International Journal of Engineering and Technical Research (IJETR)
ISSN: 2321-0869, Volume-3, Issue-4, April 2015

Deterministic and probabilistic design of pressure vessel

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Abstract— **Abstract— Pressure vessel is a closed container used to hold gases and liquids. Pressure vessels are used in a variety of applications in both industry and the private sector. Analytically, pressure vessels are designed using ASME codes known as deterministic approach. In some situations, accounting for this variability within analysis can be critical, or at least more cost-effective, than over-designing products with expensive materials or manufacturing processes. Recently, reliability and structural safety have been given highest priority in plant products as there is direct threat to human life. Hence, it is required to design critical components such as pressure vessels for wide range of input variations in geometry, material, loads and other operating parameters without oversizing these critical components. In spite of number of investigations devoted to pressure vessel research and analysis, there still remains to be developed a general approach capable of predicting the effects of variations in geometry, material and loading conditions on the behaviour of pressure vessels. Deterministic design approaches do not take into account uncertainties. Hence, this work proposes use of probabilistic design approach.**

Index Terms— **deterministic design, pressure vessel;, Probabilistic design.**

I. INTRODUCTION

Large pressure vessels were invented during the industrial revolution, particularly in Great Britain, to be used as boilers for making steam to drive steam engines. Design and testing standards came about after some large explosions caused loss of life and led to a system of certification. 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 up by laws. 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 [1]. 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 legal definition of pressure vessel varies from country to country, but often involves the maximum safe pressure that the vessel is designed for and the pressure volume product, particularly of the gaseous part. In the United States, the rules for pressure vessels are contained in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

Classification of Pressure vessels

Typically pressure vessels can be classified as mentioned below [2]:

1. Basis on wall thickness

- **Thin walled pressure vessels**

A thinned walled pressure vessel is any cylinder [shell] ratio that is 10% or less than the ratio of the thickness to the diameter.

Another way of saying this is a pressure vessel is thinned walled if the diameter is 10-times or more the thickness. Storage tanks are a type of thin walled pressure vessels.

- **Thick Walled pressure vessels**

A thick walled pressure vessel is any cylinder [shell] ratio that is 10% or more the ratio of the thickness to the inside diameter.

2. Basis on Heads [3]

Various heads can be used for pressure vessels based on requirement. Figure 1.2 shows typical heads used for pressure vessels.

- **Hemispherical head**

A sphere is the ideal shape for a head, because the pressure in the vessel is divided equally across the surface of the head. The radius of the head equals the radius of the cylindrical part of the vessel. Figure 1.1 shows the ellipsoidal head.

Figure1.1 Hemi-Spherical Head

- **Ellipsoidal Head**

This is also called a 2:1 elliptical head. The shape of this head is more economical, because the height of the head is just a quarter of the diameter. Its radius varies between the major and minor axis. Figure 1.2 shows the ellipsoidal head.

Manuscript received April 17, 2015.

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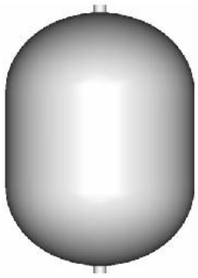


Figure1.2 Ellipsoidal Head

- **TorisphericalHead**

These heads have a dish with a fixed radius, the size of which depends on the type of torispherical head. Typical torispherical head is shown in Figure 1.3. The transition between the cylinder and the dish is called the knuckle. The knuckle has a toroidal shape.

Figure1.3 Torispherical Head

- **Flat Head**

This is a head consisting of a toroidal knuckle connecting to a flat plate as shown in Figure 1.4 This type of head is typically used for the bottom of cookware.

Figure1.5 Flat Head

- **Diffuser Head**

Figure 1.5 shows the typical diffuser head. This type of head is typically used for the bottom of chemical bottles.

Fig 1.5Diffuser Head

The pressure vessel is one of a large number of plant components for which stress analyses must be performed. A pressure vessel experiences stresses such as primary and secondary stresses because of various kinds of loads. Primary stresses are because of pressure inside pressure vessel and secondary stresses are because of thermal loading. Analytically, pressure vessels are designed using ASME codes [4] which are deterministic approach. These conventional (or deterministic) analysis techniques involve the use of safety factors as a way of accounting for variation in analysis input parameters. This often results in overly conservative designs. However, the validity or conservatism in the results from such analyses depends on the real-life variability or uncertainty of the input values. In some situations, accounting for this variability within analysis can be critical, or at least more cost-effective, than over-designing products with expensive materials or manufacturing processes [5]. Recently, reliability and structural safety have been given highest priority in plant products as there is direct threat to human life. Hence, it is required to design critical components such as pressure vessels for wide range of input variations in geometry, material, loads and other operating parameters without oversizing these critical components [6]. Design based on this approach gives information in advance about impact of input variations and risk associated.

