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Fatigue Life Prediction of Horizontal Pressure Vessel in Accordance with EN-13445

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***Abstract*—**Pressure vessel used to store fluids under pressure and temperature. The fluids can be air, water, chemicals, fuel, gases etc. is most commonly used in food factories, chemical industries, oil refineries etc. Fluids are stored in vessel at high pressure due to this structural stresses induced in it. Since the pressure vessel are subjected to structural stresses, the design of pressure vessel was done using standard code. Fatigue failure most common failure observed in pressure vessels. In this paper a detailed fatigue assessment is studied for pressure vessel as per EN 13445. The European pressure vessel standard EN 13445 provides in its part 3 a detailed fatigue assessment. The main aim of this project is to design and estimate fatigue life so that it will not fail in case of variable pressure condition. The modeling has been done using SolidWorks modeling software and analysis is done using ANSYS Workbench.

Keywords*—*Pressure vessel, Fatigue life, Finite element analysis, Ansys Workbench, EN-13445.

I. INTRODUCTION

The pressure vessels are used to store fluids under pressure. Pressure vessels find wide applications in thermal and nuclear power plants, process and chemical industries, in space and ocean depths and in water, steam, gas and in air supply system, in process Industries like chemical and petroleum industries. The term pressure vessel referred to those reservoirs or containers, which are subjected to internal or external pressures. The fluid being stored may undergo a change of state inside the pressure vessels as in case of steam boilers or it may combine with other reagents as in chemical plants. The material of a pressure vessel may be brittle such as cast iron, or ductile such as mild steel.

Construction of Pressure Vessels:

Fig (1): Pressure vessel

To help you understand the process easier, the fabrication process has been divided into steps. Before the fabrication process is begun, a few important design steps must be performed. These are given below in brief.

List the Design Criteria: This is where all the technical specifications and requirements are taken from the client. The design criteria will include aspects such as the shape of the vessel, and details such as material of construction, length, diameter, internal pressure & temperature, etc.

Perform Mechanical Strength Calculations: With pressure vessel design software, the mechanical calculations are performed to determine the required material thicknesses and weld sizes.

Generate Fabrication Drawings: Fabrication drawings are produced based on the design criteria and mechanical calculations with software such as AutoCAD. These drawings can be produced in 2D or 3D, but usually 2D will suffice.

Once the design is approved by the client and a third party inspector (A.I.), the fabrication process begins.

Cut The Plate: A large amount of plate is cut into the required width and length for the vessel shells. A specialized cutting torch is used to cut the steel. A variety of torches can be used depending on material and required edge quality. Bevels are usually cut on edges at this time.

Roll the Plate into Cylinders: The plate is rolled into cylinders of required diameter. Usually the plate is rolled cold, but can be done hot in order to use plate rolls of a smaller capacity.

Weld Long Seams of Cylinders: Usually performed with submerged arc welding.

Fit & Weld the Pressure Vessel Cylinders: Usually performed with submerged arc welding. This is only needed if more than one shell is required to meet the required vessel length.

Cut and Form the Pressure Vessel Heads: Various cutting torches can be used to cut the plate for the pressure vessel head. Then the pressure vessel heads are formed using a variety of techniques, usually flanging and spinning or press forming is used.

Fit & Weld Heads to Pressure Vessel Shell: Usually performed with submerged arc welding.

Cut Holes For Nozzles: Holes need to be cut into the steel plate for the required vessel nozzles. This is usually performed with a manual plasma-arc or oxyacetylene cutting torch. Final edge preparations performed by manual grinding.

Install Nozzles: Nozzles and reinforcement pads are welded in usually using a manual wire welding technique.

Install Required Structural Supports and Lifting Devices: These are usually welded on using a manual wire welding technique.

Final Quality Checks: This could include hydro, pneumatic, radiography, ultrasonic, and or magnetic particle testing to ensure integrity of design, material, and welding.

Final Inspections: This usually includes internal, customer, and third party inspections.

II. Objective

- To design the pressure vessel using EN 13445.
- To predict fatigue life with constant amplitude pressure fluctuation cycles i.e. 0 MPa to 1.3 MPa.

III. Methodology

Aim of this project is to predict the fatigue life of pressure vessel for constant amplitude pressure fluctuation cycles of pressure vessel i.e. 0 MPa to 1.3 MPa. We have calculated all the pressure part thickness for given design parameters and with same dimensional details 3D CAD model is prepared.3D CAD model is imported into ANSYS workbench apply loading and boundary condition to find out Von-mises stresses in vessel. As per clause 18 of EN 13445 we have calculated number cycles.

