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Effect of Manufacturing Tolerance on Pressure Vessel

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Abstract—After literature review and interviewing with expert they suggested gaps where one can work in pressure vessel domain especially on influencing factors related to pressure vessel cylinder design. Influence of manufacturing tolerance, heat treatment process parameters and material composition on Cylinder. Influence of welding methods and subsequent stress relieving processes on some pressure vessel cylinder. Here in this paper manufacturing tolerances are considered and relation between the manufacturing tolerance on strength and cost is obtained. In actual practices it is not possible to manufacture the pressure vessel with the defined dimensions. The tolerance variation is affecting on strength and cost of pressure vessel. For getting the relationship between the tolerance, strength and cost of pressure the FEA, RSM, ANOVA are used.

Keywords—Pressure Vessel, strength, cost, Tolerance, FEA, RSM

INTRODUCTION:

In the design stage the manufacturing uncertainty [1] is constriant that to be considered. For the pressure vessel(PV) tolerance may be given to the thickness or any geometriacal dimensions[3]. In the PV different manufacturing processes are carried out and tolerances are considered at each stage. Auther used the different methods like FEA regression and neural network. Here effect of tolerance is observed on the strength and cost.[9]

A) Effect on Strength:

1 INTRODUCTION:

To study the effect of tolerance on strength the FEA and Optimization techniques are used. In this modeling of thin PV in FEA package ANSYS 14. Initially hoop stresses (HS) are obtained by varying the design parameters Thickness (T), Length (L), inner radius (Ri) and Pressure (P). For getting HS at different intervals of design parameter, Response Surface Method (RSM) is used. RSM is type of probabilistic design. 30 simulations are run for getting 30 values of HS. Following methodology is adopted for getting relationship between HS and tolerance. At the end non linear relationship between HS and tolerances is obtained.

Initially relationship between hoop stress and Input parameters is obtained by using FEA.
i.e. Hoop stress = f (T, L, Ri, P)----------------(1)
Mathematically for the thin vessel formula [16] is
Hoop Stress = P*R/(2*T) ------------------(2)
Equation (1) is validated by using equation (2)

It shows that obtained relationship is in good agreement. It can be said that written program in FEA software is validated.

Moreover same program is used for next simulation which is to be run for getting the relationship between Hoop Stress and tolerance.
i.e. Hoop Stress = f (tolerance)

2 TOLERANCE:

Following table shows tolerance limit of parameters are referred from the industry and ASME Sec VIII Div 1 & II [11] [12] for case study.

Table 1 Tolerance Parameters

Sr. No.	Parameter	Mean value	Tolerance
1	Pressure	0.2 N/mm^2	-0.1 to +0.1
2	Radius	1000mm	-3.0 to +3.0
3	Thickness	6 mm	-0.7 to +0.7
4	Length	5000mm	-5.0 to +5.0

1000 simulations are carried out at any interval within 1000 and Hoop Stress is obtained. Output data of simulation is given as input to non linear relation between Hoop Stress and tolerance.

3 FINITE ELEMENT MODELING (FEM):

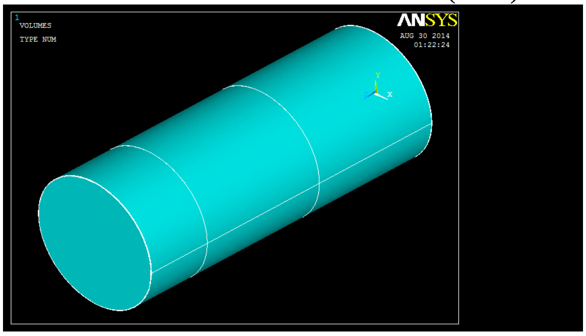

Fig. 1 Pressure Vessel model

Modeling of pressure vessel is drawn in ANSYS 14 and it is meshed by using 4node tetrahedron (solid 285), as tetrahedron supports linear and non linear elasticity and plasticity. Also it supports contact pair by using rigid elements such as CONTA 178 and TARGET 176 as shell elements does not support welding by using rigid elements.

Model is meshed and 15893 number of elements and 5443 nodes are generated. Tetrahedron element is used.

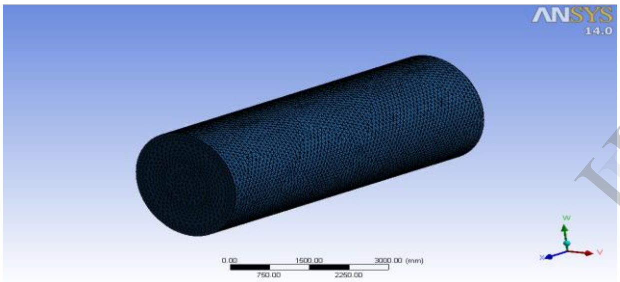

Fig. 2 Meshed model

Moreover, response surface modeling by using central composite design is carried out in ANSYS probabilistic design module. Total 30 simulations with variation of input parameters are solved.

