# Mechanical Design Calculation & Introduction of Fatigue Failures for 6500 Liters Pressure Vessel

**Mr. Nikhil T. Dhere[1] Mr.Sanjay A. Pawar[2]**
[1]M.Tech Student [2]Assistant Professor
[1,2]Department of Mechanical Engineering
[1,2]Fabtech College of Engineering and Research, Sangola, Maharashtra India

*Abstract*— A pressure vessel is defined as a container with pressure differential between inside and outside, except for some isolated situations. High pressure is developed in pressure vessel so pressure vessel has to withstand several forces developed due to internal pressure so selection of pressure vessel is most critical. The fluid inside pressure vessel may undergo state of change like in case of boilers. Pressure vessel has combination of high pressure together with high temperature and may with flammable radioactive material because of hazards it is important to design pressure vessel such that no leakage can take place as well as pressure vessel is to be designed carefully to cope with high pressure and temperature plant safety and integrity are of fundamental concern in pressure vessel design and these depends on adequacy of design codes. For safety purpose pressure vessel has to be designed according to ASME standards. The equations found in ASME code books rarely provide real stresses that can be used to compute permissible cycle life. Equation for items such as Heads, Flanges, Nozzle and others are design rules which safety make their use acceptable. To get stress values for cycle life calculations, it is usually required to run a Finite Element Analysis (FEA) cannot predict real stresses in any particular location of a vessel. Large factors of make their use acceptable. To get stress values for cycle life calculations, it is usually required to run a Finite Element Analysis (FEA).

***Keywords:*** Finite Element Analysis (FEA), ASME, Fatigue Failures

## I. INTRODUCTION

Pressure vessels are used in many industries (e.g., hydrocarbon processing, chemical, power, pharmaceutical, food and beverage). The mechanical design of most pressure vessels is done in accordance with the requirements contained in the ASME Boiler and Pressure Vessel Code. The recent evolution of Pressure vessel in industry shows the necessity of more efficient management and at the same time, developing new, more accurate, design approach to innovation, reducing cost increasing safety reliability of pressure vessel. So, attention has been focused on general fatigue cracking of pressure vessel structural detail. One of the main contributors to the structure failure of any product design is known as fatigue. Evaluation of fatigue effect on pressure vessel containing initial crack is rather complex. The complicity arising from crack growth in pressure vessel that depends on essential properties of material under fatigue load also depends on geometry of component as well as environmental conditions. Reliability can be analyzed with obtained result and proper modeling. Thus becomes an important point; for a fatigue crack to grow to such an extent to cause rupture, it usually takes thousands or even millions application of the stress, depending the magnitude of load, type of material used, and fatigue damage factor.

A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure. The pressure differential is dangerous and many fatal accidents have occurred in the history of their development and operation. Consequently, their design, manufacture, and operation are regulated by engineering authorities backed by legislation. The commonly used shapes of pressure vessel are spherical, cylindrical, cylindrical shells with hemispherical ends. Pressure vessels shapes made of sections of spheres, cylinders, and cones are usually employed. Cylindrical Pressure Vessel is widely used in the industries common design is a cylinder with end caps called heads. Head shapes are frequently either hemispherical or dished (Torispherical).More complicated shapes have historically been much harder to analyze for safe operation and are usually far more difficult to construct. The wide application of this vessel has made the studies and engineering design to be more important than before. The best design need to be obtained in order to ensure the safety, performance and reliability of the vessel. The large pressure difference necessitates careful designing of the vessels to avoid fatal accidents, which is why their design, manufacturing and operation are often regulated by engineering authorities. The ASME Boiler and Pressure Vessel Code (BPVC) is one such set of mandatory guidelines to design pressure vessels in accordance with the standards, to ensure prolonged useful life as well as safety. Within the ASME BPVC Section VIII, the Division 2 includes an alternative set of rules for material, design, fabrication, inspection and testing of pressure vessels having internal or external pressure exceeding 15psi. The Division 2 also has provisions to utilize finite element analysis, to determine stresses in the equipment and traditional theoretical calculation approach to estimate fatigue life of the vessel (mentioned in Part 5 “Design by Analysis Requirements”).

Fig. 1: The typical horizontal storage vessel in fabrication shop

## II. Applications of Pressure Vessel:

Pressure vessels are used in a variety of applications in both industry and the private sector. They appear in these sectors 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.

