly used in the design of tank containers subjected to inertial force. In this paper, a finite element model for 1AA LNG tank container was established using the ANSYS software, stress analysis and strength assessment under five load cases were performed for the tank container. The results show that the Mises equivalent membrane stress at the frame is controlled by the inertial force but at the inner vessel, however, it depends on the internal pressure although it may be significantly affected by the inertial force in some cases.

1. Introduction
With the rapid development of petrochemical industry, the demand for liquefied gases is increasing in the world. Tank containers are widely used due to their large carrying capacity, low transportation cost and so on. During transportation, the tank container will be subjected to internal pressure, external pressure, inertial force and impact force of the medium in the tank. The finite element method is commonly used in the design of tank containers subjected to inertial force.

By using the finite element software ANSYS, Jinjin Liu performed stress analysis and strength assessment for LPG tank container subjected to inertial force. Results indicate that the structure of the tank container is safe and reliable [1]. Xuemei Liu et al. used the finite element method to analyze the influence of the liquid inertial force on the stress distribution at the frame and shell of tank containers under different loading modes [2]. By using the finite element method, Zhaochun Ren et al. obtained the stress distribution and displacement of LNG tank container subjected to inertial force and assessed whether the tank container meets the strength requirements [3]. Xiaodong Wang et al. used the finite element method to simulate LNG tank container subjected to inertial force, and assessed the safety of the parts of stress concentration [4].

In this paper, a finite element model for 1AA LNG tank container was established. Stress analysis and strength assessment were performed. The study provides certain references for the design of tank containers.
2. The finite element model of the tank container

2.1. Modeling and meshing

In order to release the stress caused by the temperature difference, the tank container is supported with one end sliding and other end fixed. Main parameters of the tank container are listed in Table 1, main parameters of the tank container. The geometry of the tank container was modeled using ANSYS software as shown in Fig. 1. Solid elements (Solid185) and Shell elements (Shell181) were used to mesh the entire model. The grid model of the tank container is shown in Fig. 2.

| Item                                | Value     | Item                                | Value     |
|-------------------------------------|-----------|-------------------------------------|-----------|
| Specified filling rate              | 90%       | Material of the 8 support rings     | GFRP      |
| Design pressure of the inner vessel | 0.6MPa    | Material of the inner vessel        | S30408    |
| Design temperature of the inner vessel | -196 °C  | Material of the outer vessel        | 16MnDR    |
| Design pressure of the jacket       | -0.1MPa   | Material of the frame               | Q450NQR1  |
| Design temperature of the jacket    | 50 °C     | Corrosion allowance                | 0         |

2.2. Loading and constraints

According to the Tank containers for cryogenic, four inertial forces should be considered in the design of the tank container. In addition, because the tank container is differently supported at the two ends, it is necessary to analyze the inertial force along the direction of motion from two directions. Thus, the following load cases are considered:

- **Load case 1(2):** internal pressure (0.7MPa) + external pressure (-0.1MPa) + weight of the tank container and the LNG + inertial force being four times the gross weight along the direction of motion.
- **Load case 3:** internal pressure (0.7MPa) + external pressure (-0.1MPa) + weight of the tank container and the LNG + inertial force being twice the gross weight in the horizontal direction perpendicular to the direction of motion.
- **Load case 4:** internal pressure (0.7MPa) + external pressure (-0.1MPa) + inertial force being twice the gross weight in the vertical downward direction.
- **Load case 5:** internal pressure (0.7MPa) + external pressure (-0.1MPa) + inertial force being one times the gross weight in the vertical upward direction.

