Design and Analysis of Puncture Disc Pressure Vessel

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Abstract

This paper investigates using finite-element analysis (FEA) to determine the stress distribution and failure location for given pressure vessel. Comparing the FEA results with analytical results shows that the FEA software predicted the failure location very well for the symmetric shaped pressure vessel. By changing the design and keeping the same material of the given pressure vessel we could reduce the induced stress in the pressure vessel or we can increase the working pressure. The results are compared on the basis of Maximum distortion energy theory also known as von Mises-Hencky theory i.e. von Mises yield criterion. And the deviation between the analytical results from the software result around the critical location has been checked for the stress discontinuity. Since it is the axis-symmetric pressure vessel, it is allowed to be modeled as a 2D axisymmetric model and analysis is done.

Keywords: *We would like to encourage you to list your keywords in this section*

1. Introduction

1.1. Pressure Vessel

Pressure vessel is a closed container designed to hold gas or liquid at high pressure substantially different from the ambient pressure. They may be of any shape and range from beverage bottles to the sophisticated ones encountering in engineering construction, Fig 1.1, 1.2.

Many commonly used pressure vessels have well defined analytical equations that are used to determine their burst pressure and safety factors. Because these standard-shaped vessels have been studied for many years, their failure locations are also well documented. There are, however, instances where space constraints prevent the use of analytical equations to determine the safety factor and burst pressure for a pressure vessel. In these cases a numerical analysis must be performed to determine the failure pressure and failure location. This paper uses finite-element analysis (FEA) to determine the location and stress distribution for the given pressure vessel.

Fig 1.Reactor pressure vessel at ELK River site 1960

1.2. Types of Pressure Vessels

Two Basic Types of Pressure Vessels Based on Wall Thickness,

Thinned wall -These pressure vessels are the most categorized. A thinnedwalled pressure vessel is any cylinder [shell] ratio that is 10% or less 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.

Thick walled -These pressure vessels are the least common. A thickwalled pressure vessel is any cylinder [shell] ratio that is 10% or more the ratio of the thickness to the inside diameter. Storage tanks are a category of thin walled pressure vessels except that are typically under 15-psi and are super thin when compared to the ratio above. Transportable Containers -These are the most common pressure vessel and potentially the most ignored. These are massproduced and require testing every 10-years for propane and gas.

Cylindrical pressure vessels are most commonly used pressure vessels and sometimes spherical vessels are used. Spherical vessels are ideal one when compared to other shapes because for the given surface area spherical posses more volume for fluid and withstand more pressure, so it finally yields as a perfect material saver. But the problem is the difficulty in fabricating the spherical shapes and adds cost issues.

1.3. Heads

A head is one of the end caps on a cylindrically shaped pressure vessel.

The shape of the heads used can vary. The most common head shapes are:

Hemispherical head -A sphere is the ideal shape for a head, because thepressure in the vessel is divided equally across the surface of the head. The radius (r) of the head equals the radius of the cylindrical part of the vessel.
Ellipsoidal head -This is also called a 2:1 elliptical head. The shape ofthis 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.
Tori-spherical head -These heads have a dish with a fixed radius (r1),the size of which depends on the type of tori-spherical head. The transition between the cylinder and the dish is called the knuckle. The knuckle has a toroidal shape.
Flat head -This is a head consisting of a toroidal knuckle connecting to aflat plate. This type of head is typically used for the bottom of cookware.

Diffuser head -This type of head is often found on the bottom of aerosolspray cans. It is an inverted tori-spherical head.

1.4. Stresses on Pressure Vessel

The stresses on vessels, produce changes in their dimensions known as strains. The determination of relationship between external forces applied on it and the stresses and strains within the vessel form the basis of this field of stress analysis. The basic interaction of stresses and strains is well illustrated by conventional tensile test specimen, from which we can pursue the stress analysis in the materials and study its nature based on the stress-strain curve .

