

Design and Evaluation of Pressure Vessel as per ASME Section VIII Division 2

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ABSTRACT: This paper deals with the Finite element design and evaluation of pressure vessel. Pressure vessels are used to contain a multitude of things, including air, water, chemicals, nitrogen, and fuel. They are used in petroleum refining, food and beverage automotive and transportation, oil and gas and in chemical industries. High pressure is developed in pressure vessel and has to withstand several forces developed due to internal pressure hence pressure vessel design is quit complex as it satisfy the ASME standards and its functional aspects, safety and life requirements. ASME section VIII, Division 1 and Division 2 are normally used in design. The Division 1 corresponds to Design by rule whereas the Division 2 corresponds to Design by analysis. The aim of this project is to design a pressure vessel whose sole purpose is to withstand the pressure of the substance stored in it and is analysed by FEM to validate its design for their operational stress levels and safety. The Allowable stress limits for Stress Categories to find the Stress Intensity Limits are considered as per Part 5 of ASME Section VIII Division 2 and The Fatigue Analysis to be carried out in accordance with ASME Section VIII Division 2.

KEYWORDS: Pressure Vessel, linearised stress categories, Fatigue, ANSYS.

I. INTRODUCTION

The pressure vessel referred to those reservoirs or containers, which are subjected to internal or external pressure. The pressure vessels are used to store fluids under pressure. The fluid being stored may undergo a change of state inside vessels as in case of steam boilers or it may combine with other reagents as in chemical plants. These types of vessels are mostly used in oil and petroleum and chemical industry for storage purposes. Pressure vessels have wide applications in chemical industries, thermal and nuclear power plants, process, pharmaceutical industries, & food and beverage industries. The failure of pressure vessel may result in loss of life, health hazards and damage of property high pressure is developed in pressure vessel so pressure vessel has to withstand several forces developed due to internal pressure, so selection of pressure vessel is most critical, ASME standards is most widely used code for design ASME section VIII, Division 1 and Division 2 are normally used in design. The Division 1 corresponds to Design by rule whereas the Division 2 corresponds to Design by analysis. In pressure vessel whenever expansion or contraction occurs normally as result of heating or cooling, thermal stresses are developed. There are many types of stresses developed in the vessel Stresses are categorized into primary stresses and secondary stresses. Primary stresses are because of pressure inside pressure vessel and secondary stresses are because of thermal loading and Thermal loading is considerable in a pressure vessel due to handling of hot fluids in vessels. Since the pressure in the vessel is high, it has to withstand both thermal as well as structural loadings. To obtain safety of pressure vessel and to design Pressure vessel the selection of code is important. During service, pressure vessel may be subjected to cyclic or repeated stresses. Fatigue in pressure vessel occurs due to: Fluctuation of pressure, Forced vibration, Temperature transients, Variation in external loads, Restriction of expansion or contraction during normal temperature variations.

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II. RELATED WORK

In this section research papers are discussed related to the present work. Published papers are highlighted in this section.

Bandarupalli Praneethetal [1]: In this paper they have discussed on FE analysis of pressure vessel and piping design. The stresses developed in solid layer pressure vessel and multilayer pressure vessels are analysed. The theoretical and ANSYS results are compared. Finally it was concluded that theoretically calculated values are very close to that of the values obtained from ANSYS is suitable for multilayer pressure vessels. Multilayer pressure vessels are superior to the solid layer pressure vessel. M. Giglio etal[2]:In this paper they have discussed on Fatigue analysis of different types of pressure vessel nozzle. He carried out comparison between the two different methods for the construction of pressure vessel nozzle. He concludes that failure of nozzles was by crack passing through their thickness. Both designs (integral and external reinforcement) give good fatigue life results.

Javad Marzbanrad etal[3]:In this paper they have discussed on FE analysis of composite high pressure hydrogen storage vessels. Composite pressure vessel is largely used in industrial applications such as softening, filtration and storage. In this design, Unit load method under various internal pressures and analysis was carried out in ABAQUS. The result shows that fatigue lifetime of vessel depends on crack density, stress induced in it and cyclic loading amplitude. Umbarkar Bhagyashri B etal[4]:In this paper they have discussed on the design and analysis of pressure vessel, the design of pressure vessel depends on its pressure and temperature. In pressure vessel design, the main consideration was safety and the structural integrity of mechanical components of pressure vessel requires fatigue analysis including stress analysis and thermal analysis and the Fatigue analysis also done on modelled in Pv Elite software to improve the life of pressure vessel. According to ASME SEC VIII DIV-2, Analysis of pressure vessel is carried out at different temperature and pressure conditions and concluded that the Fatigue analysis will be carried out to the equipment for specified regeneration cycles and found that fatigue life is more than the required cycles. Accordingly he concludes that all evaluation points for fatigue are within the allowable limits specified by the code.

III. SCOPE OF ASME SEC VIII DIV 2

The scope of ASME section VIII DIV 2 has been established to identify the components and parameters that to be considered in formulating the rules given in this Divisions and regulations issued by the municipality, state, provincial, federal, or other enforcement or regulatory bodies having a jurisdiction at the location of installation establish the mandatory applicability of the Code rules. ASME section VIII div 2 contains the mandatory requirements, specific prohibitions, and non-mandatory guidance for the design, materials, fabrication, examination, inspection, testing, and certification of pressure vessels and their associated pressure relief devices.

The requirements of this Division are contained in the nine Parts listed below

- Part 1 – The general requirements that provides the scope of this division and establishes the extent of coverage's.
- Part 2 – Responsibilities and Duties, that sets for the responsibilities of user and Manufacturer, and the duties of Inspector.
- Part 3 – Materials Requirements, provides the permissible materials of construction, applicable material specification and physical properties, special requirements, allowable stresses, and design fatigue curves.
- Part 4 – Design by Rule Requirements that provides the requirements for the design of vessels and its components using these rules.
- Part 5 – Design by Analysis Requirements, provides requirements for design of vessels and its components using the analytical methods.
- Part 6 – Fabrication Requirements, provides requirements of governing the fabrication of vessels.
- Part 7 – Examination and Inspection Requirements, provides requirements governing the examination and inspection of vessels and parts.
- Part 8 – Pressure Testing Requirements, provides pressure testing requirements and

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Part 9 – Pressure Vessel Overpressure Protection, provides rules for pressure relief devices.

IV. OBJECTIVE

- The main objective is to design the pressure vessel as per ASME sec VIII div 2.
- To find the static and thermal analysis considering the given design pressure and temperature conditions.
- Critical components will be analysed for fatigue life and it was be carried out in accordance with ASME Section VIII Division 2 part 5 Design by Analysis.