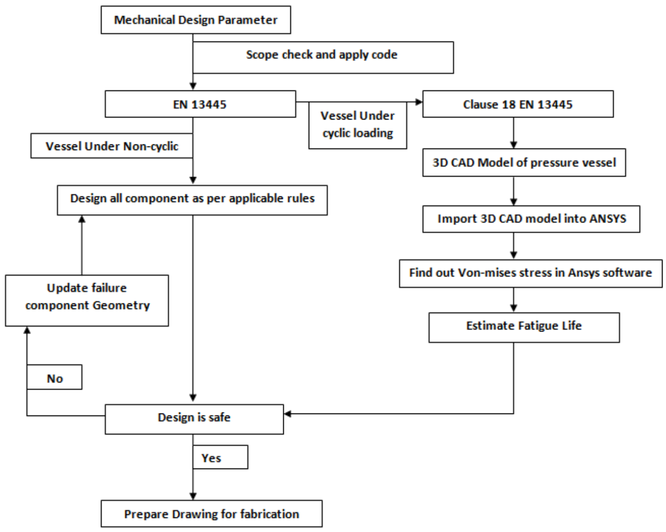


Fig (2): Methodology Flowchart

Following mechanical design parameters are used for research purpose.

Design Code	EN 13445
Fluid is in used	Water
Internal Design Pressure	1.3 MPa
Internal Design Temperature	97°C
Outside Diameter	3456
Tan Length of vessel	13200 mm
Corrosion Allowance	0 mm

Material	Density (Kg/m^3)	Allowable Stress (MPa)	Yield Strength (MPa)	Passion's Ratio	Modulus of Elasticity (MPa)
P265GH EN10028-2 (Plate, Carbon Steel)	7730	150.13	232	0.3	200 x 10^3
P235GH EN10216-2 (Seamless pipe)	7730	132	198	0.3	206 x 10^3

All mechanical properties are taken at design temprature.

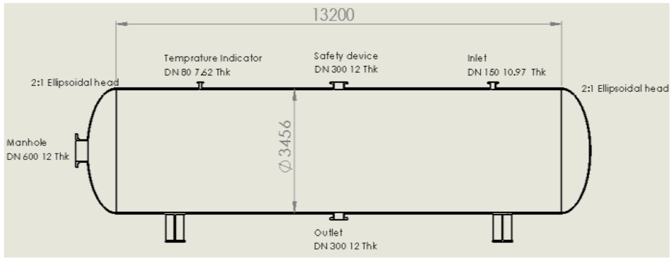


Fig (3): Methodology Flowchart

IV. Design Calculation

Elliptical Head under internal pressure (EN 13445 7.5.3.5)

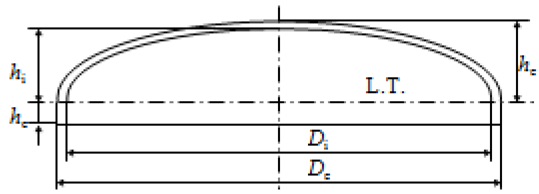


Fig (3):

$$e_s = \frac{P.R.}{2f.z-0.5.P}$$

e_s = 13.277 mm

Cylindrical shell under internal pressure (EN 13445 formula 7.4-1)

$$e_s = \frac{P.Di}{2f.z-P}$$

e_s = 14.78 mm

V. Finite Elemet Analysis

Aim of this project is to predict the fatigue life of pressure vessel for constant amplitude pressure fluctuation cycles of pressure vessel i.e. 0 MPa to 1.3 MPa. We have calculated all the pressure part thickness for given design parameters and with same dimensional details 3D CAD model is prepared.3D CAD model is imported into ANSYS workbench apply loading and boundary condition to find out Von-mises stresses in vessel. As per clause 18 of EN 13445 we have calculated number cycles.

