ISSN: 2278-0181
Vol. 1 Issue 10, December - 2012

Modeling and FEA Based Analysis of Vacuum Chamber for Buckling Failure

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Abstract

This paper shows the solid structural analysis of vacuum chamber. The analysis is done for electron microscopy applications, for scanning electron microscope it require vacuum atmosphere for viewing of the specimen. The specimen is to be viewed in vacuum. The vacuum level required for that is in the range of 700 torr, which is less than atmospheric pressure lead to compressive forces on the chamber The vacuum chamber is modeled in Catia and Simulation is done in Ansys. Also theoretical calculation is done for safety of vacuum chamber from buckling failure.
Keywords- FEA, Electron Microscope, Buckling Propagation

Introduction

An Electron Microscope uses particle beam of electrons to illuminate the specimen and produce a magnified image. Scanning electron microscope (SEM) and Transmission electron microscope (TEM) are types of its applications. Both these applications requires an vacuum atmosphere to operate. Also the level of vacuum requirement is same for both the applications. The electron gun without vacuum will experience constant interference from air particles in the atmosphere. The distraction would lead to block the path of electron beam and also they would be knocked out of the air and onto the specimen which ultimately distort the surface of the specimen. The vacuum level required for that is in the range of 690 to 720 torr, which is less than that of atmospheric pressure which lead to compressive forces on chamber which causes buckling.

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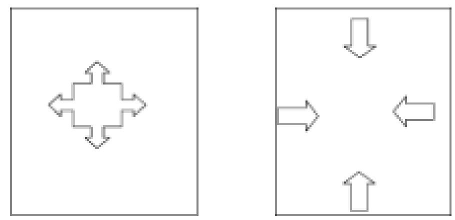

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Figure 1

2 Finite Element Analysis

The finite element analysis is a numerical technique. In this method all the complexities of the problems, like varying shape, boundary conditions and loads are maintained as they are but the solutions obtained are approximate.. The fast improvements in computer hardware technology and slashing of cost of computers have boosted this method. The different types of packages which are used for analysis such as STAAD-PRO, GT-STRUDEL, NASTRAN, NISA and ANSYS. Using these packages one can analyse several complex structures. It is used for solving different engineering problems like stress analysis , heat transfer, fluid flow etc. A finite element analysis has been done to the model for the expected stresses for 700 torr.

2.1 Modelling

The vacuum chamber comprises of cylindrical vessel with hemi spherical elliptical cover on one side and base plate on other side. The vessel and end cover is modeled in Catia part body workbench separately and fixed together in Catia assembly workbench. The assembly model is then save in stp format so it can be imported to Ansys workbench. The model is split by YZ plane as it is symmetric about it, and giving translation constrain in X-axis. A face to face contact is defined between cover flange and vessel flange.

Table 1 General dimensions of vacuum chamber

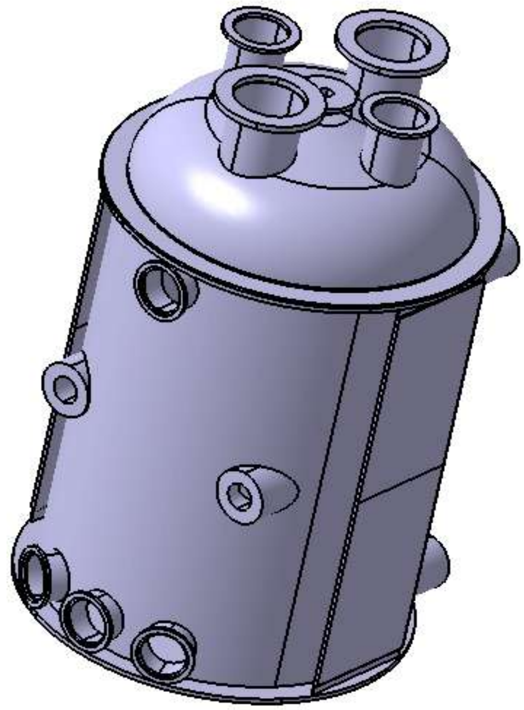
Description	Value (mm)
Vessel Inner Diameter	1070
Vessel Thickness	7
Length of Cylindrical Portion	1330
Cover inner diameter	950
Cover Thickness	7
Cover Height	250
Base Plate Thickness	23
Vessel Flange Thickness	35
Cover Flange Thickness	35

Table 2 Dimension of Flanges

Valves	Value (mm)	Thickness (mm)	Flange Thickness (mm)
1	205	4.5	23
2	154	4.5	23
3	120	34	23

2.2 Meshing

Meshing is the method of dividing the model into the number of element to obtain the good accuracy in the analysis. As the number of element increases the accuracy of analysis increases. A 15 mm 10 node tetrahedron element is used for meshing.