V. EXPERIMENTAL METHODOLOGY

The finite element is a mathematical method for solving ordinary and partial differentials equations. FEM is a numerical method; it has ability to solve the complex problems which are in differential equation. These types of equations occur naturally in virtually of all fields of the physical sciences, applications of the finite element method are limitless as regards the solution of practical design problems, and FEA has history of being used to solve cost critical and complex problems. Finite element analysis is a powerful tool in the field of engineering, Stress Analysis by finite element method is obviously the best choice. Hence FEM has been selected for analysis purposes. ANSYS FEM software is one of the most popular software used for finite element analysis of pressure vessels .The stress Analysis with the help of Finite Element Method is necessary to find out the exact behaviour of pressure vessels. Fig1: Constrained the supports of pressure vessel, This project set out to explore the applicable methods using finite element analysis in pressure vessel analysis. ANSYS environment performing the structural and thermal analysis Fig2: FE model of pressure vessel, the objective of analysis was to check fatigue life for fully reversal cycle is considered cyclic pressure service and impact loading service in accordance with ASME Section VIII, Div-2 Part 5. To study the stress levels, finite element based stress analysis is carried out.

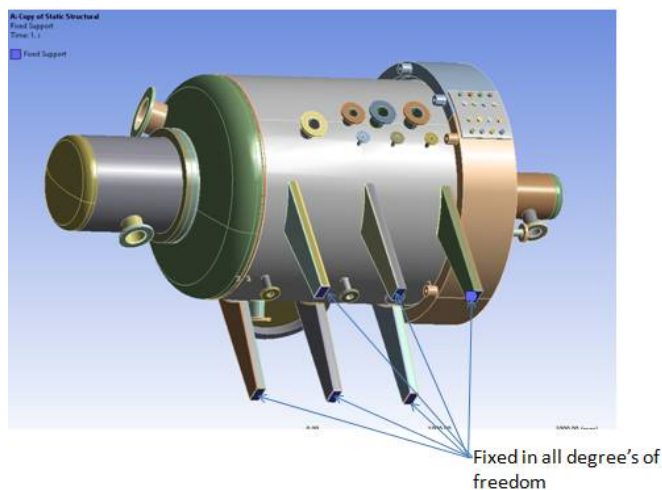


Fig1: Constrained the supports of pressure vessel

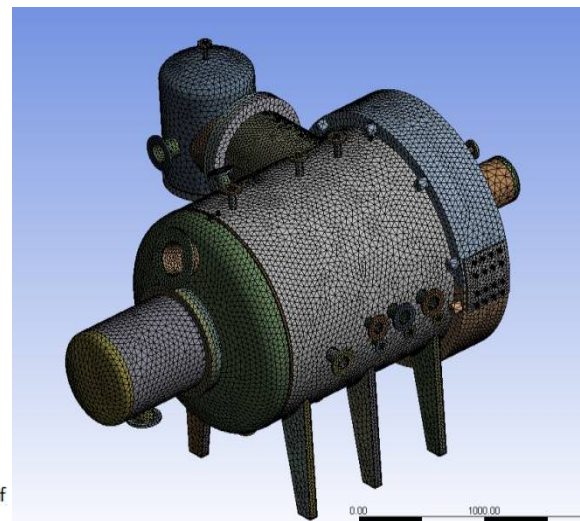


Fig2: FE model of pressure vessel

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VI. MATERIAL PROPERTY AND DESIGN DATA

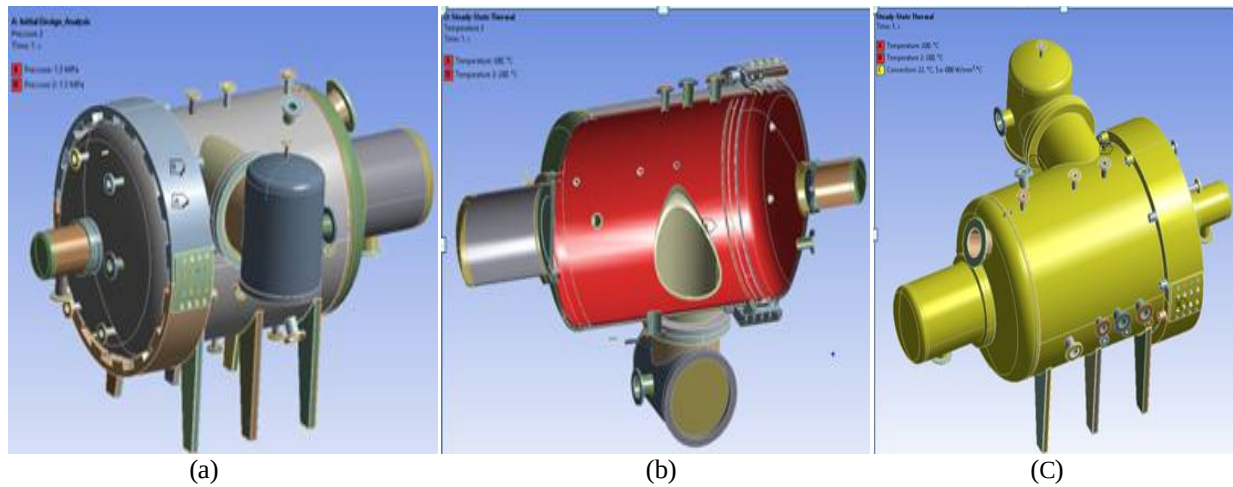
MATERIAL PROPERTIES	SA 387GR11 CLASS2	PARAMETERS	VALUES
Young's Modulus	1.71e5N/mm2	Design pressure	13bar
Poisson's ratio	0.29	Design temperature	200°C
Density	7.9E-9 tonnes /mm3	Inner Diameter of vessel	1716mm
Coefficient of thermal Expansion	6.5 x10-6/°C	Length of vessel	1779mm
Thermal conductivity	35.3K W/M° C	Operating Pressure	1-11bar
		Mass	2343kg
		Volume	1.265e9mm3

(a)

(b)

Table 1: (a) shows the material properties of SA 387GR11 CLASS 2, (b) gives design parameters for pressure vessel.