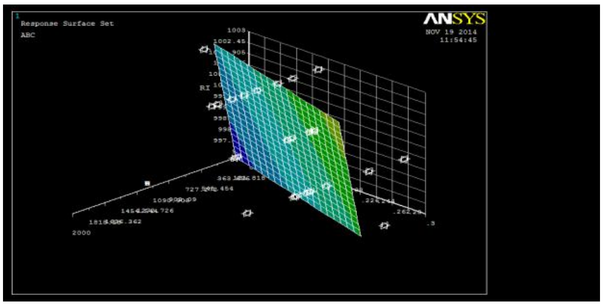

Fig. a) Tolerance P, Di & Ri vs. HS

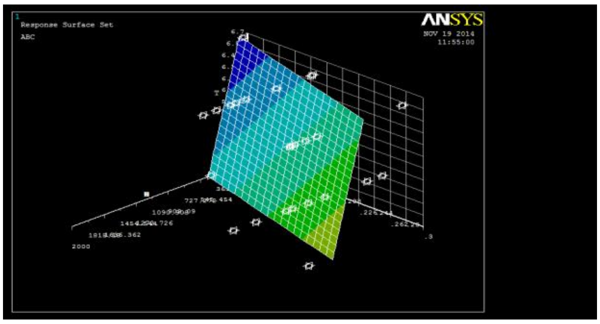

Fig. b) Tolerance P, Di & T on vs. HS

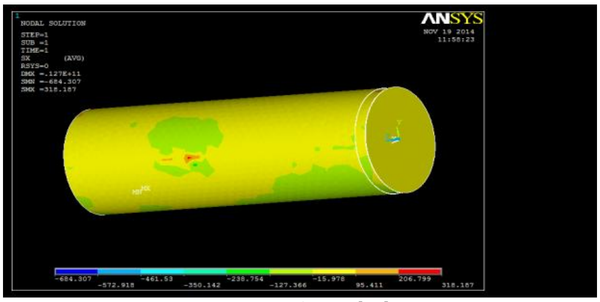

Fig. c) Residual stress

Fig. 3 Contour plot of stress vs. tolerance

4. RESPONSE SURFACE METHOD: (RSM)

Following output values of hoop stress are generated with respect to input parameters and these are compared with hoop stress obtained by standard equation for thin cylinder.

Table 2 DOE table of Hoop stress(N/mm^2)

Sr. No.	P	Ri	T	L	ANSYS	Hoop stress= P Ri/2T	% error
1.	0.3	997	6.7	4995	24.0109	22.3209	7.038471
2.	0.3	997	5.3	5005	29.90698	28.21698	5.650855
3.	0.1	1003	5.3	5005	10.49226	9.462264	9.816756
4.	0.1	997	5.3	4995	10.43566	9.40566	9.870003
5.	0.1	997	6.7	5005	8.370299	7.440299	11.11071
6.	0.3	1003	6.7	5005	24.14522	22.45522	6.999314
7.	0.2	1000	6	5000	18.35667	16.66667	9.206464
8.	0.1	1003	6.7	4995	8.395075	7.485075	10.83969
9.	0.3	1003	5.3	4995	29.29679	28.38679	3.106142
10.	0.2	1000	6	5000	18.35667	16.66667	9.206464
11.	0.2	1000	6	5000	18.35667	16.66667	9.206464
12.	0.2	1000	6	5000	16.7	16.66667	0.199601
13.	0.2	1000	7.4	5000	**15.20351**	**13.51351**	**11.11585**
14.	0.2	1000	6	5000	18.35667	16.66667	9.206464
15.	0.2	1000	6	4990	18.35667	16.66667	9.206464
16.	0.2	1006	6	5000	18.45667	16.76667	9.156583
17.	0.4	1000	6	5000	35.02333	33.33333	4.825355
18.	0.2	1000	6	5010	18.35667	16.66667	9.206464
19.	0.2	994	6	5000	18.25667	16.56667	9.256892
20.	0.2	1000	4.6	5000	23.42913	21.73913	7.213243
21.	0.1	997	5.3	5005	10.50566	9.40566	10.47055
22.	0.2	1000	6	5000	17.76667	16.66667	6.19137
23.	0.2	1000	6	5000	17.76667	16.66667	6.19137
24.	0.3	1003	5.3	5005	30.07679	28.38679	5.61895
25.	0.3	1003	6.7	4995	25.14522	22.45522	10.69786
26.	0.1	1003	5.3	4995	10.59226	9.462264	10.66816
27.	0.1	1003	6.7	5005	8.255075	7.485075	9.327596
28.	0.1	997	6.7	4995	8.210299	7.440299	9.378465
29.	0.3	997	6.7	5005	23.0909	22.3209	3.334648
30.	0.3	997	5.3	4995	28.98698	28.21698	2.656365