The need to incorporate uncertainties in an engineering design has long been recognized. Because of the stochastic nature of many of the uncertainties, probabilistic approach as opposed to a deterministic approach is better suited. Thus, the probability of structural failure can be limited to a reasonable level maintained by a risk informed program. Today, risk informed technologies and probabilistic design are widely adopted in civil structural design, aircraft, and aerospace design. In this work, the probabilistic design of pressure vessel will be carried out to know the effect of uncertainties. Probabilistic designing is performed by using FEM package (ANSYS).

. Probabilistic design is an analysis technique for assessing the effect of uncertainties in input parameters and assumptions in the design. A probabilistic analysis allows determining the extent to which uncertainties in the model affect the results. The objective of the work presented here is design of pressure vessel considering uncertainties in input parameters within framework of FEA tool ANSYS. In view of this, following objectives are set for present study:

- To design pressure vessel using ASME codes and validate design using ANSYS for selected application. This is traditional deterministic approach for design.
- Design pressure vessel by using probabilistic design approach using ANSYS to study effect of input variations (geometric, material, loading and operating) on stress.
- To study sensitivity and probability of input variation on stresses of pressure vessel.

II. DETERMINISTIC DESIGN

- In deterministic design for one set of input one gets one design. Deterministic design of pressure vessel uses ASME codes (see Fig. 1). Deterministic design of pressure vessel can use either design by rule or design by analysis using analytical methods.

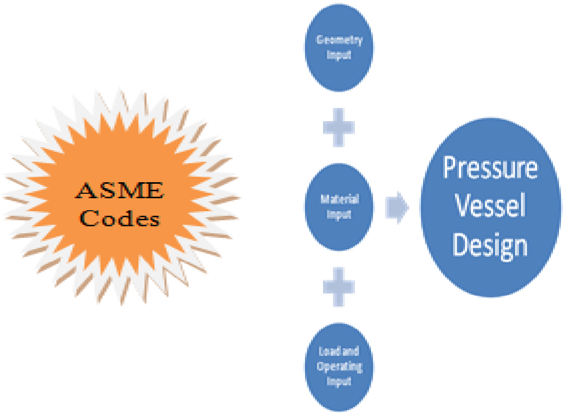


Figure 2.1 Deterministic design of pressure vessels using ASME codes

Deterministic Design using Analytical Models

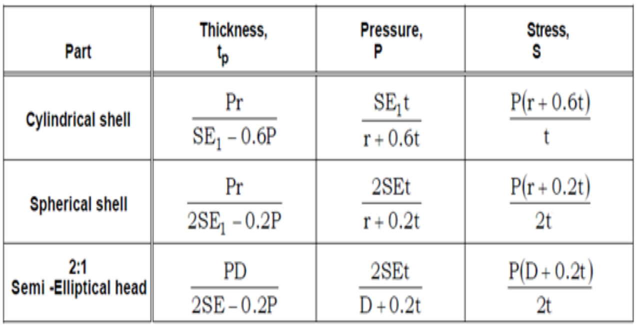
Traditionally, pressure vessel is subjected to following stresses:

- Hoop (circumferential) Stress

- Axial (longitudinal) Stress
- Thermal stresses, if thermal loading is present.

The fundamental difference between mechanical stresses and thermal stresses lies in the nature of the loading.

Table 1: Shows the different ASME codes used to design a pressure vessel



Part	Thickness, t_p	Pressure, P	Stress, S
Cylindrical shell	$\frac{Pr}{SE_1-0.6P}$	$\frac{SE_1t}{r+0.6t}$	$\frac{P(r+0.6t)}{t}$
Spherical shell	$\frac{Pr}{2SE_1-0.2P}$	$\frac{2SEt}{r+0.2t}$	$\frac{P(r+0.2t)}{2t}$
2:1 Semi -Elliptical head	$\frac{PD}{2SE-0.2P}$	$\frac{2SEt}{D+0.2t}$	$\frac{P(D+0.2t)}{2t}$