DESIGN PRESSURE, DESIGN TEMPERATURE AND CO EFFICIENT OF THERMAL EXPANSION



(a)

(b)

(c)

Fig 3: (a) Pressure applied 1.3 MPa, (b) temperature applied 200°C and (c) heat transfer co- efficient 6.5x10-6/°C

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VII. RESULTS AND DISCUSSIONS

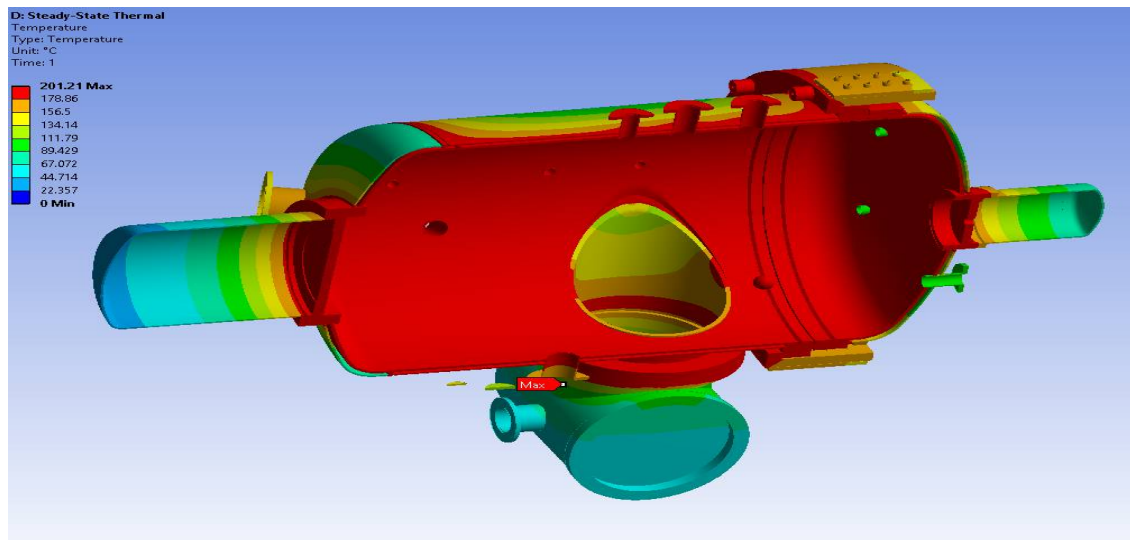


Fig4: Steady- state thermal analysis

Fig4: shows the steady state thermal analysis result of max stress of 201.21 MPa, when design pressure and temperature loads applied.

1. DISPLACEMENT RESULT

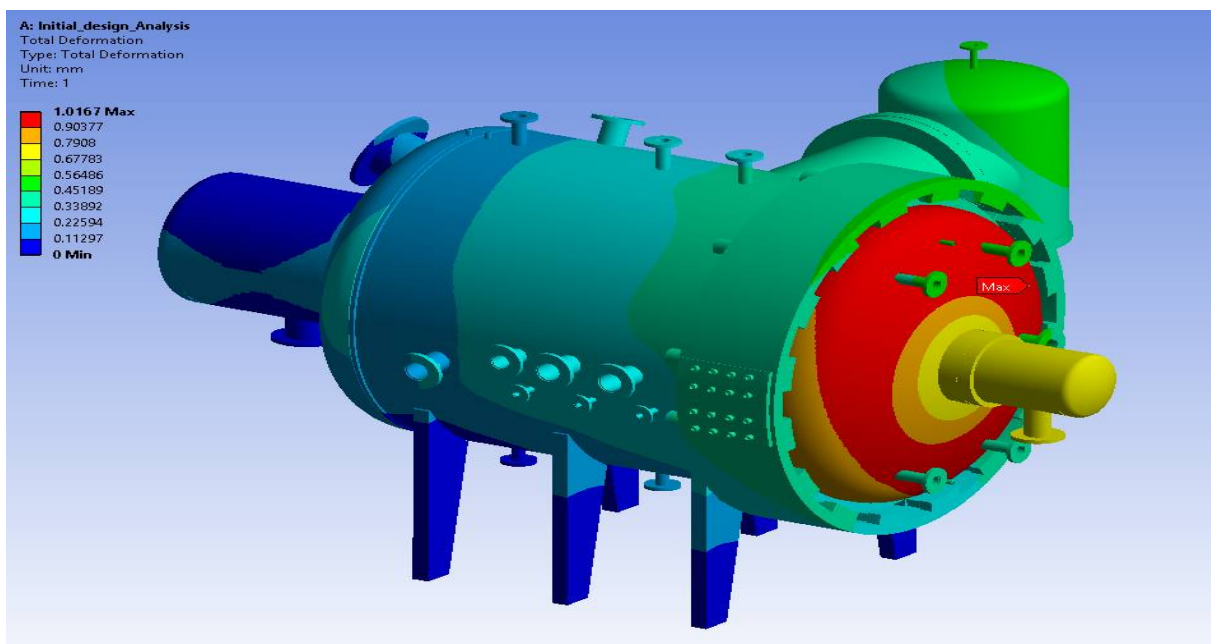


Fig5: Displacement of static analysis

Fig5: shows the total deformation of max 1.0167 mm when design pressure and temperature load applied.