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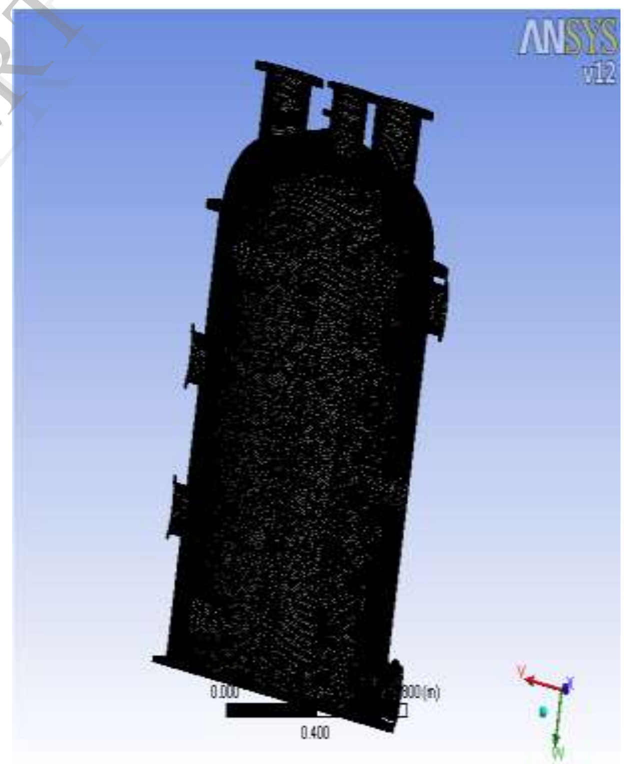

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2.3 Material Properties

Material: Structural Steel
Young's Mod. of Elasticity, E = 2e11 pa
Poisson's ratio, μ = 0.3
Density, ρ = 7850 kg / m3
Compressive yield strength = 205e6 pa

2.4 Boundary Conditions

The simulation is done for internal pressure 700 torr which is less than of atmospheric pressure 760 torr that leads to compressive pressure on chamber. One atmospheric pressure equals to 760 torr (mm of Hg).
(700 -760) torr = -60 torr = -7999.342 pa
Thus 7999.342 pa pressures is applied on vacuum chamber walls. Due to negative sign, the direction of pressure is inwards. The faces of valve flanges and side base plate are fixed .

2.5 Structural Analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.

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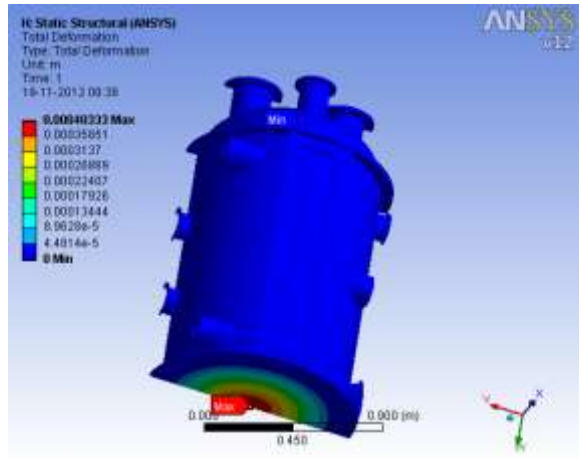
2.6 Solver

253148 tetrahedron elements are used for meshing which are connected at 759444 nodes. As there is three degree of freedom in solid structural analysis. So no of equations to be solved for displacement are 759444. Deformation is defined as the displacement in body dimensions due to application of force. The max deformation calculated from analysis is 0.0004033 m in the base plate of the vessel.

2.7 Results

Deformation and Von Mises Stress at different regions has been calculated using post processor. VON Mises Criterion also known as the maximum distortion energy criterion, octahedral, is often used to estimate the yield of ductile materials. The Von Mises criterion states that failure occurs when the energy of distortion reaches the same energy for yield/failure in uniaxial compression/tension. Max Von Mises stress calculated from the analysis is 12.065 Mpa on the vessel between valve and base plate as shown in fig which is very less than compressive yield strength 205 Mpa. So it is safe from this criterion.