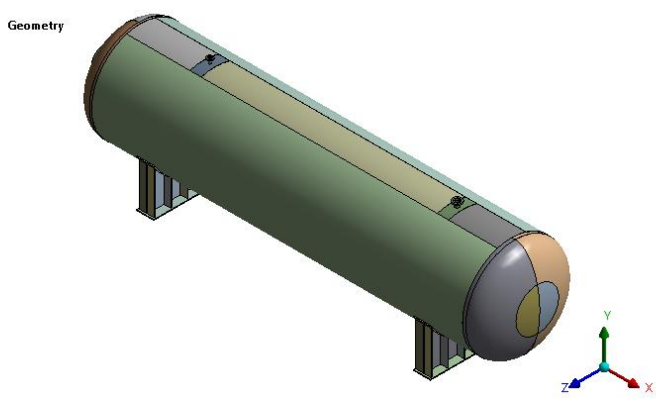


Fig (3): 3D CAD Model

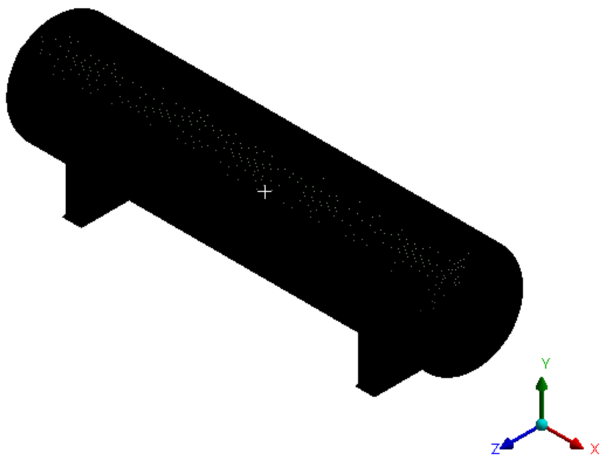


Fig (3): Meshing

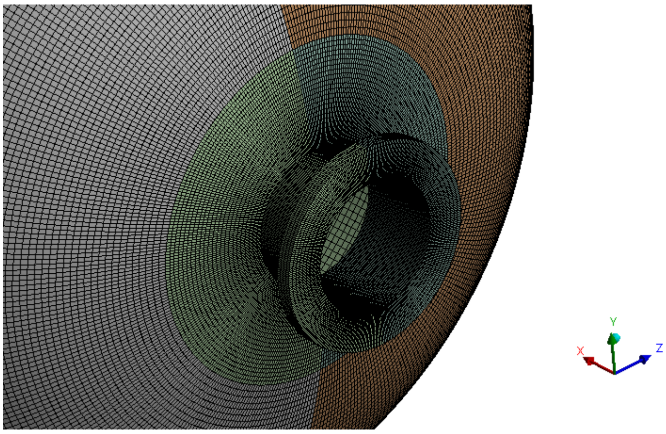


Fig (3): Zoomed Image of meshing

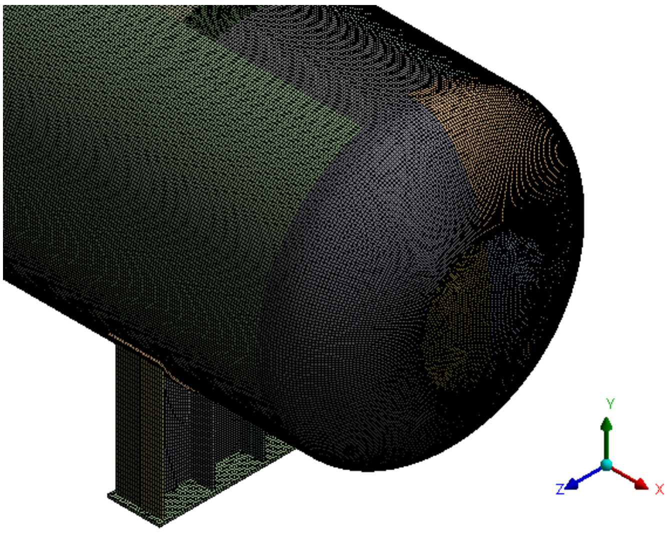


Fig (3): Zoomed Image of meshing

For this analysis Solid 186 element type is considered.

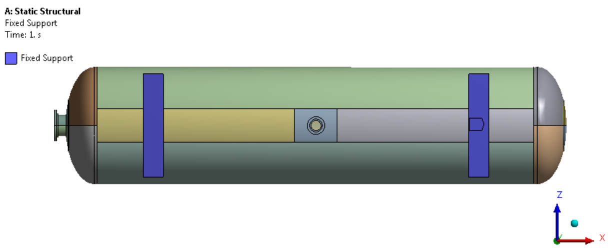


Fig (3): Boundary Condition

Fixed support is applied at bottom surface of saddle.

