# Design and Fatigue life estimation of a pressure vessel using Finite Element Analysis

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***Abstract-****Conventional design aims at finding acceptability design which merely satisfies the functional other requirements of the problem. This paper deals with the design of pressure vessel. The Fatigue life estimation is carried out to analyse stress distribution and resultant displacement in pressure vessel. Random vibration analysis is carried out to obtain results which cannot be predicted. Finite Element Method is a mathematical technique used to carry out stress analysis. In this method a model of the vessel is made using Solidworks. Constraints and loads are applied to the model. Various properties are assigned to the model. Paper involves design of horizontal pressure vessel to sustain 200 psi and determine the wall thickness required for the vessel to limit the maximum shear stress.*

***Keywords-***Pressure vessel, Design, Fatigue,, Structural, ANSYS, FEA

## I. INTRODUCTION

A pressure vessel is a closed container designed to hold gases or liquids at a pressure different from the ambient pressure.Pressure vessels are used in a variety of applications. These include the industry and the private sector. They appear in these sectors respectively as industrial compressed air receivers and domestic hot water storage tanks, other examples of pressure vessels are: diving cylinder, recompression chamber, distillation towers, autoclaves and many other vessels in mining or oil refineries and petrochemical plants, nuclear reactor vessel, habitat of a space ship, habitat of a submarine, pneumatic reservoir, hydraulic reservoir under pressure, rail vehicle airbrake reservoir, road vehicle airbrake reservoir and storage vessels for liquefied gases such as ammonia, chlorine, propane, butane and LPG. The failure of pressure vessel may result in loss of life, health hazards and damage of property. Due to practical requirements, pressure vessels are often equipped with openings of various shapes, sizes and positions. Vessels have openings to accommodate manholes, handholds, and nozzles. Openings vary in size from small drain nozzles to full vessel size openings with body flanges. The openings cannot be avoided because of various piping or measuring gauge attachments. They allow for the mounting of equipment, the insertion of instrumentation, and the connection of piping facilitating the introduction and extraction of content but they also lead to the high stress concentration which leads to the failure of pressure vessel. Openings in pressure vessels are frequent, in fact all riveted constructions make use of such means of fabrication, and all vessels must have openings. These geometric discontinuities alter the stress distribution in the neighborhood of discontinuity so that elementary stress equations no longer prevail. Such discontinuities are called stress raisers and the regions in which they occur are called the areas of stress concentrations

## II. METHODOLOGY

For the design of pressure vessel the selection of code is important as a reference guide to achieve the safety of the vessel. The selections according to the ASME VIII div 2 are described. The selection of material is described in chapters ahead. The vessel is designed according to the standards given by the ASME. Design and analysis are carried out using Solidworks and ANSYS software.

## III. CODE SELECTION

Many engineering standards give the information on the design of the vessel. For this design, ASME VIII division 2 “Construction of Pressure vessel Codes” is selected. However, it is emphasized that any standard selected for manufacture of the air receiver must be followed and complied with in entirety and the design must not be based on provisions from different standards.

## IV. MATERIAL SELECTION

The selection of material is based on the design requirement. The materials used in the design of the vessel shall be abided with the requirements of the relevant design code. The selection of materials of the shell shall take into account the suitability of the materials with the maximum working pressure. For this kind of pressure vessel, the selection of material use is according to the table.

**TABLE I**
**Material assignment**

| | |
|---|---|
| Head | SA-234 Gr. WPB |
| Shell | SA-106 Gr. B |
| Inlet | SA-105 |
| Outlet | SA-105 |
| Drain | SA-105 |
| Saddle | SA/CSA-G40.21 Gr. 38W |
| Base plate | SA/CSA-G40.21 Gr. 38W |
| Anchor Bolt | SA/CSA-G40.21 Gr. 38W |

## V. DESIGN CONDITION FOR SHELL

TABLE IIDesign specification for shell

| Notations | SI | | MKS | |
|---|---|---|---|---|
| P= Internal pressure | 200 | psi | 14.0614 | $Kg/cm^2$ |
| D= Outside diameter | 12.7500 | in | 323.85 | mm |
| S= allowable or calculated stress | 17100 | psi | 1202.249 | $Kg/cm^2$ |
| E= Joint efficiency | 70 | | 70 | |
| Corrosion allowance | 0 | | 0 | |
| Compressive stress | 17247 | psi | 1212.5841 | $Kg/cm^2$ |
| Circumferential stress | 4489 | psi | 315.6079 | $Kg/cm^2$ |
| Longitudinal stress | 2562 | psi | 180.1264 | $Kg/cm^2$ |

