Design Analysis and Optimization of LOX Tank Using Finite Element Method – A Review Paper

Nitesh R. Chaudhary
M.E. Student
Department of Mechanical Engineering
L.D. College of engineering, Ahmedabad 380015

Prof. U.V.
Associate professor
Department of Mechanical Engineering
L.D. College of engineering, Ahmedabad 380015

Abstract

In this Present study covers properties of LoX. It covers the design steps of LOX tank, modelling and FE analysis of the same. It include support structure analysis. It includes the design of frame structure where the LOX tank will be supported and Transport analysis with different load cases and load combinations.

Keywords: Lox Tank; FEM; Support Structure.

I. Introduction

Lox is cryogenic fluid. Cryogenic liquids are used for accessing low temperatures. They are extremely cold, with boiling points below 123K. Blue color of LoX caused by the presence of the polymer or long-chain molecule O_4. Liquid oxygen has a density of 1.141 g/cm^3 (1.141 kg/L or 1141 kg/m^3) and is cryogenic with a freezing point of 54.36 K (−361.82 °F, −222.65 °C) and a boiling point of 90.19 K (−297.33 °F, −182.96 °C) at 101.325 kPa (760 mmHg). It is widely used in industries like rocket, waste water treatment process, medical and iron and steel manufacturing.

II. Literature Review

Shafique M.A. Khan[1] presents analysis results of stress distributions in a horizontal pressure vessel and the saddle supports. The results are obtained from a 3D finite element analysis. He showed the stress distribution in the pressure vessel, the results provide details of stress distribution in different parts of the saddle separately,i.e. wear, web, flange and base plates. A value of 0.25 for the ratio A/L is favored for minimum stresses in the pressure vessel and the saddle. The slenderness ratio (L/R) of less than 16 is found to generate minimum stresses in the pressure vessel and the saddle. Which is shown in below fig. 1. The highly stressed area, beside the pressure vessel at the saddle horn, is the flange plate of the saddle.

Aceves S.M. et al.[2] shows an evaluation of the applicability of the insulated pressure vessels for light duty vehicles. The paper shows an evaluation of evaporative losses and insulation requirements and a description of the current analysis and experimental plans for testing insulated pressure vessels. The most important results can be summarized that . Insulated pressure vessels do not lose any hydrogen for daily driving distances of more than 10 km/day for a 17 km/l energy equivalent fuel economy. Since almost all cars are driven for longer distances, most cars would never lose any hydrogen. Losses during long periods of parking are small. Due to their high pressure capacity, these vessels retain about a third of its full charge even after a very long period of inactivity, so that the owner would not risk running out of fuel. Also previous testing has determined the potential of low-temperature operation of commercially available aluminium -lined wrapped vessels for a limited number of cycles. Further testing will extend the number of cycles to the values required for a light-duty vehicle. Additional analysis and testing will help in determining the safety and applicability of insulated pressure vessels for hydrogen storage in light-duty vehicles.

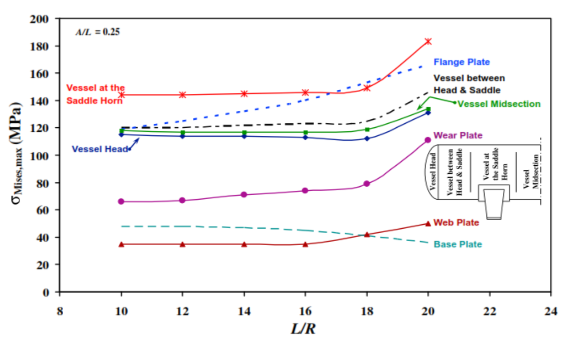

Fig 1: Effect of The Ratio L/R, A/L=0.25

Mr. Abdul Sayeed et al [3] worked on solid structural analysis of vacuum chamber. The analysis is done for electron microscopy applications, for scanning electron microscope it require vacuum atmosphere for viewing of the specimen. The specimen is to be viewed in vacuum. The vacuum level required for that is in the range of 700 torr, which is less than atmospheric pressure lead to compressive forces on the chamber They made vacuum chamber model in Catia and Simulation is done in Ansys. The Vacuum chamber is safe from buckling failure as applied p is very small in comparison to max theoretical buckling pressure. Compressive yield strength of structural steel is greater than Von Mises stress is calculated by solid structural analysis so it is safe from this criterion.