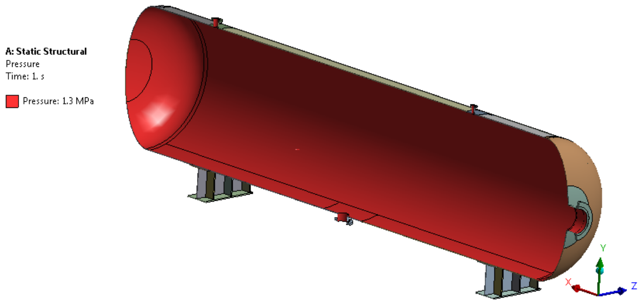


Fig (3): Internal Pressure (1.3 MPa)

1.3 MPa internal pressure is applied to internal faces of pressure vessel.

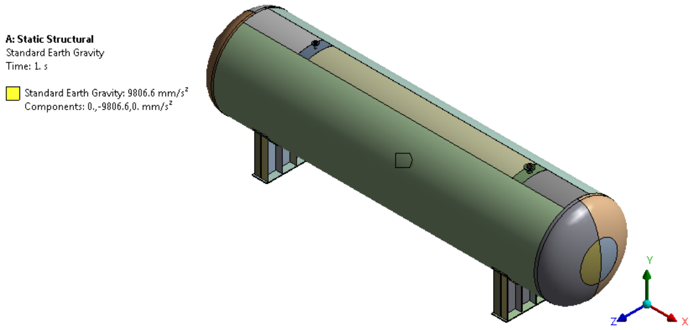


Fig (3): Standard earth gravity

Dead weight of equipment is considered in terms of standard earth gravity.

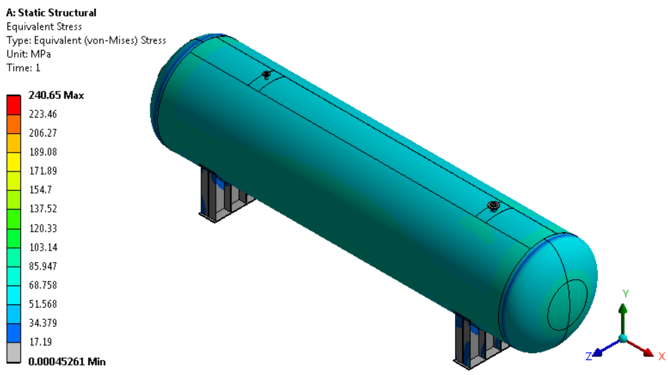


Fig (3): Von-Mises stresses

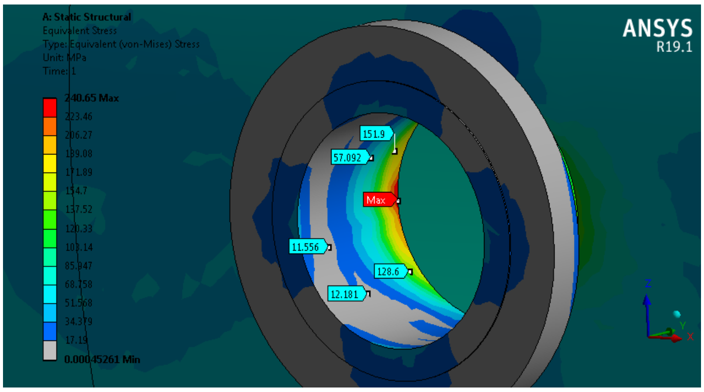


Fig (3): Zoomed view of Max. Von-mises stresses

240.65 MPa Max. Von-mises induced in vessel for given loading and boundary condition.

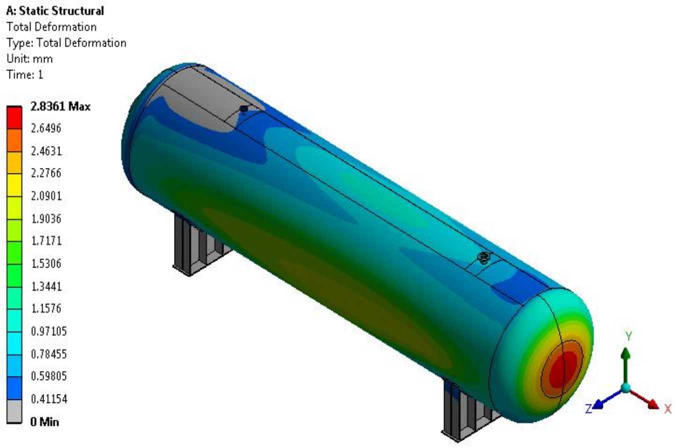


Fig (3): Deformation plot

2.836 mm deformation is observed.