2. VON-MISES STRESS RESULT

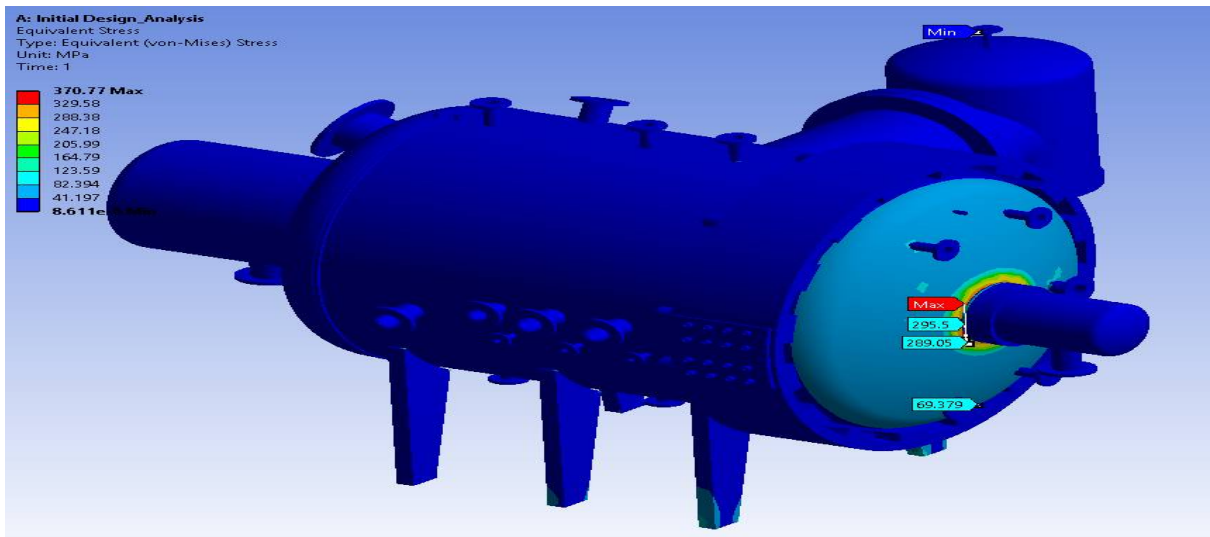


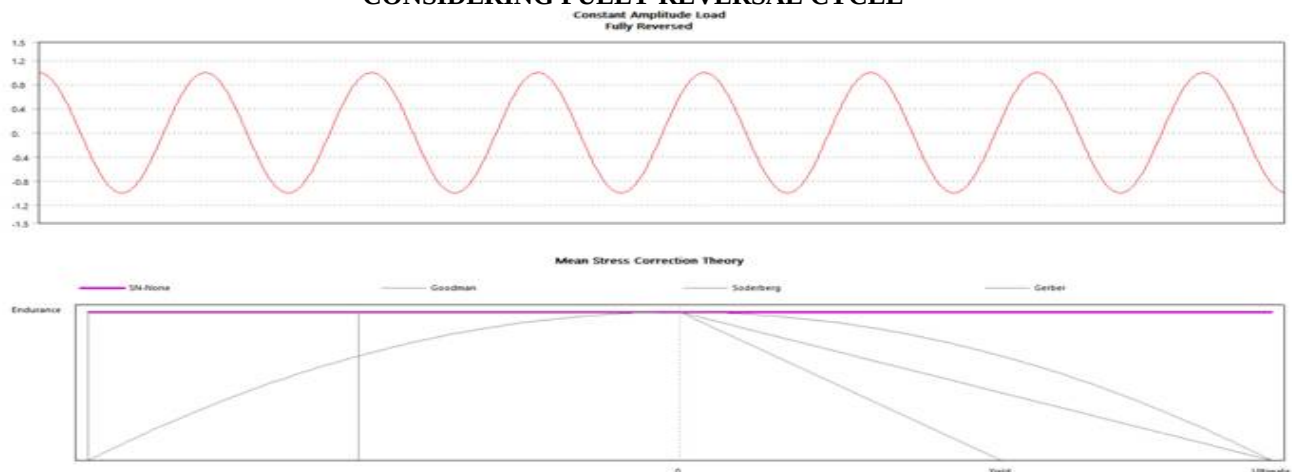
Fig6: Von-mises stress of static analysis

Fig6: shows the equivalent (von-mises) stress of max 370.77 MPa when design pressure and temperature load applied.

FATIGUE ANALYSIS

Fatigue failure is due to repeated loadings, Fatigue is Essentials intended to provide a user friendly tool for conducting Stress-Life analysis either using classical stress calculations, While many parts may work well initially, they often fail in service due to fatigue failure caused by repeated cyclic loading In practice, The purpose of this analysis is to show that this pressure equipment is capable of withstanding the operation for its intended life cycles. Pressure and temperature is changed for operating condition. Due to this stress ranges are induced by the pressure and temperature variations, fatigue crack can be initiated at the discontinuity where fatigue strength is very weak.

CONSIDERING FULLY REVERSAL CYCLE



Constant amplitude load and mean stress correction

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S-N CURVE ALTERNATING STRESS VALUES AND S-N CURVE GRAPH PLOT

	B	C
1	Cycles	Alternating Stress (Pa)
2	10	3.999E+09
3	20	2.827E+09
4	50	1.896E+09
5	100	1.413E+09
6	200	1.069E+09
7	2000	4.41E+08
8	10000	2.62E+08
9	20000	2.14E+08
10	1E+05	1.38E+08
11	2E+05	1.14E+08
12	1E+06	8.62E+07
*		

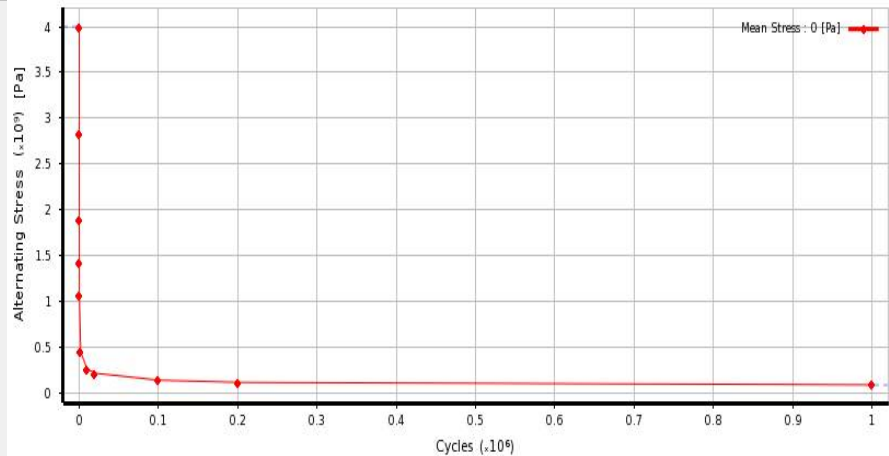


Table2: S-N curve values

Graph1: S-N curve plot

Table 2 gives the values of alternating stress v/s life cycles and graph 1 gives the S-N curve plot alternating stress v/s life cycles.

3. FATIGUE ANALYSIS RESULT

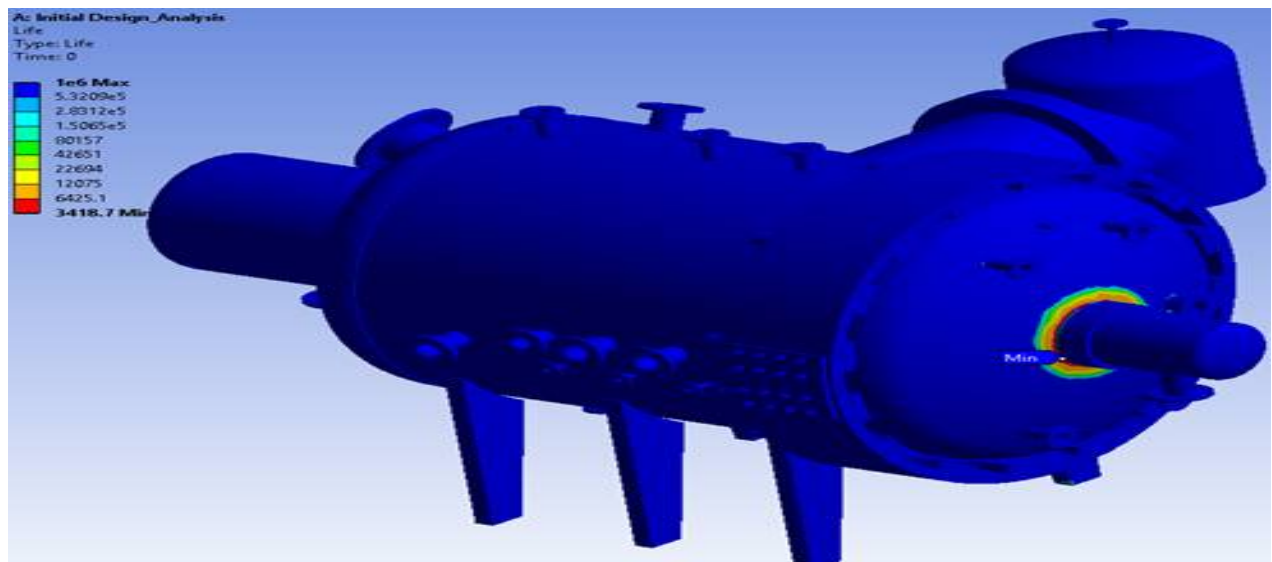


Fig7: fatigue life analysis

Fig 7 gives the fatigue analysis result of minimum life cycle is 3418 for considering fully reversed cycle. Stress Life is based on S-N curves, the high cycle fatigue (hcf) will be greater than 1e6 cycles for infinite life