Pressure vessel closures are pressure retaining structures designed to provide quick access to pipelines, pressure vessels, pig traps, filters and filtration systems. Typically pressure vessel closures allow maintenance personnel to load a sphere or pig into a pig trap for pipeline cleaning purposes.

## III. Experimental Methodologies

1) The study is conducted to determine the geometry mechanical calculations of 6500 L Air Receiver.
2) Hence the study is conducted using the following methodology of 6500 Liter Air Receiver.
3) Geometry of pressure vessels by geometrical formulas.
4) To achieve accuracy within satisfactory level, convergence Study is conducted for 2 MPa pressure case.
5) Mechanical calculations are performed based on the results of FEA analysis as per ASME Section VIII, Division 2.

## IV. Design of Pressure Vessel as per ASME Codes

Pressure Vessel design using ASME BPVC Section VIII, the Division 1 includes an alternative set of rules for material, design, fabrication, inspection and testing of pressure vessels having internal pressure. The Division 2 also has provisions to utilize finite element analysis, to determine stresses in the equipment and traditional theoretical calculation approach to estimate fatigue life of the vessel.

### A. Design Data

| Design Code | ASME |
|---|---|
| Fluid in Service | Air |
| Internal Design Pressure (P) | 2 MPa |
| Internal Operating Pressure | 1.818 MPa |
| Internal Design Temperature | $100^0$C |
| Internal Operating Temperature | $65^0$C |
| External Design Pressure | NA |
| Inside Diameter | 1392 mm |
| Tan Length of Vessel | 4023 mm |
| Overall Length of Vessel | 4600 mm |
| Corrosion Allowance | 1 (int) |
| Position For Hydro test | Horizontal |

### B. Geometry Calcutions-

*1) Cylindrical Shell Volume-*

Cylinder Volume = Л * R*R * L
Volume = Л *696*696*4023
Volume = 6122 Liters
Where,
R= Radius of vessel,
L= Length of vessel.

*2) Torispherical Dish End Volume-*

a) Dish Volume without S/F
ID = 54.80 Inches

Volume = $\left(\frac{ID}{12}\right)3$ * 0.58

Volume = 55.23 gallons
Volume = 210 Liters
b) Volume of S/F
Dish Volume = Л * R*R * L
Volume = Л *696*696*50
Volume =76 Liters
Total Volume of one Dish End= 210+76
Total Volume of one Dish End= 286 Liters
Where,
R= Radius of vessel,
L= Length of vessel.
Total Volume Of this Vessel is 6694 Liters.
MOC Shell, Dish end, Lifting Lug, Lifting Lug Pad & Wear Plate for Saddle -SA 516 Gr. 70

### C. Pressure Vessel Dish End [LHS & RHS]

All formulas as per ASME code-
Inside Corroded Head Depth (h):-

$$h= L - \sqrt{\left(L - \frac{D_i}{2}\right) \times \left(L + \frac{D_i}{2} - 2 \times r\right)}$$

$$h= 1377 - \sqrt{\left(1377 - \frac{1388}{2}\right) \times \left(1377 + \frac{1380}{2} - 2 \times 138.60\right)}$$

h = 70.128 mm
M factor for Torispherical Heads (Corroded):-

$$M= (3+\sqrt{\frac{(L+C)/(r+C)}{4}})$$

$$M = (3+\sqrt{\frac{(1376+1.00)/(137.+1.00}{4}})$$

M = 1.5380
Required thickness due to internal pressure [tr]:-

$$tr= \frac{(P \times L \times M)}{(2 \times S \times E + P*(M-0.2)} + C$$

$$tr= \frac{(2 \times 1393 \times 1.5380)}{(2 \times 137.90 \times 1.00 + 2*(1.5380-0.2)} + 1.0$$

tr=15.3900 +1.00
tr= 16.3900 mm

### D. Pressure Vessel [SHELL]:-

Required thickness due to internal pressure [tr]:-

$$tr = \frac{(P \times R)}{(S \times E + 0.4 \times P)}$$

$$tr= \frac{(2 \times 710.00)}{(137.90 \times 1.00 + 0.4 \times 2.0)} + C$$

tr= 10.240+1.00
tr= 11.2400 mm

## V. Fundamental of Fatigue

Weakness in metal or other materials caused by repeated variation of stress.