Aceves S.M.et al.[4] worked on high pressure and evalution of insulated pressure vessele for cryogenic hydrogen storage. The work described in this paper directed at verifying that commercially available pressure vessels can be safely used to store liquid hydrogen. This paper describes a series of tests ehich are shown below, that have been done with aluminumlined, fiber-wrapped vessels to evaluate the damage caused by low temperature operation. In FEM testing Cyclic, ultrasound and burst testing of the pressure vessels is being complemented with a finite element analysis, which will help to determine the causes of any potential damage to the vessel during low temperature operation.

N.Vukojeviæ et al.[5] presented Vertical pressure vessels according EN 13445 are supported on four different kind of supports. In paper is presented stress-strain analysis of pressure vessel supported by brackets. Problems with supports is specially marked by great preassure vessels and without correctly choosing, supports type can become potentially weak point in construction. The Results based on presented analysis shown that great pressure vessel supported on bracket supports demonstrate poor solution in relation to continual cofigutared supports (scirt supports). Bracket type of supports is unfavorable in case of initial crack failures with growth tendention. Results deviaton between numerical experimental analysis are implication of different wall thicjness of pressure vessel made by forging.

A.Th. Diamantoudis et al.[6] tried comparative study for design by analysis and design by formula of a cylinder to nozzle intersection has been made using different finite element techniques. The cylinder to nozzle intersection investigated is part of a typical vertical pressure vessel with a skirt support. For the study the commonly used ductile P355 steel alloy and the high strength steel alloy P500 QT were considered. the application of Design by Analysis(DBA) leads to much less conservative design parameters. The high strength steel P500 is severely punished when Design by Formula(DBF) rules are applied, instead of DBA methodology.

S. Murugan et al [7] performed the thermo-structural analysis of high pressure cryogenic tank (liquid hydrogen tank). The chill-down process is performed on a9.6m3 Water Capacity (WC) and 22 MPa Maximum. Allowable Working Pressure (MAWP) hydrogen tank with controlled rate of cooling. The finite element analysis (transient thermal and structural) of hydrogen tank is performed with ANSYS Software. This analysis incorporates temperature dependant material properties, temperature and pressure variations across the height of the tank during chill-down with liquid Nitrogen (LN2) followed by liquid Hydrogen (LH2) foranalyzing behaviour of the tank.. In order to avoid thermal crack, chill-down at controlled rate of cooling restricting temperature difference across the tank height is maintained.

P. Xu et al. [8] established 3D parametric finite element model of the Al–carbon fiber/ epoxy composite laminates under internal pressure to simulate the failure and damage evolution behavior of the composite hydrogen storage vessels. Here a finite element algorithm is proposed to simulate the real-time failure properties of composite vessels with increasing internal pressure Four failure criteria including the maximum stress, Hoffman, Tsai–Hill and Tsai–Wu criteria are employed respectively to determine the failure initiation of carbon fiber/epoxy composite elements. They found that Tsai–Wu failure criterion leads to most accurate failure pressure among all failure criterion.

L Zhang [9] deals with the finite element modelling (FEM) of a storage ring vacuum vessel. The geometry and heat load distribution of the ESRF storage ring have been used in the FEM. This study showed the feasibility of predicting the thermal deformation of a storage ring vacuum vessel with FEM. Sub-structuring technique is adequate to handle a large system. Thermal deformation of storage ring vacuum vessels can be minimised by using appropriate fixtures. They have performed FEM on one cell of a storage ring vessel without Insertion Devices (ID) vessel. It is possible to make FEM for a full storage ring vessel with all Insertion Devices (ID) vessels.