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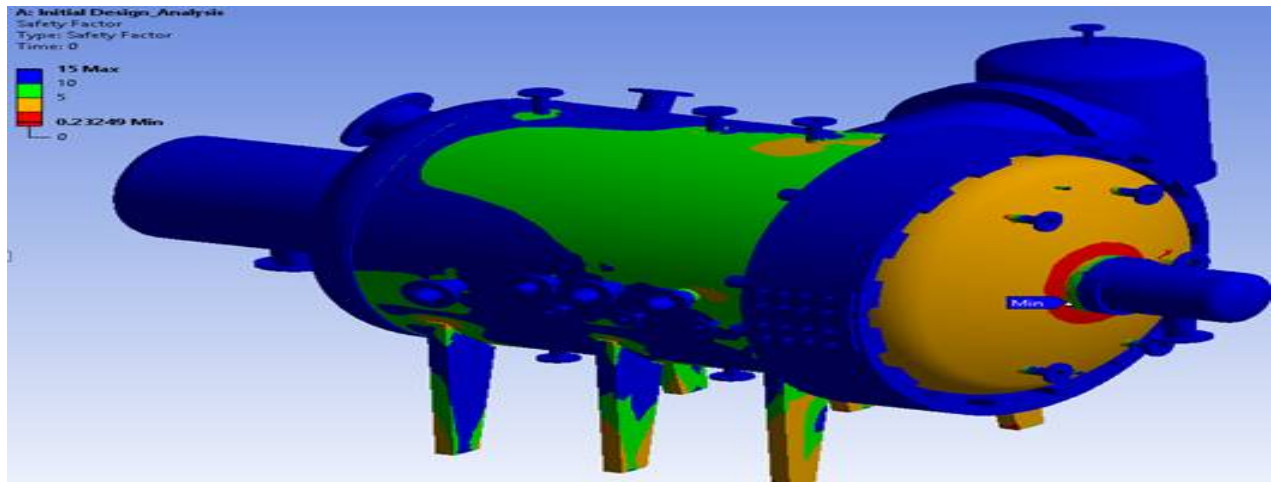


Fig8: safety factor analysis

Fig 8 give the factor of safety analysis result minimum of 0.232 but The Safety factor should be greater than 1 to achieve life cycle greater than 1E6 cycles for fully reversed cycle.

LINEARIZED STRESS CATEGORY

In the FE method, when the structural elements are used in analysis, the total stress distribution is obtained. Therefore, to produce a membrane and bending stresses, the total stress distribution shall be linearized on a stress component basis and used to calculate the equivalent stresses. If the shell elements (shell theory) are used, then membrane and bending stresses will be obtained directly from the shell stress resultants. Membrane and bending stresses are developed on the cross sections through the thickness of the components. These sections are called as stress classification planes (SCPs). In a planar geometry, Stress Classification Line (SCL) is obtained by reducing the two opposite sides of a SCP to an infinitesimal length. The SCPs are flat planes that cut through a section of components and SCLs are the straight lines that cut through a section of a component. SCLs are the surfaces when viewed in an axis-symmetric or planar geometry as shown in Fig 9 gives the linearised equivalent stress results.

4. LINEARIZED STRESS RESULT

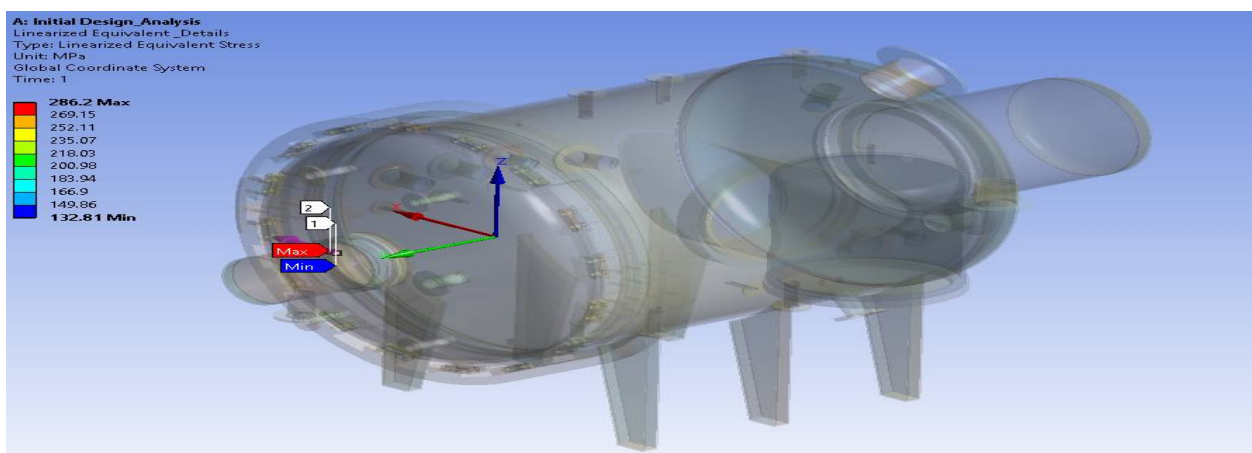


Fig9: linearized equivalent stress analysis

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ALLOWABLE STRESS LIMITS FOR STRESS CATEGORIES

Stress Category	Stress Limit	Normal Operating Condition (200°C), MPa
General Primary Stress	$P_m = S_m$	119
Local Primary Stress	$PL = 1.5S_m$	178.5
Primary and Secondary Stress	$PL + Pb + Q = 3S_m$	357