VI. FATIGUE CALCULATION

The Fatigue assessment is carried out by Elastic stress analysis and equivalent stresses – Effective total equivalent stress amplitude is used to evaluate the fatigue damage for results obtained from a linear elastic stress analysis. The controlling stress for the fatigue evaluation is the effective total equivalent stress amplitude, defined as one-half of the effective total equivalent stress range calculated for each load case.

The maximum von mises stress for the Case 1 is 0 MPa

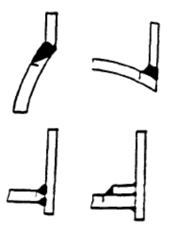
The maximum von mises stress for the Case 2 is 1.3 MPa

The operating cycles are having pressure range of 0 MPa to 1.3 MPa so the effective total equivalent stress range

To obtain the permissible number of load cycles, N, at a specified stress range, $\Delta\sigma_{eq}$ or $\Delta\sigma$, the following shall be calculated.

If $\frac{\Delta\sigma_{eq}}{f_w} \geq \Delta\sigma_D$ or $\frac{\Delta\sigma}{f_w} \geq \Delta\sigma_D$ then

$$N = \frac{C_1}{\left(\frac{\Delta\sigma_{eq}}{f_w}\right)^{m_1}} \tag{18.10-17}$$

3.2	Weld toe in shell		71 80 63 71	 63 63 63	Full penetration welds: - as welded - weld toes dressed (see 18.10.2.2) - in all cases Partial penetration welds: - weld throat ≥ 0,8 x thinner thickness of connecting walls, as welded - weld toes dressed (see 18.10.2.2)

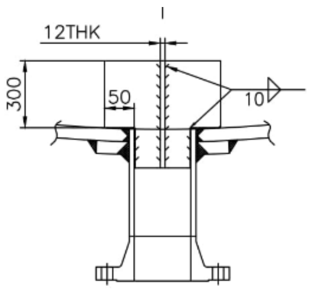


Table 18-7 — Coefficients of the fatigue design curves for welded components

Class	Constants of $\Delta\sigma_R$ - N curve*				Stress range at N cycles, N/mm^2	
	For $10^2 < N < 5x10^6$		For $5x10^6 < N < 10^8$		$N = 5 \times 10^6$	$N = 10^8$
	m_1	C_1	m_2	C_2	$\Delta\sigma_D$	$\Delta\sigma_{Cut}$
100	3,0	2,00 x 10^{12}	5,0	1,09 x 10^{16}	74	40
90	3,0	1,46 x 10^{12}	5,0	6,41 x 10^{15}	66	36
80	3,0	1,02 x 10^{12}	5,0	3,56 x 10^{15}	59	32
71	3,0	7,16 x 10^{11}	5,0	1,96 x 10^{15}	52	29
63	3,0	5,00 x 10^{11}	5,0	1,08 x 10^{15}	46	26
56	3,0	3,51 x 10^{11}	5,0	5,98 x 10^{14}	41	23
50	3,0	2,50 x 10^{11}	5,0	3,39 x 10^{14}	37	20
45	3,0	1,82 x 10^{11}	5,0	2,00 x 10^{14}	33	18
40	3,0	1,28 x 10^{11}	5,0	1,11 x 10^{14}	29,5	16
32	3,0	6,55 x 10^{10}	5,0	3,64 x 10^{13}	24	13

* For $E = 2,09 \times 10^5$ N/mm^2

$\Delta\sigma eq$ = 240.65 MPa (the equivalent stress range obtained from ANSYS result.)

Class = 63

C1 = 5 x 10^{11} No. required cycles 102 < N < 5 x 10^{11}

$$N = \frac{5 \times 10^{11}}{\left(\frac{240.65}{0.97}\right)^3}$$

N = 33011 cycles

CONCLUSION

Horizontal pressure vessel can withstand 33011 pressure fluctuating cycles for given condition in accordance EN 13445-3.

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