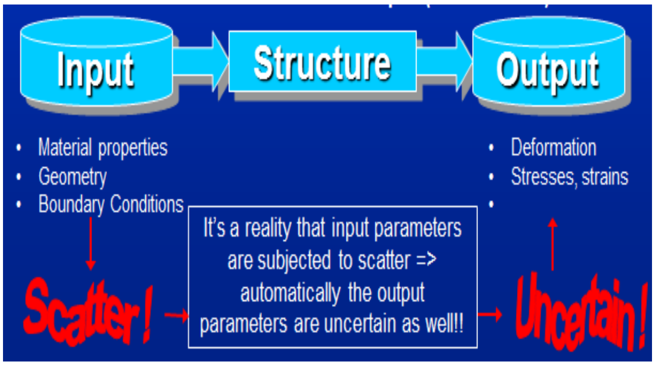
Where:

P = Internal design pressure
r = Internal radius
S = Allowable Stress
E_1, E = Weld joint efficiency
t_p= Required wall thickness
t = Actual wall thickness
D = Inside diameter

III. PROBABILISTIC DESIGN

Although it is possible to account for one distributed variable in a deterministic analysis, by using some basic statistics, it is when a number of input variables have a well understood distribution that probabilistic analysis can be most useful. Multiple distributed inputs can interact in unpredictable ways, in some cases to give higher than expected probabilities of bad things happening, like structural failure. Only probabilistic analysis can represent this situation (see Fig. 2).Typical questions answered with probabilistic design:

- How large is the scatter of the output parameters?
- What is the probability that output parameters do not fulfill design criteria (failure probability)?
- How much does the scatter of the input parameters contribute to the scatter of the output (sensitivities)?



It's a reality that input parameters are subjected to scatter => automatically the output parameters are uncertain as well!!

Figure 2.2 Effect of input variations on structure response.

The normal (Gaussian) distribution is the most widely known distribution. Equation 2.1 shows the probability density function (PDF) where‘t’ defines the range, mean and standard deviation are given by μ and σ. Figure 2.7 shows the normal with the effect of different standard deviations. As σ decreases, the PDF gets squeezed toward the mean. From the central limit theorem we know that the sum of a large number of identical independent random variables is approximately normal. Normal distribution is one of the least conservative distributions that can be used because t is a much smaller likelihood of obtaining extreme values from the distribution, which in turn translates to lower probability of failure.

$$f(t;\mu,\sigma)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{1}{2}\left(\frac{t-\mu}{\sigma}\right)^{2}}$$

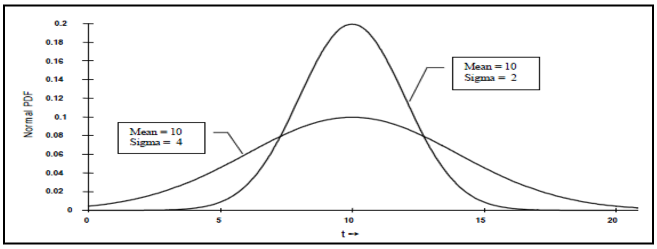


Fig 2.3 Normal (Gaussian) distribution curve

As seen in earlier sections, FEA is widely used in design of pressur vessels for variety of purposes. Use of FEA is limited to deterministic design.

The ANSYS commands can be used to perform the entire probabilistic design analysis by creating input file and submitting it as a batch job.

IV. CONCLUSIONS

From literature it appears that traditionally design of pressure vessel is carried out using ASME codes i.e. deterministic approach. From literature review it appears that there is no or little information available on probabilistic design of pressure vessels. Hence, in present study, it is proposed to carry out design of pressure vessels using following approaches:

- Deterministic Design: Selection of application and designing a pressure vessel using ASME codes and comparing analytical results with corresponding FE results.

Probabilistic Design: This involves parametric modeling of pressure vessel and studying various input variations such as geometric, material and loading. Next stage involves performing probabilistic design using ANSYS to study effect on input variations on stress. Probabilistic design also gives on information on sensitivity of input variations on stress.

REFERENCES

[1] http://en.wikipedia.org/wiki/Pressure_vessel
[2] David Roylance, “Pressure vessel”, Department of Material Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, August 23, 2001.
[3] http://www.weisstaler.de
[4] ASME Boiler and Pressure Vessel Code (1992 edition) Code Case N-47-29
[5] http://www.nafems.org/downloads/benchmark/july05/knowledge_base-008.pdf
[6] P. Bhattacharjee Structural Reliability Assessment of PressureVessel. Journal of Aerospace Quality and Reliability. Vol.5 pp 159-163 Jan 2009.
[7] Dennis Moss, “Pressure vessel” published by Gulf Professional Publishing, 3rd Edition
[8] VB Bhandari, “Design of Machine Elements”, TATA McGraw Hill, New Delhi
[9] Donatello, Annaratone, "Pressure vessel design", ISBN-10 3-540-49142-2 springer berlin heidelberg new york, springer-verlag berlin heidelberg, (2007)
[10] http://www.hansontank.com/