**Design Thickness calculations**

Longitudinal Stress Calculations per Paragraph UG-27(c)(2)

$$t = \frac{PR}{2SE+0.4P} = 0.0501 \text{ in}$$

Circumferential Stress Calculations

$$t = \frac{PRo}{SE+0.4P} = 0.0875\text{in}$$

## VI. DESIGN CONDITION FOR ELLIPSOIDAL HEAD

TABLE IIIDesign specification for head

| Notations | SI | | MKS | |
|---|---|---|---|---|
| P= Internal pressure | 200 | psi | 14.0614 | $Kg/cm^2$ |
| D= Outside diameter | 12.7500 | in | 323.85 | mm |
| S= allowable or calculated stress | 17100 | psi | 1202.249 | $Kg/cm^2$ |
| E= Joint efficiency | 85 | | 85 | |
| Corrosion allowance | 0 | | 0 | |
| Head Stress | 4371 | psi | 307.3117 | $Kg/cm^2$ |

**Design Thickness Calculations**

$$t = \frac{PDoK}{2SE + 2P(K - 0.1)} = 0.0869 \text{ in}$$

## VII. DESIGN OFNOZZLE

TABLE IVDesign specification for Nozzle

| Specifications | Nozzle | | | |
|---|---|---|---|---|
| | Vent | Inlet | Outlet | Drain |
| $t_r$=Required Shell Thickness | 0.0742 | 0.0670 | 0.0670 | 0.0744 |
| $t_{rn}$=Nozzle Required Thickness | 0.0237 | 0.0121 | 0.0121 | 0.0043 |
| $f_{r1}$= Strength reduction factor | 1 | 1 | 1 | 1 |
| $f_{r2}$= Strength reduction factor | 1 | 1 | 1 | 1 |
| $t_a$= Nozzle thickness for pressure loading | 0.0237 | 0.0121 | 0.0121 | 0.0043 |
| $t_{b1}$= Nozzle Thickness for Internal Pressure | 0.0742 | 0.074 | 0.074 | 0.0744 |
| $t_{b3}$= Minimum Thickness | 0.2070 | 0.0189 | 0.0189 | 0.1160 |
| $t_b$= Nozzle Minimum Thickness Based on Host | 0.0742 | 0.074 | 0.074 | 0.0744 |
| $t_{UG-45}$ | 0.0742 | 0.074 | 0.074 | 0.0744 |

**Nozzle Reinforcement**

Available area = 1.6808 sq. in.
Required area = 0.2987 sq. in.
Thus, Available area > Required area
Therefore, Reinforcement is not required.

## VIII. DESIGN OF SADDLE

TABLE VSaddle Design Information

| Specification | |
|---|---|
| d= Length | 11.0418 |
| b'= Top width | 2 |
| bb'=Bottom Width | 2 |
| tso=Outside Stiffener thickness | 0.3750 |
| tsi=Inside Stiffener Thickness | 0.3750 |
| Saddle Angle of contact | 120 |
| Material Stress | 17100 |
| Yield Strength | 33600 |
| tw= Web plate thickness | 0.3750 |
| h=Vessel Centerline Height | 12 |

## IX. CAD MODELLING

The pressure vessel is modelled using a CAD software, CREO parametric 2.0 using different features ranging from solve, sweep, extrude, fillet and surface features. The model of pressure vessel is created using the calculations performed. Fig.1 shows CAD model of pressure vessel.

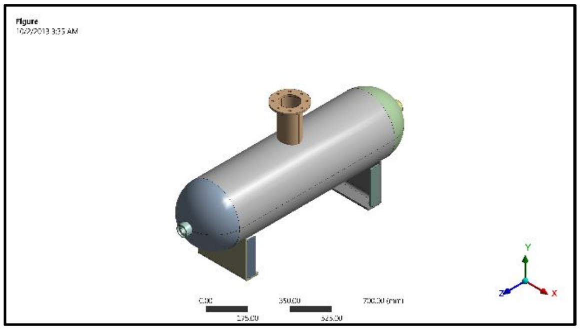

Fig 1: Pressure vessel assembly

**Meshing**

The ANSYS workbench uses a finite element method to discretize the model into finite elements. Finer the size accurate will be the answer but the software would take more time for processing and lot of memory. Therefore, optimum meshing is used. Fig.2 shows the discretized model of the pressure vessel.

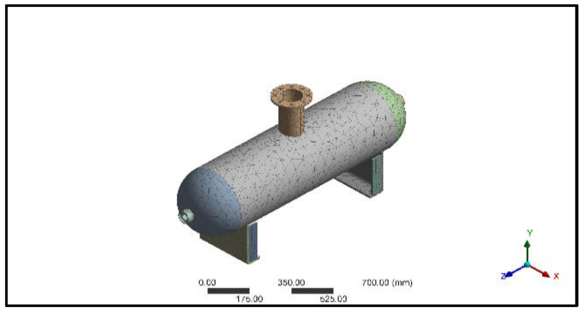

Fig 2: Discretized Model

**Analysis Setup**

The pressure in the vessel was kept 200 psi which is equivalent to 1.379 MPa as per ASME section VIII Divison 2. The pressure is applied on the internal surface of the vessel and the temperature is maintained at 300 F. The force is also applied at the inlet. Initial time step for the analysis of 1 second was 0.001 sec.