It is observed that there is maximum 11% deviation in results obtained by FEA and Standard equation. Above data is analyzed in ANSYS software and following relationship is obtained in between input parameter and hoop stress.

Hoop Stress = 0.353955 + 84.0715 P + 0.01682 Ri - 2.85665 T - 2.20707e-017 L

5. RSM analysis:

Table 3 RSM values

Factors: 4	Replicates: 1			
Base runs: 30	Total runs: 30			
Base blocks: 3	Total blocks: 3			
Two-level factorial: Full factorial				
Cube points: 16				
Center points in cube: 4	Axial points: 8			
Center points in axial: 2	Alpha: 2			
Regression Analysis: STRESS versus P, Ri, T & L				
The regression equation is				
Hoop Stress = 0.353955 + 84.0715 P + 0.01682 Ri - 2.85665 T - 2.20707e-017 L				
Predictor	Coef	SE Coef	T	P
Constant	0.354	179.201	0.002	0.998
P	84.0715	1.868	44.9945	0.000
Ri	0.0168	0.057	0.2968	0.769
T	-2.8566	0.243	-11.7627	0.000
L	-0.00	0.034	-0.00	1.000

The obtained data is used for regression analaysis and equation is found.

S = 0.832822 R-Sq = 98.86% R-Sq(adj) = 98.67% PRESS = 27.5706 R-Sq(pred) = 98.18%

6. RELATIONSHIP BETWEEN TOLERANCE AND STRENGTH

Non linear regression has been carried out in mini tab. By using data obtained from finite element analysis. Following non linear relationship is obtained in between hoop stress and tolerance.

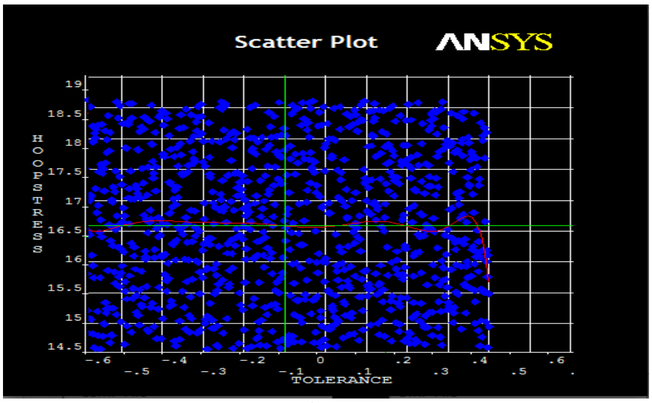

Fig. 4 scatter plot of hoop stress vs. tolerance

Fig.4 shows nonlinear relation between tolerance and hoop stress. It is observed that there is more scatter in hoop stress value when tolerance varied from 0.1 to 0.4 mm. Red colour lines in graph represents polynomial curve. Uncertain data obtained from analysis is fitted on line of 21 degree. Also there is more variation curve shape in the region of 0.1 mm to 0.4mm. There is less variation in curve in region -0.6 to -0.2 mm. It is observed that hoop stress uncertain with respect to tolerances. Therefore non linear regression is carried out and following relationship is obtained which shows uncertainty in hoop stress with respect to tolerance value.

Hoop Stress = 1 - 1 / (Tolerance^ 0.008)

B. EFFECT OF TOLERANCE ON COST

1. Introduction:

Cost is the main parameter from the manufacturer as well as from the customer point of view. So this must be considered at the design stage only. Few authors [5][10] have worked on the cost.

To study the effect of manufacturing tolerance on the cost of pressure vessel the same live case study is taken as stated previous. The optimization technique i.e. RSM and ANOVA are used.

Here for the cost calculation the different cost are considered these are raw material cost, manufacturing cost and other expenditures. By combining these cost the total cost is calculated and the graphs are plotted which are showing the relationship between the tolerance and cost.

The tolerance is given to the plate or sheet i.e. input parameter of PV. For the plate the input parameters are length (L), width (W) and thickness (T) are considered. Considering the variation in plate dimensions the effect on cost is plotted and predicted.