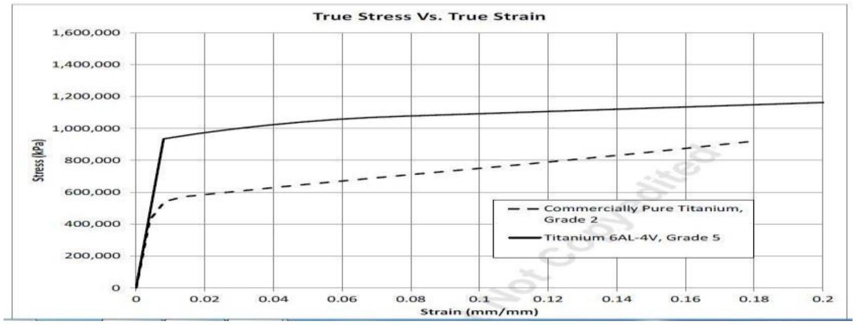

Fig 2. Stress strain curve

1.5. Cylindrical Vessel under Internal Pressure

When we take an plane element from the surface of the cylindrical vessel, it is subjected to biaxial stress namely hoop stress and longitudinal stress as shown in Fig 2.2

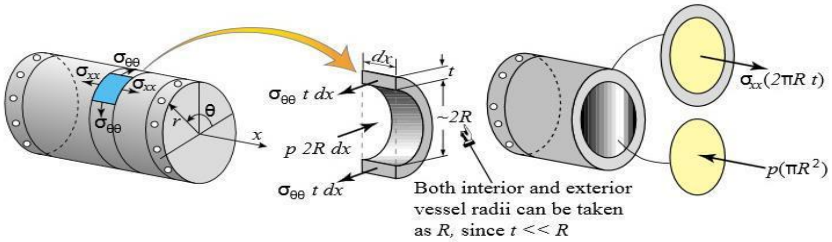

Fig 3. Hoop and longitudinal stresses

1.6. Spherical Vessel under Internal Pressure

When we take an plane element from the surface of the Spherical Vessel , it is subjected to biaxial stress namely hoop stress and longitudinal stress where both stresses are equal and constant over the entire vessel as shown in Fig 2.3

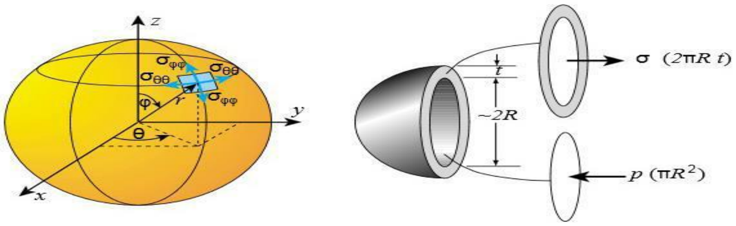

Fig 4. Stresses in spherical vessel

1.7. Ellipsoidal Vessel under Internal Pressure

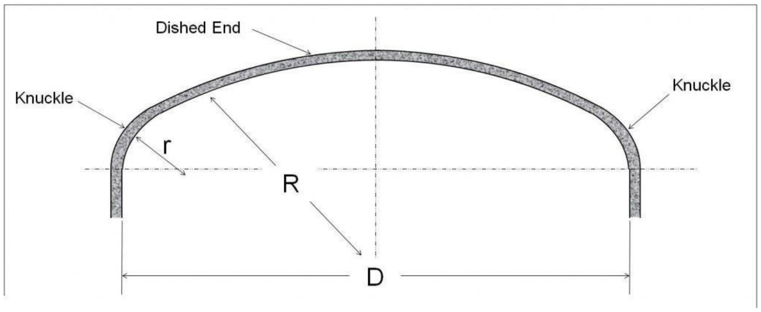

Fig 5. Ellipsoidal Head

2. Modelling and Analysis

2.1. Puncture-Disc

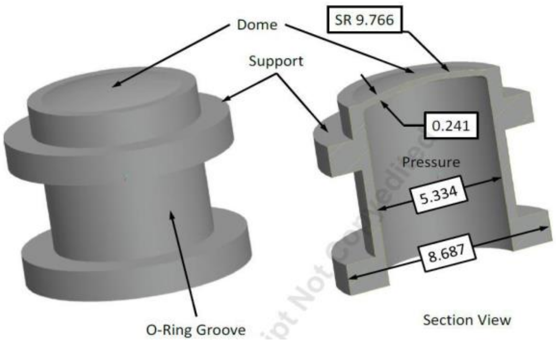

Fig 6.Geometry of Puncture disc pressure vessel (all dimensions are in mm)