## X. RESULTS

### A. Deformation

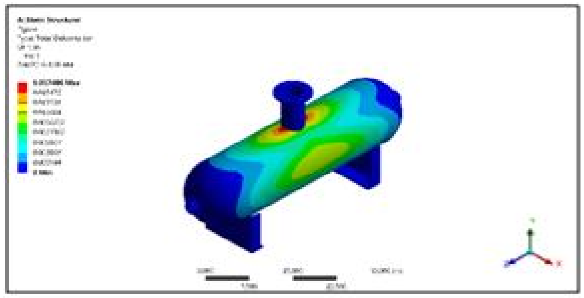

Fig 3: Deformation

The analysis bequeathed the total deformation about 0.0154inches and the location for the same was on the surface of the vessel near the nozzle. The maximum deformation is found to be 0.0174 inches. The location of the both is free from deformation

### B. Stress results

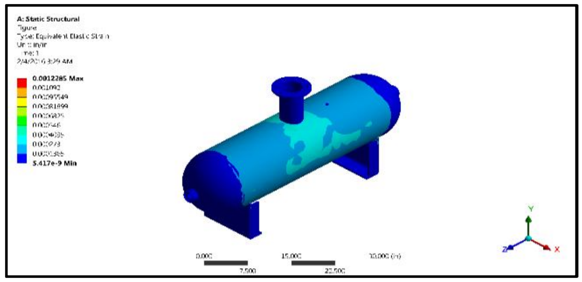

Fig 4: Equivalent Stress

The maximum equivalent stress in the vessel is found to be 2.383 Mpa which is less than yield strength for pressure vessel. The maximum stress concentration is below the surface of the vessel near the nozzle.

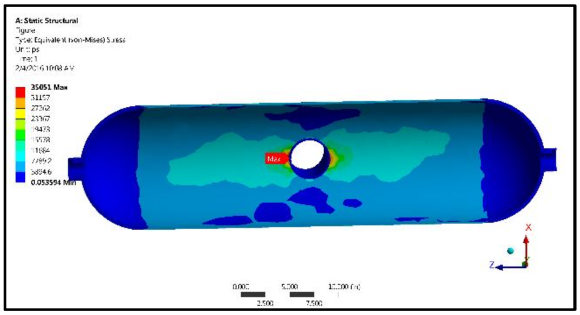

Fig 5: Maximum stress

### C. Fatigue tool

To estimate the fatigue life of the vessel, The fatigue tool is used. For the given test load conditions and material properties, the minimum life is found to be

## XI. DESIGN OF EXPERIMENT

To save the time of labour and experimenting multiple times with different variables the experiment is conducted to obtain required results, we utilized Design of experiment tool available in ANSYS. The tool is capable to perform the experiment by linking input and output parameters.

This tool is utilized to give us safe range of operation for the vessel and the designed points obtained are as follows in table VI

TABLE VIDesign Points

| Sr no | Pressure Magnitude (psi) | Total Deformation Maximum (in) | Equivalent Stress Minimum (psi) | Life Minimum |
|---|---|---|---|---|
| 1 | 200 | 0.0174 | 35051 | 13187 |
| 2 | 180 | 0.0156 | 31549 | 18911 |
| 3 | 220 | 0.0191 | 38553 | 9563.3 |
| 4 | 200 | 0.0174 | 35051 | 13188 |
| 5 | 200 | 0.0176 | 35052 | 13187 |
| 6 | 180 | 0.0156 | 31549 | 18912 |
| 7 | 220 | 0.0191 | 38552 | 9563.7 |
| 8 | 180 | 0.0156 | 31550 | 18910 |
| 9 | 220 | 0.0191 | 38553 | 9563 |

The reference chart allows you to graphically view the impact that changing each input parameters has on the displayed output parameters. Based on the above design points a 3-dimentional response surface is acquired.

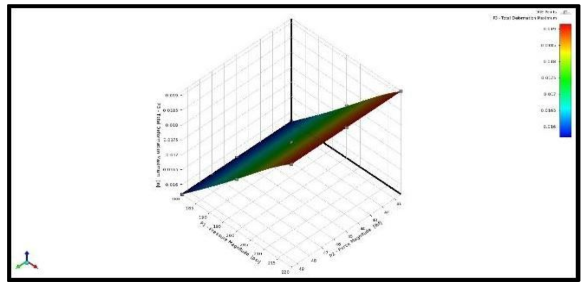

Fig 7: Response surface

## XII. CONCLUSION

- Design approach of pressure vessel are by ASME codes and Finite element analysis of pressure vessel is carried out which is easy and we get optimum parameters.
- The design of a pressure vessel is more of a selection procedure, selection of its components to be more precise rather designing each and every component.
- The life of the pressure vessel is calculated using fatigue analysis with the help of developed maximum and equivalent stress.

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