Chapter 22

Pressure Vessels and Vacuum Chambers: Common Concepts for Understanding

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Pressure vessels and vacuum chambers are commonly used in various applications of pulsed power. The difference between these two in the structural design point of view is that vacuum chamber is a class of pressure vessel subjected to external pressure. It is common practice to call internal and external pressure vessels with common name as pressure vessels. Some concepts regarding the pressure vessels are essential for the design, fabrication and operation of the processes involved with external or internal pressure. In this article, we introduce various concepts commonly required for working with these pressure vessels.

22.1. Introduction

A simple definition of internal pressure vessel is a vessel or chamber having an internal pressure above the atmospheric pressure. Similarly external pressure vessel or vacuum chamber is a vessel, in which the pressure is below the atmosphere. There are applications of external pressure vessels other than vacuum, where the vessel is having atmospheric pressure inside and external pressure outside. There are also applications that a vessel can have vacuum as well as additional external pressure. Some concepts of design and operation are essential for effective design and safe working with the pressure vessels. The concepts introduced here are related to shape of the pressure vessel, how pressure is defined in a pressure vessel, failure mode of the pressure vessel, commonly used formulae in pressure vessel design, precautions for use of non metals in pressure vessel components, special considerations in vacuum vessel design and safe practices.

22.2. About A Pressure Chamber

The pressure chamber is essentially a vessel where the shape of the vessel suits the application or process used in the chamber. The most common shapes of the pressure vessel are cylindrical and spherical. There can be other shapes such as elliptical, rectangular etc. to best suit the application.

The different parts of the pressure chamber are shell, ports and flanges. Ports are the openings in the chamber. The end flanges are known as heads. Both vacuum chamber and internal pressure vessel contain similar kind of shells and heads. The design concepts of vacuum vessel include the lowering outgassing loads and trapped volumes.

Table 22.1. Different geometries for pressure vessel

Sr. No.	Description	comparison
1	Spherical shell	Lower stresses and comparatively lower thickness
2	Cylindrical shell	Reasonably low stresses Standard forms can be used Can be rolled easily
3	Rectangular shell	Subjected to more stresses Used when process/equipment provides advantage such as less space, easy assembly etc.
4	Flat Head	Simplest form suitable for lower diameters Higher stresses and hence higher thickness of flange Becomes heavier as the diameter of the vessel or opening increases

5	Formed heads such as hemi spherical, torispherical, ellipsoidal etc	- Lower thickness and can be adapted for higher diameters of the pressure vessels

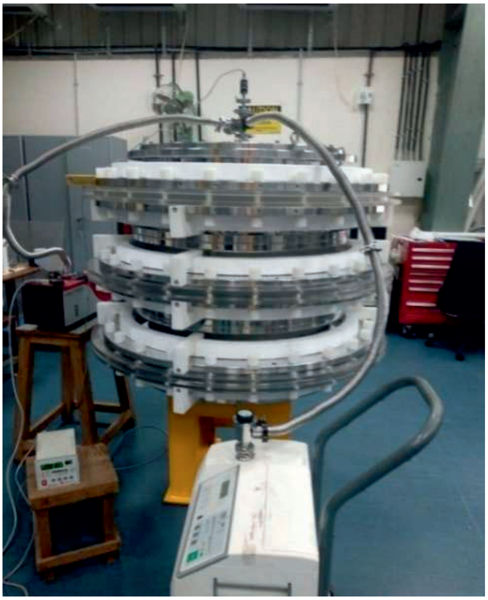

Figure 22.1. Vacuum system for LTD-2.

Figure 22.1 shows vacuum system for LTD-2. It is an example of a vacuum system with external pressure. In this system there is vacuum inside the chamber and there is a pressure of 5 bar outside the chamber. So for structural design, this is equivalent to 6 bar external pressure.

22.3. Different Stages in Making a Pressure Vessel

There are different stages in making a pressure vessel. They are

a. Design of a pressure vessel

b. Material selection

c. Inspection of the material

d. Fabrication of the pressure vessel

e. Testing of a pressure vessel

These stages sometimes are interlinked. As an example design and fabrication depends upon the material selection. Various tests depend on the fabrication etc. One of the important motives behind all the stages of making pressure vessels is to avoid the failure of pressure vessel. Pressure vessels can fail in different ways,

- Failure such as buckling of an external pressure vessel
- Explosion of parts of internal pressure vessel
- Fast cracking of internal pressure vessel
- Failure that depends on time such as Hydrogen embrittlement and stress corrosion cracking
- Fatigue failure depending upon number of cycles or variable loads
- Creep failure which again depends on the time.

22.4. Defining Pressure in a Vessel

There is a process of evaluating pressures for designing a pressure vessel for a laboratory. It starts from noting the working pressure. Any process takes place at a particular pressure and the equipment or the system is operated at that pressure. This pressure is known as working pressure. Sometimes the process may take place at different pressures or for research purpose the pressure may need to vary. In such cases the highest of these values will be the working pressure. It is very important to understand that the design starts from the working pressure and during the entire life of the equipment one should not go to the pressures above working pressure without careful analysis of the actual vessel. The vessel will be designed to a pressure higher than the working pressure, to take care of accidental surge of pressure before the pressure relief valves operate. This is known as design pressure.

But standard terminology uses another term MAWP also, which is maximum allowable working pressure, which is calculated after the vessel is fabricated. There are two test pressures. They are hydrostatic test pressure and pneumatic test pressures, which are used to test a pressure vessel. It is always recommended to go for hydrostatic pressure test and the pneumatic test is used only when hydrostatic test is not allowed due to system constraints. Test pressures will be higher than the design pressure and one should not use the pressure vessel without testing. All these pressures are defined at a particular temperature. If the temperature is increased, the system has to work in less pressure.

