Structural & Thermal Analysis of Pressure Vessel by using Ansys

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Abstract: A pressure vessel is a container used to contain things at higher pressure this means that if can withstand greater than normal amounts of pressure without bursting. Pressure vessels are used to contain a multitude of things, including air, water, chemicals, nitrogen, and fuel. They are used in paper and pulp, energy, food and beverage, and chemical industries. Since the pressure in the vessel is high, it has to withstand both thermal as well as structural. The aim of this project is to design a pressure vessel whose sole purpose is to withstand the pressure of the substance stored in it. Modeling has been done in Pro-E modeling software and analysis is done using ANSYS. The dimensions of the vessel have been arrived by analytical calculations as per ASME standards. Finally the design calculations and the values obtained by analysis are compared to do the final design. The above results are verified in software by using ANSYS-14.5. The pressure vessel is analyzed for the thermal loads, pressure loads and combined pressure as well as thermal loads, also analyzed for induced stresses to show that the developed stresses and temperatures are within the controlled values.

Keywords: Pressure Vessel, PRO-E, Mild Steel, Finite Element.

I. INTRODUCTION

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 fatal accidents have occurred in the history of pressure vessel development and operation. Consequently, pressure vessel design, manufacture, and operation are regulated by engineering authorities backed by legislation. For these reasons, the definition of a pressure vessel varies from country to country, but involves parameters such as maximum safe operating pressure and temperature. The main objective of this project is to design a pressure vessel which is subjected to internal fluid pressure of 100 bar. This pressure vessel is used to test the components, which are used in submarine applications. This cylinder pressure chamber of mild steel is subjected to internal fluid pressure of 100 bars, which has 200mm internal diameter, and of 200mm height. The following are determined in design process:

1. The thickness of the shell wall (t).
2. The diameter of bolt and number of bolts required for flange and pressure chamber assembly.
3. The thickness of flange for the pressure chamber and hemispherical cover plate.
4. The thickness of the gasket in between the flange and cylindrical chamber are determined in order to sustain the internal fluid pressure.

The pressure vessels are designed as per ASME Code Section VIII, Division 1. The pressure chambers, when empty are subjected to atmospheric pressure internally as well as externally. So the resultant pressure on the walls of chamber is nil. The component placed in the pressure vessel may fail in service when subjected to an excessively high internal fluid pressure. 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 cylinders, recompression chambers, distillation towers, pressure reactors, autoclaves, and many other vessels in mining operations, oil refineries and petrochemical plants, nuclear reactor vessels, submarine and space ship habitats, pneumatic reservoirs, hydraulic reservoirs under pressure, rail vehicle airbrake reservoirs, road vehicle airbrake reservoirs, and storage vessels for liquefied gases such as ammonia, chlorine, propane, butane, and LPG. Pressure vessels can theoretically be almost any shape, but shapes made of sections of spheres, cylinders, and cones are usually employed. A common design is a cylinder with end caps called heads. Head shapes are frequently either hemispherical or dished (tori spherical). More complicated shapes have historically been much harder to analyze for safe operation and are usually far more difficult to construct.
A pressure vessel is a container used to contain things at more than higher pressure; this means they can withstand greater than normal amount of pressure without bursting. Pressure vessels are used to contain a multitude of things, including air, water, chemicals, nitrogen, and fuel. They are used in paper and pulp, energy, food and beverage, and chemical industries. Pressure vessels also frequently control for temperature as well as for pressure. This is especially important when they hold more volatile substances. Gauges on the outside can be read that will show what the internal pressure and temperature is. If the substance inside is potentially dangerous, alarms, pressure releases, and other safety-measures should be built-in to the pressure vessel. The fluids being stored may undergo a change of state inside the pressure vessel as in case of steam boilers or it may combine with other reagents as in a chemical plant. The pressure vessels are designed with great care because rupture of a pressure vessel means an expression which may cause loss of life and property.

III. CLASSIFICATIONS OF PRESSURE VESSELS

We will divide the pressure vessel into five parts:

A. According to the Dimensions

1. Thin shell: If the thickness of shell is less than 1/20 of the diameter of the shell, then the shell is said to be thin shell. Thin pressure vessels can withstand only internal fluid pressure, but they cannot withstand external fluid pressure.
2. Thick shell: If the thickness of the shell is greater than 1/20 of the diameter of the shell, then the shell is said to be thick shell. Thick pressure vessels can withstand both internal as well as external fluid pressure.

B. According to the internal fluid pressure

1. Thin shell: If the internal fluid pressure (p) is less than 1/6 of allowable stress (σt), then the shell is said to be thin shell.
2. Thick shell: If the internal fluid pressure (p) is greater than 1/6 of the allowable stress (σt), then the shell is said to be thick shell.

C. According to end Construction

1. Open ended: It is obtained when none of the pressure force on the end closures is transferred to the cylinder walls. It is similar to a cylinder which is closed by pistons. Ignoring frictional forces between the pistons and cylinder, the axial forces on the pistons are balanced by external forces in piston rods, and in the cylinder walls.
2. Closed ended: A cylinder provided with end caps is called as closed end pressure vessel. When the entire pressure load on each end of the cylinder is transmitted to the walls, this load must be balanced by the axial stress in the wall, which is uniform in the central region of the cylinder away from its ends.

