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Pressure and Support Analysis of an Air receiver using FEM

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Abstract

An Air receiver is a simple volume tank used to store the air at high pressure received from the compressor. It acts as a pressure vessel, which depends on the working pressure and temperature. The present work's main purpose is to design an air receiver for an industrial application according to ASME standards and check for the design using a Mechanical finite element analysis software.

Keywords: *Thickness, pressure, ASME Code, ANSYS, stress, FEM*

I.INTRODUCTION

Air receivers are the pressure vessels used to store the air at high pressure and pressure-temperature (Figure 1). Air receivers have applications in various industries such as in Pharmaceuticals, Mining, Aerospace, Automotive, Chemical industries, Food and Beverage, General Manufacturing, Glass Manufacturing, Medical, Power Generation, and many more. An air receiver is mainly subjected to forces primarily due to the internal pressure and external pressure. The pressure vessel's design depends upon the number of factors such as working pressure, temperature, material of the vessel, corrosion, and other loadings. Failure of such a vessel can cause industrial damage and is hazardous for human safety. Hence selection of accurate design aspects becomes more important. ASME(American Society of Mechanical Engineers) Sec.VIII div-1 is the most widely used code used for the design & construction of pressure vessels. Div-1 considersthe biaxial state of stress combined following maximum stress theory. The thickness of the pressure vessel is selected according to the internal working pressure. The increase in the thickness beyond a certain value has difficulty in the fabrication and requires stronger vessel construction material.

There areseveral elements which are considered while designing an air receiver, including a)Working Pressure, b)Working temperature, c)Material used for manufacturing depending upon their mechanical properties, d)Theories of failure, e)Type of structure, whether it is cast, forged or welded and f)Destructive nature of reactants and yields.The saddle supports/Legsare usually used for the vertical vessel, typically made out of "channel" or "I" sections.

Figure 1: Air Receiver

The Finite Element Analysis is carried out to check for the thickness under the internal pressure and to ensure the stresses induced in the material are under the endurance limit.

II.METHODOLOGY

The method focuses on the stress analysis of an Air receiver (vessel) for the working condition. The first step in the methodology is to determine the functional and operational requirements of the vessel. Based on the design codes, the thickness and overall dimensions of the vessel are calculated. The design is checked for the given working conditions, and the design conditions are established. The proper material is selected according to the working environment, referring to the design data book. The stress analysis is carried out for the design pressure and design temperature, which is assumed 1.1 to 1.25 times the working conditions, and the induced stresses are checked for the material. The optimum limit is analyzed, and if the design exceeds the limits, the dimensions are changed, and the process is repeated until the design is safe under the working conditions. In the present work, the design is checked by carrying out several iterations for the vessel's stresses. Also, the Finite Element Analysis was carried out to obtain the stress results.

III. DESIGN CALCULATIONS

air receiver is considered a pressure vessel to be designed for pneumatic application as per ASME sec VIII, Div-1. for the capacity 2000 liters (2 cubic meter) with internal pressure(Internal operating pressure) 3.5Mpa. The design data is to be considered as follows.

1. Internal Operating pressure- 3.5 MPa
2. Internal Design pressure- 3.846 MPa
3. Operating temp- 65℃
4. Design temp- 75℃
5. Design No. of Cycles- 50000 cycles
6. Inside diameter- 1250 mm
7. Corrosion Allowance- 1mm
8. Type of Head- Semi elliptical dished head
9. Maximum allowable stress- 170 Mpa

The material for the construction of the component is taken as,

Sr	Component	Material
1	Shell	SA-516 Gr 70
2	Head	SA-516 Gr 70
3	Support Leg	SA-516 Gr 70
4	Nozzle	SA- 105

From the design data book, for the material SA-516 Gr 70 and SA-105, the Elastic of modulus and poisons ratio is taken as,

Material	Temperature (^{0}C)	Design Elastic Modulus (MPa)
SA 516 Gr 70	75	199.33e3
SA 105	75	198.33e3

Poisson's Ratio for the above materials is 0.3

The other specification of material is as follows:

1. Elastic modulus= 199.33e3
2. Density=7800 Kg/m3
3. Yield Strength= 335 Mpa

The Air Receiver is designed to meets all the ASME standards requirements. The minimum thickness of the shell considering cylindrical shell can be estimated as,

t_s= (P_i *D_i)/(2S*E-P_i) + Corrosion Allowance

Where $t_h$is the minimum thickness of the shell, Pi is the internal design pressure;Di is the inner diameter of the shell, S is the maximum allowable stress value of the shell material, and E is the joint's efficiency.

t_s = (3.84*1250)/ (2*170*1-3.84) +1 =15.9 mm.

Hence, The Nominal Thickness can be taken as 16 mm.