The inertial force is divided into tank container inertial force and LNG inertial force. The LNG inertial force was applied by the average pressure method, that is, the LNG inertial force divided by the projected area of the inner vessel in the direction of the inertial force [5]. The calculation results of
the LNG inertial force under five load cases are listed in Table 2, the calculation results of the LNG inertial force under five load cases. For constraints, the bottom surfaces of the four corner fittings at the bottom of the frame were fully constrained.

| Load case | 1(2) | 3   | 4   | 5   |
|-----------|------|-----|-----|-----|
| Acceleration | 4g   | 2g  | 2g  | g   |
| Inertia force (N) | 754462 | 377231 | 377231 | 188615.5 |
| Projected area (m²) | 3.97 | 26.2 | 26.2 | 26.2 |
| Average pressure (MPa) | 0.19 | 0.014 | 0.014 | 0.007 |

3. Results and discussions

For tank containers, there are two strength assessment standards, namely Part 5 of ASME CODE SEC.VIII Div.2 and Container inspection specifications 2016. Based on these two standards, the Mises equivalent stress is taken as a parameter to perform strength assessment. However, the allowable stress values in these two standards are different. According to the Container inspection specifications 2016, the Mises equivalent stress values of tank containers are required to be limited to 1/1.5 of the material yield strength. According to the Part 5 of ASME CODE SEC.VIII Div.2, the Mises equivalent stress should be classified as five categories according to its effect on equipment strength failure and the corresponding Mises equivalent stress value is required to be limited to respective allowable stress value.

Because the toughness of the material of tank containers is generally good and local plastic deformation will not lead to the failure of tank containers, the Container inspection specifications 2016 is conservative and unreasonable in strength assessment. Comparatively, Part 5 of ASME CODE SEC.VIII Div.2 is more scientific and reasonable and thus, was employed for strength assessment in this paper. The allowable stress values of materials are listed in the Table 3, allowable stress values of materials. The results show that the LNG tank container meets the strength requirements according to the Part 5 of ASME CODE SEC.VIII Div.2, 2017.

| Material | S30408 | 16MnDR | Q450NQR1 |
|----------|-------|--------|----------|
| m        | 167   | 181    | 211      |
| 1.5s_m   | 250   | 271    | 316      |
| 3s_m     | 500   | 542    | 632      |

Figs. 3-7 show the Mises equivalent membrane stress distributions at the frame under the five load cases. It is seen that the inertial force obviously affects the Mises equivalent membrane stress distribution at the frame. Figs. 8-12 show the Mises equivalent membrane stress distributions at the
Figure 3. The Mises equivalent membrane stress distribution at the frame under load case 1 (Pa)

Figure 4. The Mises equivalent membrane stress distribution at the frame under load case 2 (Pa)

Figure 5. The Mises equivalent membrane stress distribution at the frame under load case 3 (Pa)

Figure 6. The Mises equivalent membrane stress distribution at the frame under load case 4 (Pa)

Figure 7. The Mises equivalent membrane stress distribution at the frame under load case 5 (Pa)

Figure 8. The Mises equivalent membrane stress distribution at the inner vessel under load case 3 (Pa)
Inner vessel under the five load cases. It is found that under different load cases, the values of the maximum Mises equivalent membrane stresses are all located at the connections between the cylindrical shell and the head. Their values, however, depend on the load cases. For load cases 3-5, as the LNG inertial forces are twice the gross weight acting on a larger projected area, the Mises equivalent membrane stresses are mainly caused by the internal pressure and thus, their values are almost the same as shown in Figs. 8-10. But as shown in Figs. 11 and 12, for load cases 1 and 2, however, as the LNG inertial forces are four times the gross weight acting on a smaller projected area, the Mises equivalent membrane stresses are significantly influenced by the inertial forces and as a result, their values are much larger than those for load cases 3-5.
4. Conclusion

(1) The LNG tank container meets the strength requirements according to the Part 5 of ASME CODE SEC.VIII Div.2.

(2) The inertial force obviously affects the Mises equivalent membrane stress distribution at the frame. The maximum value is 204MPa, which is located on the connection between the L-TYPE beam and the corner fitting.

(3) Under different load cases, the maximum Mises equivalent membrane stresses at the inner vessel are all located at the connection between the cylindrical shell and the head. Their values depend on the internal pressure but may significantly affect by the inertial force.

References

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