22.5. Stress and Calculations

Commonly used pressure vessels are thin cylindrical or spherical shells. The forms of stresses in these pressure vessels are hoop stress and longitudinal stress. In a thick shell another stress, known as radial stress also exists. These stresses are primary stresses.

In thin cylindrical shells, the hoop stress depends on pressure (P), internal diameter (d), and the thickness (t) and given by the formulae

$$\sigma = \frac{Pd}{2t} \tag{22.1}$$

Where, σ = Hoop stress in MPa

P = Pressure in MPa

d = Internal diameter

t = Thickness of the shell

Though this formula cannot be precisely used for the design of pressure vessels, this equation gives an idea about stress in the vessel. For safe working of pressure vessel, the hoop stress should be less than allowable tensile stress.

In practice, for design of pressure vessels formulae from ASME Boiler and Pressure Vessel Code can be used. Some of the most commonly used formulae from ASME Boiler and Pressure Vessel Code, Section VIII, Division I are given here

For calculating the thickness of internally pressurised vessel,

$$t = \frac{PR}{SE - 0.6P} \tag{22.2}$$

Where, P and t are same as above

R = Radius of the shell in mm

S = Maximum allowable stress in Mpa

E = Joint efficiency

For external pressure vessel,

$$P_a = \frac{4B}{3(D_0/t)} \tag{22.3}$$

Where, Pa = Maximum allowable external working pressure

B = Factor decided by material and another factor A, which depends on length of vessel, outside diameter of the vessel and thickness of the vessel

t = Thickness in mm

However in both the cases, stiffeners can be used to reduce the thickness or to reduce the stress.

There are openings in the shell, known as ports. Sometimes reinforcement is required for the opening, since the opening reduces the strength of the shell. When reinforcement is provided, Code specifies available areas at different locations of the opening. In such case the removed area of the opening has to be replaced by available area of reinforcement.

The blank flange thickness is given by

$$t = d\sqrt{CP/SE} \tag{22.4}$$

Where d, P, S, E are same as above

t = Thickness of flange

C= A factor depends on method of attachment of head, shell dimensions etc. Usually this factor is between 0.1-0.3.

Thickness of a Welded flange for loose type flange without hub is given by,

$$S_T = YM_0/Bt^2 \tag{22.5}$$

Where, S_T = Tangential stress in the flange

Y = A factor depends on another factor K, which is the ratio of outside diameter to inside diameter

M_0 = Tangential moment acting on the flange

B = Inside diameter of the flange

t = Thickness of the flange

Few formulae are introduced above. But various conditions and designs of pressure vessels are explained in detail in ASME Boiler and Pressure Vessel Code

22.6. Considerations in Vacuum Vessel Design

a. Vacuum vessel is treated as externally pressurised vessel.

b. Long external pressure vessels fail by buckling and dimensional parameters that define failure are length of the chamber, diameter of the chamber and thickness.

c. As the length increases the vessel fail at lower pressures. But the effective length for calculation of buckling can be reduced by using stiffeners.

d. The calculation for the thickness of externally pressurised vessel and internally pressurised vessel are based on different formulae. So if a vacuum system needs to be used for internal pressure, then the maximum allowable working pressure has to be calculated before pressurizing.

e. Small sized laboratory scale vacuum systems can be directly qualified with leak testing by using a leak detector and ultrasonic and radiography may not be done.

f. The compatible sealing is always preferred. As an example, knife edge flanges with metal gaskets for ultra high vacuum (UHV) systems.

g. In the UHV, bellow sealed feedthrough motions give better performance and reliability as compared to o-ring sealed motions.

h. Reducing the outgassing is one of the important parameter for design and fabrication in the vacuum system.

i. The surface finish plays important role in the vacuum and rough surfaces should be avoided.

j. The design of vacuum system should focus on minimizing the trapped volume.

k. Cleanliness of vacuum side surfaces is very important factor in the vacuum system.

22.7. Safe Handling of Pressure Vessels

Some of the important points for design and handling of pressure vessels are:

a. Always test the internal pressure vessel as per the code procedure before the actual application.

b. For testing of the pressure vessel, prefer hydrostatic test wherever possible.

c. Know the design pressure of a pressure vessel before start using.

d. Mark the maximum operating pressure on the pressure vessel.

e. It is to be noted at higher temperature than designed, the vessel has to be operated at lower pressure as calculated.

f. Use the materials for construction of pressure vessels as recommended by standards such as code.

g. When non-metallic flanges or shells are required to be used, then reduce the bore diameter as minimum as possible

h. It is to be noted that non-metals require higher factor of safety as recommended for use as pressure vessel components.

i. It is to be noted that stress concentration factor has to be included in the design for use of non-metals as pressure vessel components.

j. A properly designed non metal pressure vessel component cannot be altered, without proper calculations. Even a single additional hole in a non metal pressure component can cause stress concentration and failure of component. Even method of fabrication may need to be controlled.

k. Wherever possible, it is preferable to go for destructive pressure testing of non metallic pressure vessel component under controlled conditions.

l. Use protection covers or meshes for non metallic flanges.

m. Use at least two pressure relief valves (PRV) in the pressurised system. The required minimum out flow rate of PRV needs to be maintained.

n. Use fine controlled gas flow to fill the pressure vessel.

o. Always observe the reading of pressure gauge while filling the pressure vessel.

References

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