Table 3: allowable stress limits

LINEARIZED STRESS CATEGORY VALUES

fabular Data						
	Length [mm]	Membrane [MPa]	Bending [MPa]	Membrane+Bending [MPa]	Peak [MPa]	Total [MPa]
13	8.479	254.43	65.379	203.61	1.0614	202.57
14	9.1855	254.43	59.93	207.53	1.1681	206.42
15	9.8921	254.43	54.482	211.52	1.2847	210.33
16	10.599	254.43	49.034	215.58	1.409	214.31
17	11.305	254.43	43.586	219.69	1.5392	218.35
18	12.012	254.43	38.137	223.87	1.6741	222.44
19	12.718	254.43	32.689	228.09	1.8126	226.59
20	13.425	254.43	27.241	232.37	1.9542	230.79
21	14.132	254.43	21.793	236.69	2.0982	235.04
22	14.838	254.43	16.345	241.07	2.2444	239.33
23	15.545	254.43	10.896	245.48	3.5339	243.04
24	16.251	254.43	5.4482	249.93	3.3341	247.6
25	16.958	254.43	0.	254.43	3.136	252.21
26	17.664	254.43	5.4482	258.96	2.9397	256.85
27	18.371	254.43	10.896	263.52	2.7455	261.52
28	19.078	254.43	16.345	268.12	2.5536	266.23
29	19.784	254.43	21.793	272.75	2.3645	270.96
30	20.491	254.43	27.241	277.41	2.1787	275.72
31	21.197	254.43	32.689	282.1	1.997	280.51
32	21.904	254.43	38.137	286.81	1.8203	285.32
33	22.611	254.43	43.586	291.55	1.65	290.16
34	23.317	254.43	49.034	296.31	1.4882	295.01
35	24.024	254.43	54.482	301.1	1.3375	299.89
36	24.73	254.43	59.93	305.91	1.2019	304.79
37	25.437	254.43	65.379	310.74	1.0869	309.7
38	26.143	254.43	70.827	315.59	0.99904	314.64
39	26.85	254.43	76.275	320.46	0.94575	319.59
40	27.557	254.43	81.723	325.35	0.93261	324.56
41	28.263	254.43	87.171	330.25	0.96095	329.54
42	28.97	254.43	92.62	335.18	1.0271	334.54
43	29.676	254.43	98.068	340.12	1.1241	339.55
44	30.383	254.43	103.52	345.07	1.2445	344.57
45	31.09	254.43	108.96	350.04	10.983	360.22
46	31.796	254.43	114.41	355.02	8.3709	362.63
47	32.503	254.43	119.86	360.02	5.8144	365.06
48	33.209	254.43	125.31	365.03	3.44	367.51
49	33.916	254.43	130.76	370.05	2.0374	369.99

Table4: linearised stress category values

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LINEARIZED STRESS RESULTS

Material	Stress Classification	Allowable Stress MPa	Stress Category	Allowable Stress intensity MPa	Induced Stress MPa
SA387GR11 Class2	SC1	119	Membrane	178	254
			Membrane + Bending	357	370

Table 5: linearised stress results

Table 3 shows the allowable stress limit categories, table 4 shows the linerised stress category values and The results obtained by linearized stress categories are shown in table5 , the allowable stress intensity for membrane is 178 MPa but we obtained 254 MPa that will exceeds the value of allowable stress and the allowable stress intensity for secondary stress, membrane + bending is 357 MPa, but we obtained induced stress of 370 MPa ,these stress exceeds the allowable stress of the material hence we need to modified the initial design to obtained minimum allowable stress of material to withstand for the safe design.

MODIFIED DESIGN

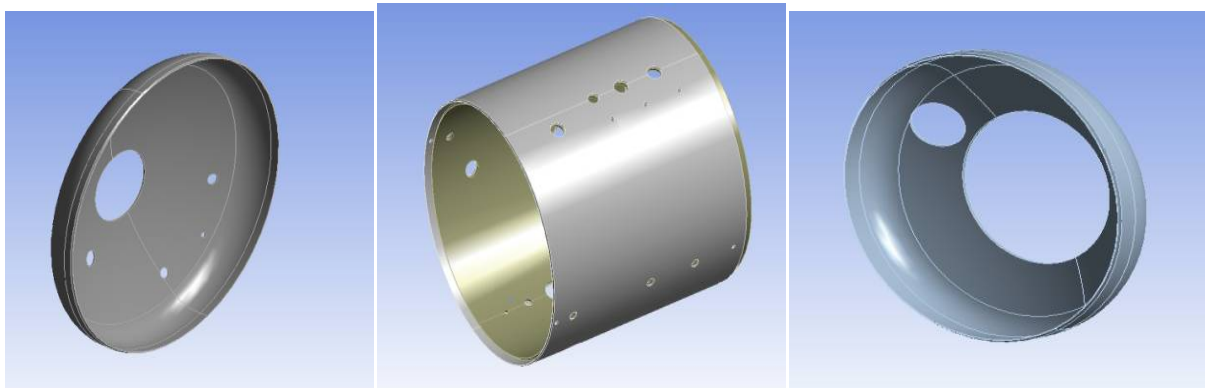


Fig10: modified design modelwhere thickness of shell and heads will increase by 5 mm

The initial design fails to achieve linearised stress categories within their allowable stress limits and the fatigue life obtained the minimum life cycle is 3418 to achieve for infinite life according to stress life s-n curve it should be greater than 10e6 cycles according to stress life s-n curve to achieve life cycle greater than 1e6 the safety factor should be greater than 1 hence we need to modify the initial design to new design in order to overcome all this limits. Since the stresses are more in the cylinder heads and in shell we need to change its thickness according to ASME Section VIII Division 2 as shown fig 10 modified design modelwhere thickness of shell and heads will increase by 5 mm.