Semi elliptical dished headsare advantageous than the other types of heads since they are stronger than the plain dished type heads and tori spherical heads and are used for vessels with working pressure above 1.5 Mpa. The minimum thickness for the Semi elliptical dished Headfor internal pressure is calculated as

t_{he} = (P*D_i)/(2S*E-0.2P_i) + Corrosion Allowance

Where is the minimum thickness for the dished end, Pi is the internal design pressure, and Di is the shell's inner diameter. S is the maximum allowable stress value of the material and E is the joint's efficiency.

t_h= (3.84*1250)/ (2*170*1.00-0.2*3.84) +1 =15.27 mm. Nominal thickness can be taken as 16mm.

The length of the shell can be determined by considering the total volume of the Air receiver. The vessel's totalfluid capacity is the summation of the volume of the shell and the volume of the two ends.

The fluid contained within the semi-elliptical dished Head, excluding the straight flange portion, can be calculated as,

V_h= 0.131*D_i ^{3}= 0.131*(1250)^3=255859375mm^{3}Similarly, the volume of fluid contained within cylindrical Shell can be calculated as,

V_s= ((∏/4) *1250^2))*L = (1227184.6*L)mm^3

Total volume Fluid contained in the vessel= Total Volume of V shell + (Volume of Dish end*2)

2000*10^6= [((∏/4)*12502))*L] + (2*255859375)
L=1421.5mm

With the evaluated data, the geometrical dimensions of the vessel can be summarized as,

Inside diameter of shell (D_i) = 1250 mm

The thickness of the shell () = 16mm

Outside diameter of vessel shell = (D_i+2t) = 1282mm

The thickness of the semi-elliptical Head (t_h) = 16 mm

Straight Lange length (st) = 3*16= 48 mm

The Stresses induced in an air receiver are primarily due to the fluid's internal pressure and the weight of the vessel. The maximum tensile stresses induced in the vessel body are the circumferential stress and are also known as tangential stress. The maximum compressive stress is the Radial Stresses, and it is negative. The negative sign indicates that the Radial Stress is opposite equal to design stress Compressive stress. Also, the stresses induced in the longitudinal direction are due to internal pressure and the weight of the vessel and fluid are Longitudinal stresses, also called Axial stresses. Axial stresses generally content in vertical pressure vessels.

a) Tangential Stress = $(P_i (D_i + t))/2t$ (tensile)
   = 3.84(1250+ 16)/2(16)
   = 138.49 MPa

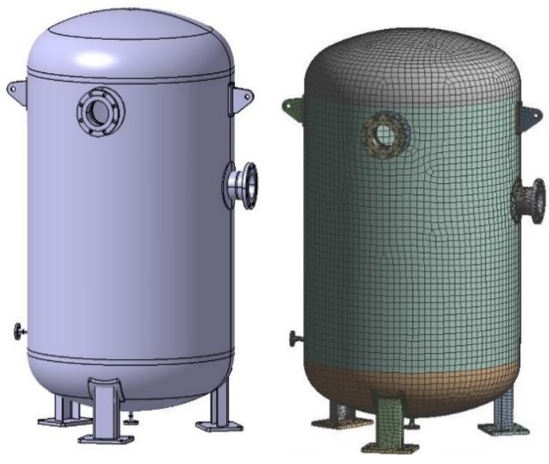
b) Radial stress = $(P_i . R_i^2)/(R_o^2 – R_i^2)*(1-(R_o^2/R_i^2))$
   = $3.84 (625)^2/(641^2-625^2)*(1- (641^2 /625^2)$
   = -35 MPa (compressive)

c) Longitudinalstress=$(P_i *D_i^2)/(D_o^2 – D_i^2)$
   = $3.84x(1250^2)/ (1282^2 – 1250^2)$
   = 67.49MPa

Since the induced stresses are less than the maximum allowable stress 170MPa, the design is safe for the working condition.

IV.STRESS ANALYSIS USING ANSYS

The vessel with the calculated geometrical dimensions is modeled using a 3D modeling software package, CATIA V5R20, referring to the calculated geometrical dimensions (Figure 2a).It is further imported in ANSYS Workbench simulation software package and analyzed for the given Working conditions. The procedures in the ANSYS simulation mainly includes the three processes, the "Pre-processor," the "Solution," and the "Post-processor."The vessel's geometry is imported in the "pre-processor" process, and the material properties are defined. For meshing, the Hex Dominant method is used for the shell, and the Head with the element size equals 30 mm,and Tetrahedral (10 nodes) elements areused for nozzle(figure 2b). After meshing, the boundary conditions are applied, fixing the vertical saddle and applying pressure on the vessel's inside faces. The design temperature of 75℃ is inserted for the vessel. Based on the Finite Element Theory, the "solution" process obtains the metrical equations' numerical solution. The last process, "Post-processor," gives the result solution such as Equivalent (Von Mises) stress, Total deformation, and Thermal stress. The problem can be solved by applying the symmetry boundary conditions dividing the vessel into eight quarter parts. This methodology reduces the number of nodes and elements; thus,the less computational time is required.