G.D. Berry et al. [10] described the development of an alternative technology for vehicular storage of hydrogen. Insulated pressure vessels are cryogenic-capable pressure vessels that can accept cryogenic liquid fuel, cryogenic compressed gas or compressed gas at ambient temperature. Insulated pressure vessels offer advantages over alternative hydrogen storage technologies Insulated pressure vessels are more compact and less expensive than compressed hydrogen vessels. They have lower evaporative losses and lower energy requirement for fuel liquefaction than liquid hydrogen tanks , also they are lighter than hydrides. The work described in this paper is directed at verifying that insulated pressure vessels can be used safely for vehicular hydrogen storage. The paper describes multiple tests and analyses that have been conducted to evaluate the safety of insulated pressure vessels. Insulated pressure vessels have been subjected to multiple DOT, ISO and SAE certification tests, and the vessels have always been successful in meeting the passing criteria for the different tests. A draft procedure for insulated pressure vessel certification has been generated to assist in a future commercialization of this technology. Ongoing work includes the demonstration of this technology in a vehicle.

K. Magnucki et. al[11] tried to the supporting saddle of a horizontal cylindrical pressure vessel filled with liquid. The vessel is treated as an integral system, including the deformable supports with stiffness adjusted to minimize the stress concentration in the vessel shell. The support should be of appropriate shape, simple design, and suitable thickness relative to the thickness of the vessel shell. The use of supports of high stiffness (e.g. concrete, in the form of a bed) is certainly unfavourable taking into account the strength of the vessel. The geometrical slenderness of the vessel, defined as the length to radius ratio, should be in the range $2L/r = 12–16$.

Stanley S. S. et al. [12] studied thermal evaluation of a composite tank wall design for a liquid hydrogen tank. The primary focus of the current effort was to perform one dimensional, temperature nonlinear, transient thermal analyses to determine the through-the thickness temperature profiles. These profiles were used to identify critical points within the flight envelope that could have detrimental effects on the adhesive bondlines used in the construction of the tank wall. Additionally, they present the finite element models, analysis strategies, and thermal analysis results that were determined for several vehicle flight conditions. As a result of the thermal analyses conducted, a sufficient level of confidence was demonstrated in the thermal modeling and analysis capabilities of ABAQUS to warrant future use as a thermo-structural analysis tool to evaluate cryogenic tank wall designs.

Adithya M et al.[13] analysis horizontal reactor pressure vessel according to ASME section code VIII division I and division II. It is found clearly that the design by analysis is most desirable method to evaluate and predict the behaviour of different configurations of pressure vessel supported on saddle with/without stiffener rings. . 22% weight reduction is achieved for the shell alone. This also shows that addition of stiffener rings helps to reduce the thickness of the shell which in turn helps in saving lot of material and cost associated with it.

Giordano Tomassetti et al. [14] developed FEM optimization procedure in order to both increase payload (by decreasing tank mass) and improve aerodynamic and controllability (by increasing global flexural stiffness). Below tables show the rsult of this paper.

Decrease of Lateral Displacement of the Node of Control

Before FEM optimisation (m)	*After FEM Optimisation (m)*	*Difference (%)*
1.22× $^{10-3}$	*1.18× 10^{-3}*	*3.28*

Increase in Payload (Full Size Tank)

Net mass before FEM optimisation	*Net mass after FEM optimisation*	*Increase in payload caused by the optimisation*
8954 kg	*8596 kg*	*358 kg*

III. CONCLUSION

It can be found that LoX tank support can be changed and different effect of that change can be analysised. Also with different materials it can be find out different load conditions. LoX tank's safety and storage flexibility is neccasarry. Also frame structure and analysis of combined result is necccesarry to concluded.

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