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RESULTS FOR MODIFIED DESIGN

1. DISPLACEMENT RESULT

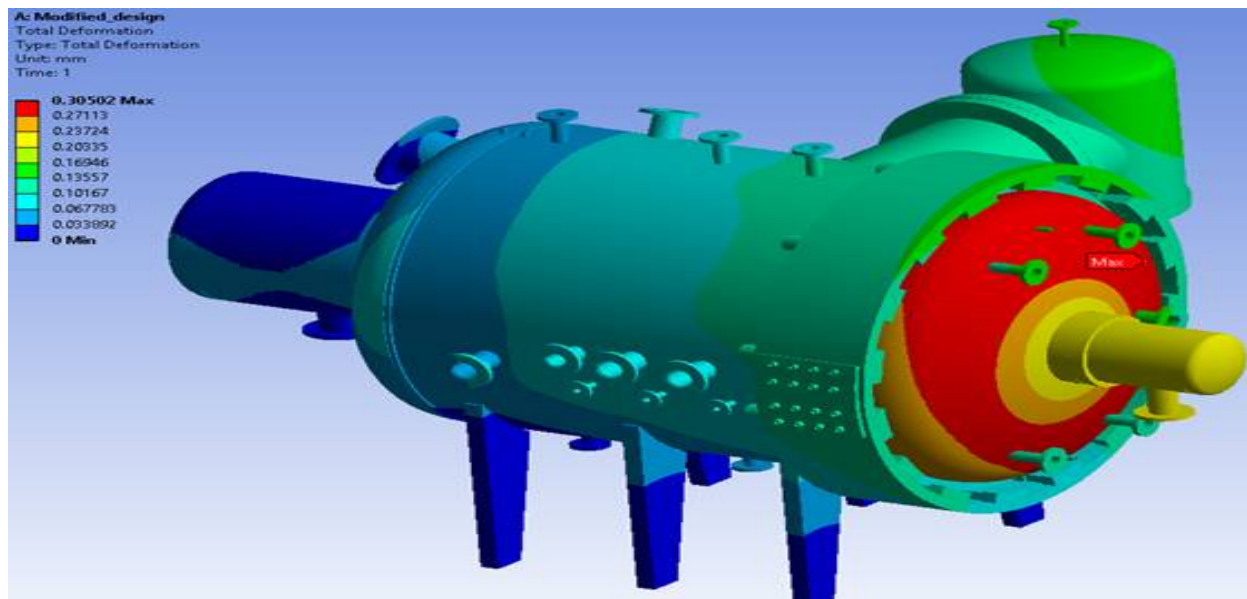


Fig11: Displacement result for modified design

Fig 11 shows the total deformation of max 0.30205 mm for modified design when applied design pressure and temperature load conditions.

2. VON-MISES STRESS RESULT

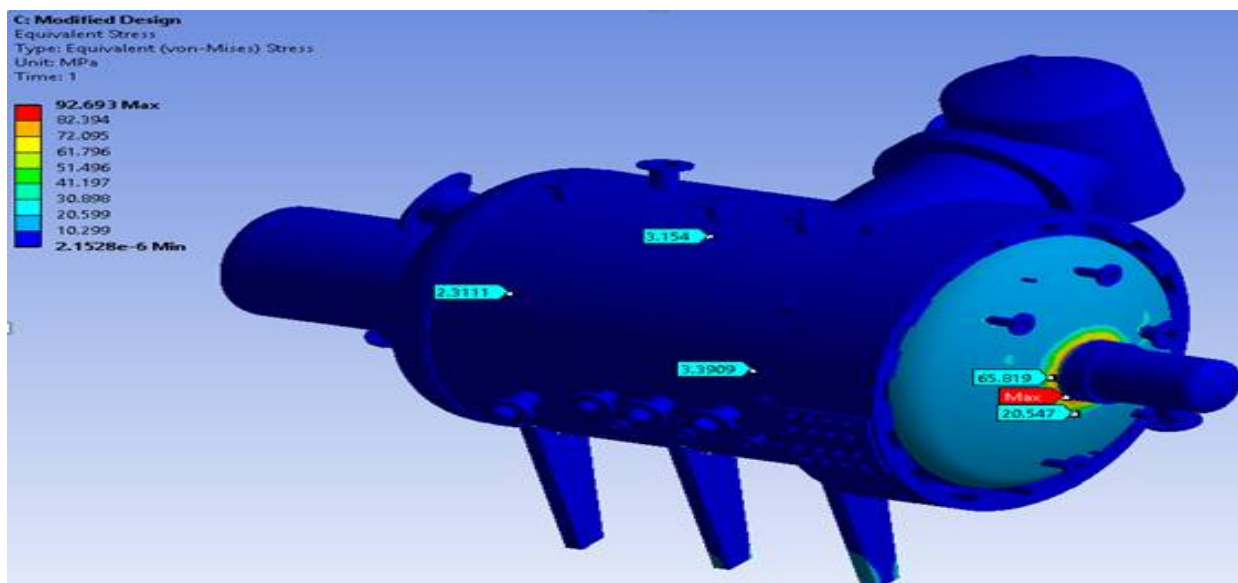


Fig12: von- mises result for modified design

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Fig 12: shows the equivalent (von-mises) stress of max 92.693 MPa for modified design when applied design pressure and temperature load conditions.

3. FATIGUE ANALYSIS RESULTS

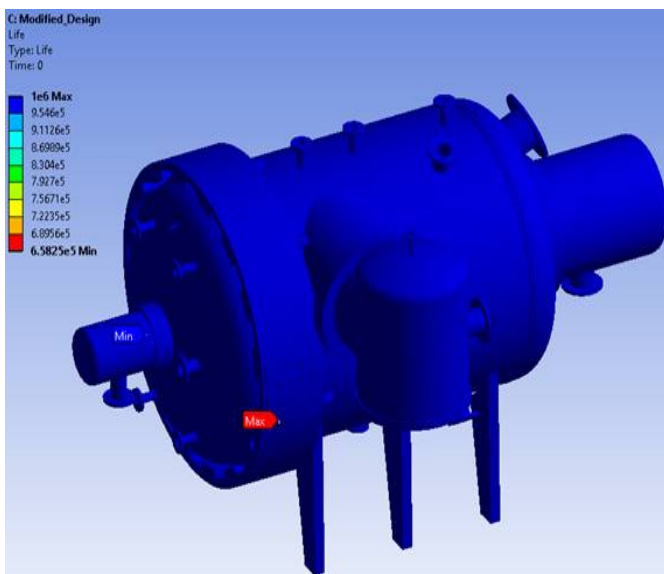


Fig13: fatigue analysis result for modified design

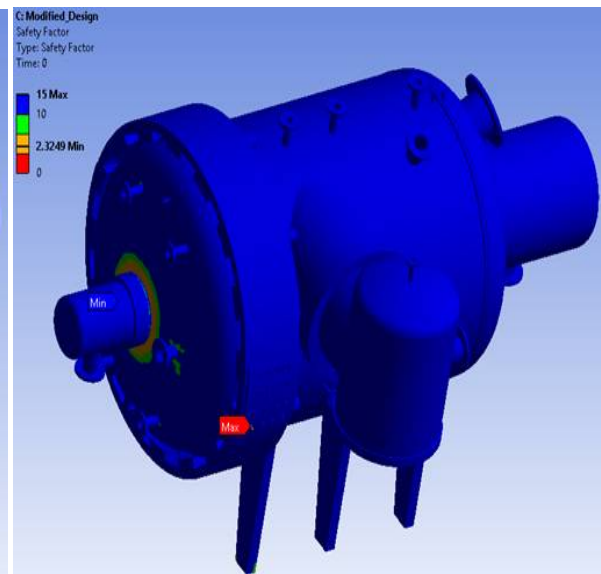


Fig14: safety factor result for modified design

For a modified design of vessel, we obtained the life cycle of minimum 6.5825 cycles for fully reversed cycle for Stress Life based on S-N curves as shown in fig 13 and For a modified design of vessel we obtained the safety factor of min of 2.32 as shown in fig14, for high cycle fatigue should be greater than 1e6 cycles for infinite life, and The Safety factor should be greater than 1 to achieve life cycle greater than 1E6 cycles hence it achieved after modified the model.