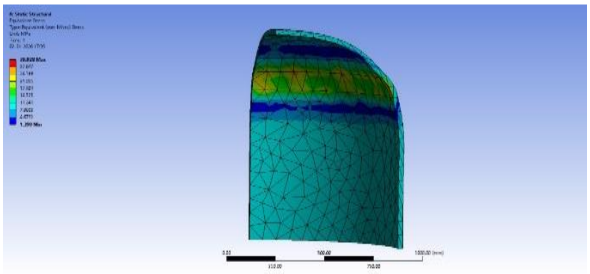


(a) (b)

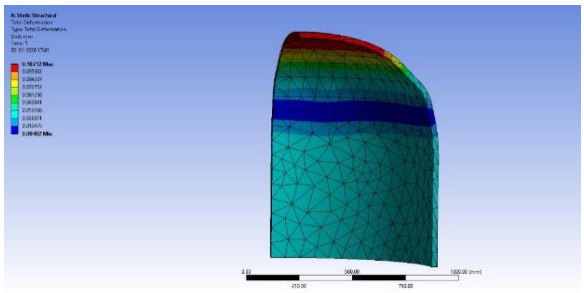
Figure2:(a)Geometry, (b)Meshed Geometry of an Air receiver vessel

V. RESULTS AND DISCUSSION

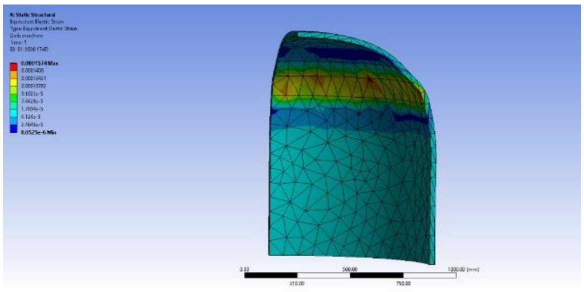
The Quality and number of elements influence the accuracy of the solution and simulation time; hence, it becomes necessary to create a proper meshing. Since the Geometry is symmetrical, it can be spited into eight geometries, and the analysis can be done using one. For this purpose, the asymmetry system is inserted, and the results are analyzed by applying the boundary conditions. The maximum Equivalent (Von Mises) Stress obtained is 30.928 Mpa (Figure 3a), Total Deformation is 0.10712 mm (Figure 3b), and the Elastic strain for the Air Receiver Vessel is obtained as 0.0001574 (Figure 3c).



(a)



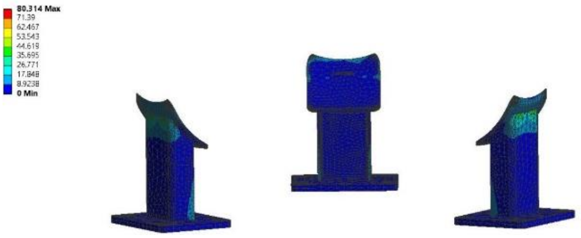
(b)



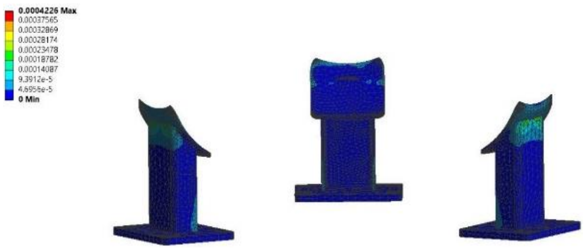
(c)

Figure 3: (a)Equivalent (Von Mises) stress, (b)Total deformationobtained for Air receiver vessel

The vessel is supported on the vertical saddles/Legs, which are subjected to compressive stresses or buckling on account of load due to the vessel's weight and the weight of the fluid inside the vessel. The Air receiver's weight is obtained from the density of vessel material and the volume. It can be directly obtained from the 'Measure Inertia' tool in CATIA or ANSYS. The fluid's weight can be calculated by the product of the density of the fluid(air) and the volume of fluid. The total weight's calculated value is obtained as 11,158.60N, and the Legs are analyzed for the weight load.



(a)



(b)

Figure4:(a)Equivalent (Von Mises) stress, (b)Elastic strain obtained for Vertical saddle/Legs.

The maximum equivalent (Von Mises) stress was obtained as 80.314 MPa (Figure 4a), and the elastic strain is 0.0004226 (Figure 4b). Since the induced stress is less than the maximum allowable stress (170Mpa), the Saddle/Legs are safe under the weight loading.

VI. CONCLUSION

For the specific pneumatic application in an industry, the analytical solution is obtained for the thickness of the shell and Head. Thus, the geometrical dimensions of an Air receiver Vessel are determined. The assessment is done using a numerical stress analysis for the induced stresses in the vessel, and the stresses are found to be less than the maximum allowable stress. This indicates the design is safe under the working conditions.

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