D. According to the Internal Pressure

1. Low-pressure pressure vessel: If the internal fluid pressure is less than 1 Mpa, then the pressure vessel is said to be low-pressure pressure vessel.
2. Medium-pressure pressure vessel if the internal fluid pressure lies in between 1 Mpa and 20 Mpa, then the pressure vessel is said to be medium-pressure pressure vessel.
3. High-pressure pressure vessel

If the internal fluid pressure is greater than 20 Mpa, then the pressure vessel is said to be high-pressure pressure vessel.

IV. FINITE ELEMENT METHOD

The finite element is a mathematical method for solving ordinary and partial differentials equations. Because it is a numerical method, it has the ability to solve complex problems that can be represented in differential equation form. As these types of equations occur naturally in virtually all fields of the physical sciences, the applications of the finite element method are limitless as regards the solution of practical design problems. Due to high cost of computing power of years gone by, FEA has history of being used to solve complex and cost critical problems. Classical methods alone usually cannot provide adequate information to determine the safe working limits of a major civil engineering construction or an automobile or an aircraft. If a tall building, a large suspension bridge or an automobile or a nuclear reactor failed catastrophically, the economic and social cost would be unacceptably high.

In recent years, FEA has been used almost universally to solve structural engineering problems. One discipline that has relied heavily on this technology is the automotive and aerospace industry. Due to the need to meet the extreme demands for faster, stronger, efficient and light weight automobiles and aircrafts, manufacturers have to rely on the technique to stay competitive. But more importantly, due to safety, high manufacturing costs of components and the high media coverage that the industry is exposed to, automotive and aircraft companies need to ensure that none of their components fail, that is to cease providing the services that the design intended. FEA has been used routinely in high volume production and manufacturing industries for many years, as to get a product design wrong would be detrimental. For example, if a large manufacturer had to recall one model alone due to a piston design fault, they would end up having to replace up to 10 million pistons. Similarly, if an oil platform had to shut down due to one of the major components failing (platform frames, turrets, etc), the cost of lost revenue is far greater than the cost of fixing or replacing the components, not to mention...
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The huge environmental and safety costs that such an incident could incur.

The finite element is a very important tool for those involved in engineering design; it is now used routinely to solve problems in the following areas:

- Structural strength design
- Structural interaction with fluids flows
- Analysis of shock (underwater and in materials)
- Acoustics
- Thermal analysis
- Vibrations
- Crash simulations
- Fluid flows
- Electrical analysis
- Mass diffusion
- Buckling problems
- Dynamic analysis
- Electromagnetic evaluations
- Metal forming
- Coupled analysis

Nowadays, even the most simple of products rely on the finite element for design evaluation. This is because contemporary design problems usually cannot be solved as accurately and cheaply using any other method that is currently available. Physical testing was the norm in years gone by, but now it is simply too expensive and time consuming.

V. THE PRACTICAL ILLUSTRATIONS

Figure 1. Solid Model of Pressure Vessel.

Internal pressure load is 100*105 Pa.

Figure 2. Internal pressure load and Boundary conditions.

Displacement plot: UX plot
Change in diameter from analysis is absolute of maximum or minimum values from ANSYS because pressure vessel axis is the center line i.e absolute of (-0.133x10^-3) =0.133mm and this value is well matched with the analytical results.

Figure 3. Displacement plot for x-direction (Ux).

Figure 4. Graphs showing material allowable limit and Analysis result.

International Journal of Scientific Engineering and Technology Research
Volume. 02, Issue No. 08, August-2013, Pages: 740-744
VI. RESULTS AND DISCUSSION

1. The thickness of the cylindrical shell wall, obtained by analytical calculation is 5mm.
2. The thickness of the flange by analytical calculations is found to be 6.25mm.
3. The displacement obtained is 0.2133 mm which is acceptable and well comparable with analytical Results.
4. The thickness of the hemispherical cover plate, which is at the top of the pressure vessel, is obtained as 2.5mm.
5. The diameter of the bolt of C40 material is calculated by analytical method and obtained as 12mm by assuming the number of bolts to be 12 and considering the ‘SILICONE’ gasket material in between the flanges.
6. Thus the stress induced in the bolt material is 673.04Mpa. Therefore the stress produced in the bolt is less than the maximum stress i.e., 680MPa. Hence the design of bolt is safe.
7. At the outer surface of the thick cylindrical pressure vessel hoop stress is minimum (non-zero) and radial stress is minimum (zero).
8. At the outer surface of the thick cylindrical pressure vessel hoop stress is maximum and radial stress is maximum (equal to internal fluid pressure).
9. The variation of hoop and radial stresses across the cross-section is Hyperbolic.
10. Hoop stress is maximum principal stress and radial stress is minimum principal stress in case of thick cylinders.

VII. CONCLUSION

The pressure vessel is designed based on the thin cylindrical approach because diameter to thickness ratio is >20. The thin cylinder can withstand internal fluid pressure and thermal loads. The Von Misses stress produced by using FINITE ELEMENT METHOD in the pressure test chamber is...
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220 Mpa, which is less than the allowable stress (400Mpa) for the material of the pressure vessel. So the design is safe for pressure loads. The design is also checked with thermal loads. The vonmises stress is 74.8Mpa which is also less than the allowable stress, so the design is safe with thermal loads. The design is also analyzed with both thermal and structural loads. Vonmises stress for this case is 266MPa which is slightly above the allowable stress (200 MPa) but the design still safe because the yield stress of this material is 400MPa. The factor of safety of the pressure vessel is 1.5 for combined effect of thermal and pressure loads. If the factor of safety is 2 strictly required, we will need to increase the thickness by based on number of design iterations.

VIII. REFERENCES


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