Table 3.1 Linear Elastic Material Properties

Material	Titanium CommerciallyPure (Grade 2)
Component	Puncture-disc
Density	4511.8 kg-m^{-3}
Modulus of Elasticity	106,868 Mpa
Poisson’s Ratio	0.32
Yield strength	450 Mpa
Specification	ASTM B 348
Working pressure	1000Kpa

2.2. Ellipsoidal Dome

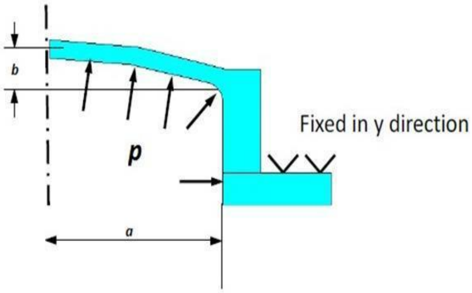

Fig 7. Semi major and semi minor axes of the dome

2.3. Alternative Design

In order to increase the working pressure or to reduce the induced stress for given working pressure, the design of the geometry of the pressure vessel can be changed by playing with parameters.

We may believe that thickness and ratio helps us effectively to meet our expectations. But the reality is changing those parameters blindly we may get in trouble in stress localised in other locations.

Vessel and we may be forced to add up thickness in the lower part as shown in the Fig

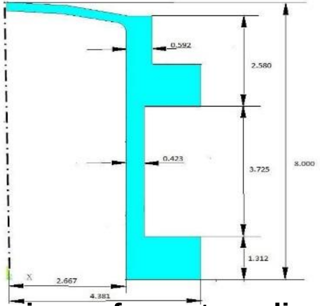

Fig 8.Detailed dimensions of puncture disc (all dimensions are in mm)

2.4. FEA Model

Both the FEA models (existing and modified pressure vessels) are completed using ANSYS 14.5 Mechanical software. The symmetrical shape of the puncture disc allowed it to be modeled as a 2-D axisymmetric model. The 2D puncture disc model utilized the ANSYS Plane 183 element. This element type is an 8-node quadratic element that can be used in an axisymmetric model. The mesh was highly refined in the area where the disc was expected to fail, the elements in the predicted failure location had a nominal edge distance of 0.0127mm.

2.5. Material Model

The linear elastic material properties for each material are listed in *Table3.1*. The puncture disc is made from Grade-2 commercially-pure titaniumin accordance with American Society for Testing and Materials ASTM B 348, both materials were treated as isotropic.

2.6. Boundary Conditions

The puncture disc has a surface pressure applied to all of the inside surfaces, as shown in *Fig5.1*, A displacement constraint fixes the y-axis movement on the surface where it is held in the pressure vessel assembly. This surface is still allowed to move in the x-axis direction. There is also an axisymmetric constraint along the y-axis at the edge of the domed section. The axis is shown by the center-line in *Fig5.1*. Since this is an axisymmetric model, the left edge shown in *Fig5.1* is the center of the part. The axisymmetric boundary condition eliminates the need for any additional constraints tokeep the model from moving in space.

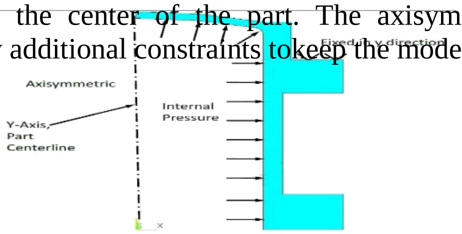

Fig9. Puncture-Disc Pressure-Vessel Boundary Conditions

Since the models are axisymmetric, so the problem is considered as 2D problem. Modelling and analysis is carried out in Ansys APDL. Here the modelling is done by keypoints, these keypoints are determined from the given dimensions and making a frame of reference. One assumption is done that the curvatures of the pressure vessel head are considered as number of individual lines joining the keypoints and these keypoints satisfy the equation of circle and elliptical respectively.

Meshing is finely done to determine the failure location and maximum induced stress, it given 0.021 mm of fine mesh to make a ccurate sets of results.

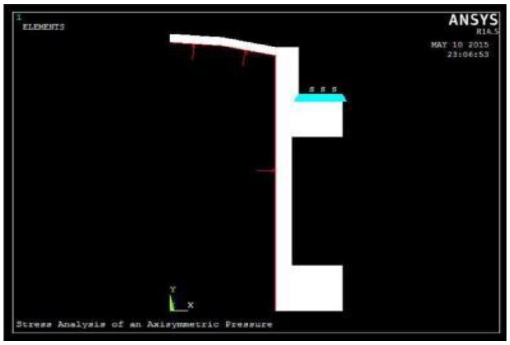

Fig 10.Loading and constraints of existing vessel.