Fatigue is a phenomenon associated with variable loading or more precisely to cyclic stressing or straining of a material. Just as we human beings get fatigue when a specific task is repeatedly performed, in a similar manner metallic components subjected to variable loading get fatigue, which leads to their premature failure under specific condition.

### *A. Fatigue Loading:-*

Fatigue loading is primarily the type of loading which causes cyclic variations in the applied stress or strain on a component. Thus any variable loading is basically a fatigue loading.

### *B. Objective & Scope Fatigue Consideration in Design:-*

Fatigue failure results mainly due to variable loading or more prissily due to cyclic variations in the applied loading or induced stress so starting from the basic concepts of (variable) non static loading, this study will be discussing in detail how it leads to fatigue failure in components, what factor influence them, how to account them & finally how to design parts components to resist failure by fatigue.

#### *1) Variable Loading:-*

It result when the applied load or the induced stress on a component is not component is not constant but changes with time i.e. load or stress varies with time in some pattern. Most mechanical system & device consists moving or rotating components. When they are subjected to external loading, the induced stresses are not constant even if the magnitude of the applied load remains invariant.

Most mechanical components experiences variable loading due to

- Changes in the magnitude of applied load.
- Changes in direction of load application.
- Change in point of load application.

#### *2) ASTM Definition of Fatigue:-*

The process of progressive localized permanent structure changes occurring in material subjected to conditions that produce fluctuating stresses at some point or points & that may calumniate in cracks or complete fracture after a sufficient number of fluctuations.

## VI. Fatigue Failure:-

Cause ⟹ Material Body ⟹ Cyclic Stress

### *A. EFFECTS:-*

- Atomic
- Dislocation movements
- Dislocation multiplication
- Defects interaction
- Cross slip
- Microscopic
- Slip formation
- Slip saturation
- Structural deterioration
- External intrusion
- Energy changes
- Crack nucleation & growth crystallography
- Microscopic
- Crack propagation
- Stable stages
- Unstable stages
- Critical length
- Final fracture

### *B. Probability of Corrosion Fatigue Failure:-*

For estimating the probability of corrosion fatigue failures, the stress level, environmental conditions, and the influence of operation mode have to be evaluated. Two of these factors of influence, the stress level and the operation mode, are typically a standard part of any analysis of root causes. Their influence on the probability of corrosion fatigue failures is most important and should not be disregarded in the root cause analysis. Corrosion fatigue, however, occurs by the combined synergistic actions of cyclic loading and an adverse environment. Note that the environment or cycle chemistry is only of a minor influence compared to the stress or strain. For this reason, it is hardly possible to numerical express the probability of corrosion fatigue as a function of improper environmental conditions.

## VII. Conclusions

1) Total Volume as per geometry of pressure vessel- 6694 Liters.
   As per client 6500 Liters volume required, hence we calculated volume is ok.
2) As per ASME Code required finished shell thickness of pressure vessel-11.24 mm.
3) As per ASME Code required finished dish thickness of pressure vessel-16.39 mm.

## Acknowledgment

It is of immense pleasure to me in expressing sincere and deep appreciation towards my guide Prof. S.A Pawar., for priceless execution of steering this contribution all the way through this work with soft suggestions, embedded supervision and invariable advocacy. Special thanks to the principal and teaching staff of FTC, COER Sangola. For needful support and encouragement throughout the course.

## References

[1] E.O.Bergman &Alhambra Calif,"The design of vertical pressure vessel vessels subjected to applied forces",Printed from ASME transaction,1955,pp(959-970)

[2] Siva Krishna Raparla and T .Seshaiah," Design & Analysis of Multilayer High Pressure Vessel ",IJERA-2012,pp(355-361)

[3] Anandhu.P D and Avis A, "Design and Analysis of Horizontal Pressure Vessel and Thickness optimization", IJIRSET-2017, pp(8171-8177)

[4] Prof. Amol Mali & Mr. HemantBhosale, "A Review Paper on Study of Pressure Vessel, Design and Analysis", IRJET – 2017, pp(1369-1374)

[5] ASME SECTION VII DIVISION 2 Edition 2015