4. LINEARIZED STRESS CATEGORY RESULTS

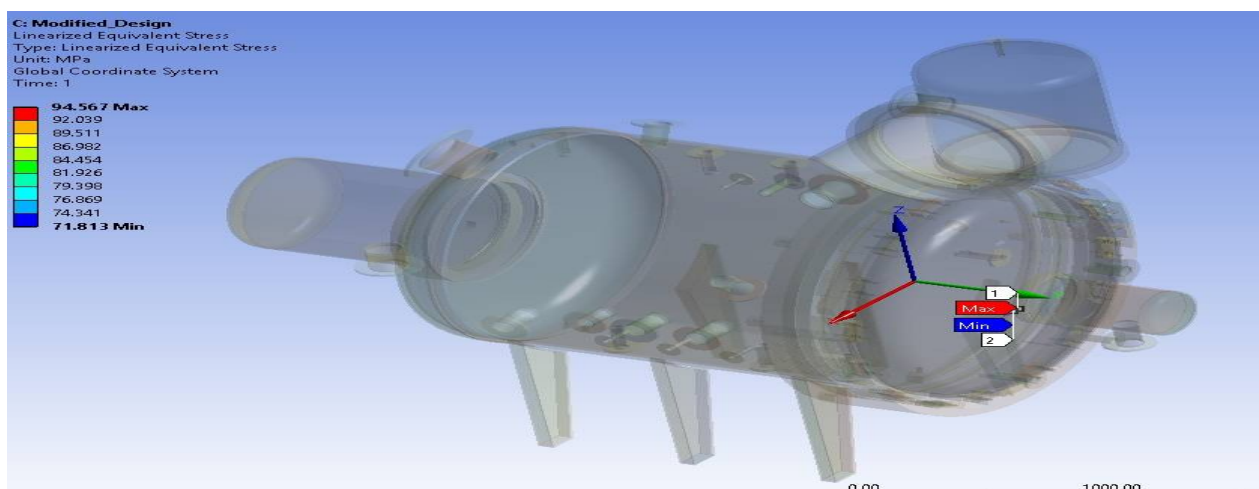


Fig15: linearised stress result for modified design

Fig15 shows the linearised equivalent stress results of max 94.567 MPa for a modified design and load conditions.

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LINEARIZED STRESS CATEGORY VALUES

Tabular Data						
	Length [mm]	Membrane [MPa]	Bending [MPa]	Membrane+Bending [MPa]	Peak [MPa]	Total [MPa]
18	13.02	81.333	4.0088	84.684	3.3795	84.149
19	13.786	81.333	3.4361	84.202	4.0427	83.584
20	14.552	81.333	2.8634	83.721	4.7059	83.025
21	15.318	81.333	2.2907	83.241	5.3691	82.472
22	16.084	81.333	1.7181	82.762	6.0324	81.925
23	16.85	81.333	1.1454	82.285	6.6957	81.385
24	17.615	81.333	0.57269	81.809	7.3085	80.86
25	18.381	81.333	4.0432e-016	81.333	6.6973	80.46
26	19.147	81.333	0.57269	80.86	6.1992	80.056
27	19.913	81.333	1.1454	80.387	5.7015	79.657
28	20.679	81.333	1.7181	79.916	5.2042	79.262
29	21.445	81.333	2.2907	79.446	4.7077	78.872
30	22.211	81.333	2.8634	78.977	4.2121	78.487
31	22.977	81.333	3.4361	78.51	3.7179	78.108
32	23.743	81.333	4.0088	78.045	3.2255	77.733
33	24.508	81.333	4.5815	77.58	2.7361	77.363
34	25.274	81.333	5.1542	77.117	2.2516	76.998
35	26.04	81.333	5.7269	76.656	1.776	76.638
36	26.806	81.333	6.2996	76.196	1.3189	76.284
37	27.572	81.333	6.8722	75.738	0.90867	75.935
38	28.338	81.333	7.4449	75.281	0.64257	75.592
39	29.104	81.333	8.0176	74.826	0.70788	75.254
40	29.87	81.333	8.5903	74.372	1.0582	74.941
41	30.636	81.333	9.163	73.92	1.6974	74.534
42	31.401	81.333	9.7357	73.47	2.6015	74.135
43	32.167	81.333	10.308	73.022	3.5597	73.753
44	32.933	81.333	10.881	72.575	4.5365	73.387
45	33.699	81.333	11.454	72.13	5.5211	73.038
46	34.465	81.333	12.026	71.687	6.5089	72.706
47	35.231	81.333	12.599	71.246	7.498	72.391
48	35.997	81.333	13.172	70.806	8.4872	72.094
49	36.763	81.333	13.744	70.369	9.4758	71.813

Table6: linearised stress category values for modified design

ALLOWABLE STRESS LIMITS FOR STRESS CATEGORIES

Stress Category	Stress Limit	Normal Operating Condition (200°C) MPa
General Primary Stress	$P_m = S_m$	119
Local Primary Stress	$PL = 1.5S_m$	178.5
Primary and Secondary Stress	$PL + Pb + Q = 3S_m$	357

Table 7: allowable stress limits

STRESS LINEARIZATION RESULTS AFTER MODIFIED DESIGN

Material	Stress Classification	Allowable Stress MPa	Stress Category	Allowable Stress intensity MPa	Induced Stress MPa
SA387GR11Class2	SC1	119	Membrane	178	81
			Membrane + Bending	357	94

Table8: stress linearization results for modified design

VIII. CONCLUSION

The main objective of this project is to design and evaluation the pressure vessel as per ASME sec VIII div 2, and determining the static and thermal analysis considering for a given pressure and temperature design conditions. Fatigue Analysis was carried out in accordance with ASME Section VIII Division 2 part 5 Design by Analysis, obtained the

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stress linearization values greater than the allowable stresses of the material and obtained the min fatigue life less than $1e6$ cycles and where as the safety factor of less than 1 when considering fully reversal cycle hence the designed fail. The modified pressure vessel design has an increased the thickness of the pressure vessel heads and shell by 5mm in accordance to ASME sec VIII Division 2 rules, the results obtained after increasing the thickness of vessel as shown in Table 6 gives the value of linearised stress category, Table 7 gives the allowable stress limits and Table 8 gives the stress linearization results for modified design and hence obtained the induced stress values below the allowable stress limits of the materials and obtained the min fatigue life cycle greater than $1e6$ cycles for infinite life design and with factor of safety more than 1 to achieve fatigue life greater than $1e6$ cycles for considering fully reversal cycle.

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