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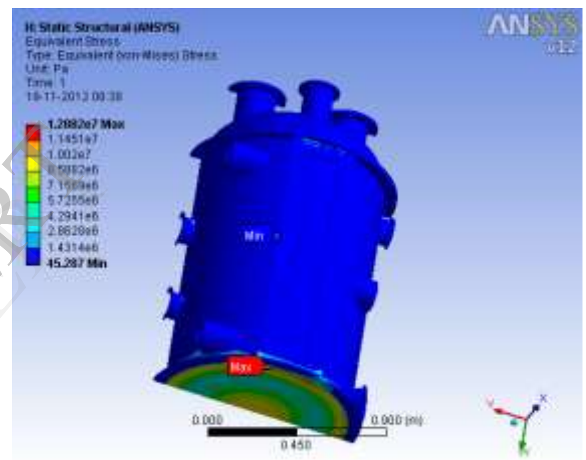

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3. Reinfinement of Meshing

To get accurate value of deformation and stress, the element size is changed from 15 mm to 10 mm and 9 mm resulting increase in elements from 253148 to 646331 and 756102 respectively. It is clear from the graph that as no of elements has been increased, high precision value is obtained. The max deformation has increased to 0.0004033 m from 0.00040033 m as no of elements increased to 756102 from 253148. Max Von Mises stress is converged at 12.92 Mpa for 756102 elements

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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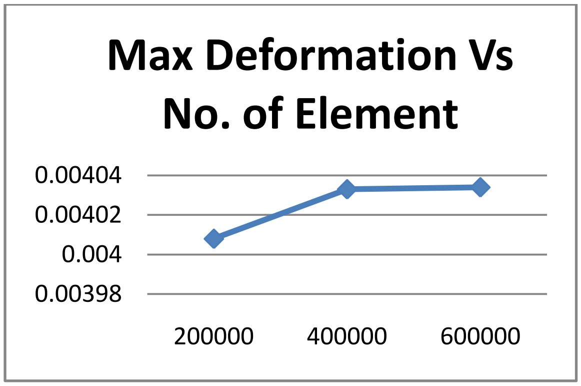
Graph 1



Graph 2

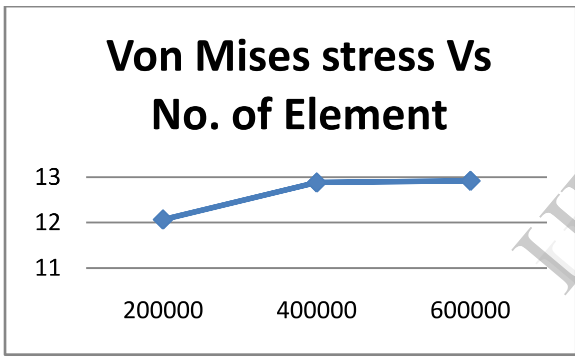


Table 3 Solid Structural Analysis Result

No. of Element	p=700 torr,Δp=7999.34 pa	
	Max Deformation(m)	Von Mises Stress (Mpa)
253148	0.0040077	12.065
646331	0.0040333	12.882
756102	0.004034	12.92

4. Theoretical Calculations

Buckling is a failure mode characterized by a sudden failure of a structural member subjected to high compressive stress. Cylindrical vacuum vessels subject to external pressure are subject to compressive hoop stresses. Consider a length L of the vessel

The total force acting = Intensity of pressure × area

$$= p \times D \times L$$

The total resisting force acting on the vessel walls

$$= \sigma_h \times 2t \times L$$

From above two equations',

$$\sigma_h \times 2t \times L = p \times D \times L$$

$$\sigma_h = \frac{p \times D}{2t}$$

The compressive hoop force,

$$W_h = \sigma_h \times L \times t$$

$$W_h = \frac{\nabla pbuckle \;\; DLt}{2t} \qquad (1)$$

Buckling will occur when compressive hoop force will equal to buckle force, W

$$W = \frac{\pi^2 EI}{(\frac{L}{2})^2} = \frac{4\pi^2}{(\pi D)^2} EI = \frac{4\pi^2 E \times (\frac{\pi D t^3}{12})}{(\pi D^2)}$$

$$W = \frac{E\pi D t^3}{3} \qquad (2)$$

Equating eq (1) & (2)

$$\nabla pbuckle = \frac{2E}{3} (\frac{t}{D})^3$$

$$= \frac{2 \times 2 \times 10^{11}}{3} \; (\frac{7}{1056})^3$$

$$= 38836.59 \text{ pa}$$

We have applied approximately p = 7999.342 pa for 700 torr (10 to 15) % of max buckling pressure as per requirement, the impact will be very small. So it is safe from buckling failure.

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Conclusion

- The Vacuum chamber is safe from buckling failure as applied p is very small in comparison to max theoretical buckling pressure.

- Compressive yield strength of structural steel is greater than Von Mises stress is calculated by solid structural analysis so it is safe from this criterion.

- A linear graph comes out for max deformation and max Von Mises stress with internal pressure so for different value of internal pressure theoretically they can be calculated.

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