3. Result and Discussion

3.1. VON MISES Stress of Existing & New Model

Fig 11. VON MISES stress of existing&new model

3.2.VON MISES Stress At Equator of Head of the Existing & New Model

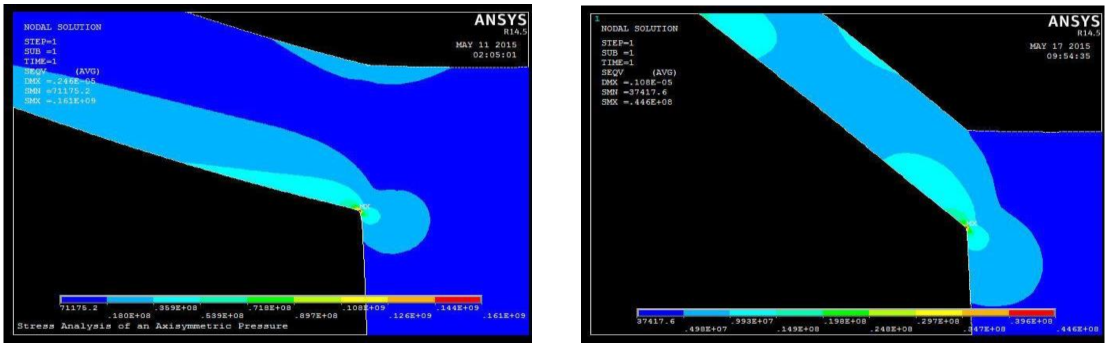

Fig 12.VON MISES stress at equator of head of the existing& new model

3.3. VON MISES Stress At Crown of Head of the Existing& NewModel

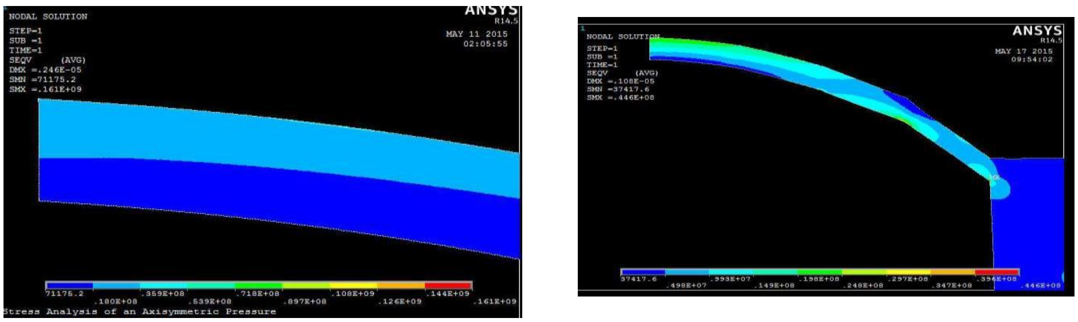

Fig 13.VON MISES stress at crown of head of the existing& new model

3.4. Nodal Displacement in Existing & New Model

Fig 14.Nodal displacement of existing & new model

Table 2. Result

S.no	Observation	Existing Model Analytical result	Existing Model ANSYS Result	New Model Analytical Result	New Model ANSYS Result
1	VON MISES Stress at Crown (MPa)	39.77	35.9	16.599	19.8
2	VON MISES Stress at Equator (MPa)	196.239	161	41.75	44.6
3	Nodal Displacement	2.32e-4	2.15e-4	2.32e-4	1.8e-4

- The stress induced in the pressure vessels by giving 1 MPa of working pressure to both the models.
- New model can withstand 4.7 times of working pressure of existing one.

4. Conclusion

Based on the above design and analysis, the following conclusions can be drawn,The critical location in the pressure vessel lies along the equator of the pressure head and from where the crack propagation starts.Changing the thickness in design may produce discontinuity stress in the junction, thus by altering the ratio reasonably we can get positive results.When ratio is increased, we observe that lower part of the cylindrical portion gets stressed up and yet not significantly.Making such design, we can increase the working pressure without changing the material.

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