2. Tolerance: Here to study the effect of manufacturing tolerance the sheet is considered. The tolerance on the sheet is taken into consideration. The tolerance given to sheet is studied and effect on the cost is determined with best optimized values. Sheet is used to manufacture the pressure vessel. Tolerance for the sheet is considered. The parameter where tolerance is to be considered for the sheet is Length, width and thickness.

Table 4 Parameters and levels

Level(tolerance) / Parameter	-1	0	+1
1. Length	12.4	12.5	12.6
2. Thickness	5	6	7
3. Width	2.45	2.50	2.55

3. DOE table for COST:

DOE table for the cost is as shown in the table 6

4 Analysis of Variance for total cost

Table 5 RSM values

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	4684357101	4684357101	1561452367	14578.06	0
Linear	3	4684357101	4684357101	1561452367	14578.06	0
L	1	10615438	10615438	10615438	99.11	0
W	1	66346490	66346490	66346490	619.43	0
T	1	4607395172	4607395172	4607395172	43015.64	0
Residual Error	16	1713756	1713756	107110		
Lack-of-Fit	11	1713756	1713756	155796		
Pure Error	5	0	0	0		
Total	19	4686070857				

S = 327.276 Press = 4056228
R-Sq = 99.96% R-Sq (Pred) = 99.91%
R-Sq (Adj) = 99.96%

The Regression Equation Is

Total cost = - 202578 + 10303 L + 51515.6 W + 214648 T

5 SURFACE, CONTOUR AND OPTIMIZATION PLOTS:

The surface, contour and optimization plots are drawn in the fig. 5

In general from this plots it is clear that the value of parameter for the minimum cost should be selected at the bottom of left side.

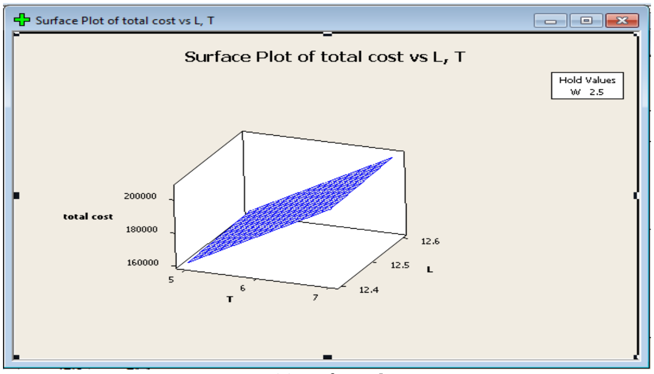

Fig.(a) surface plot

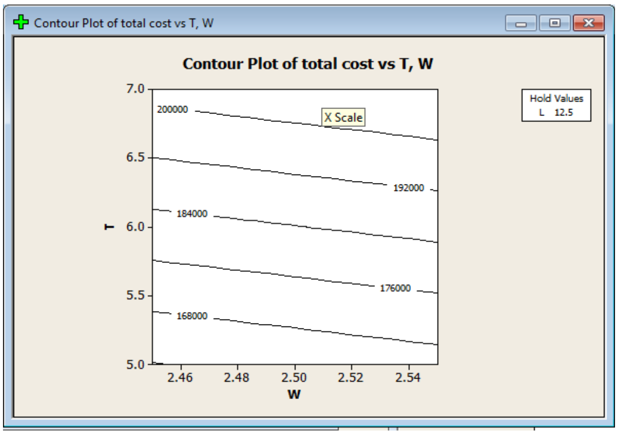

Fig.(b) contour plot cost vs T,W

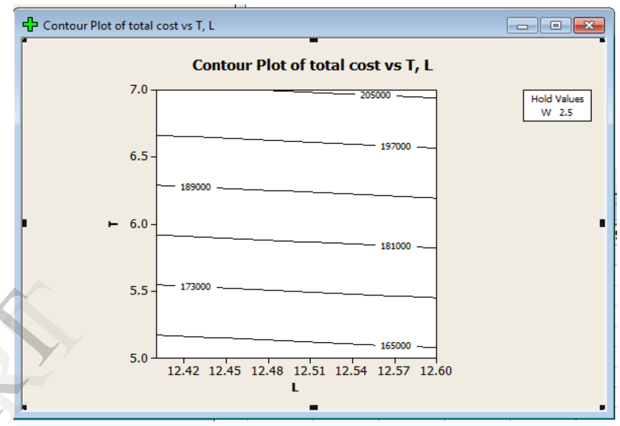

Fig.(c) contour plot cost vs T,L

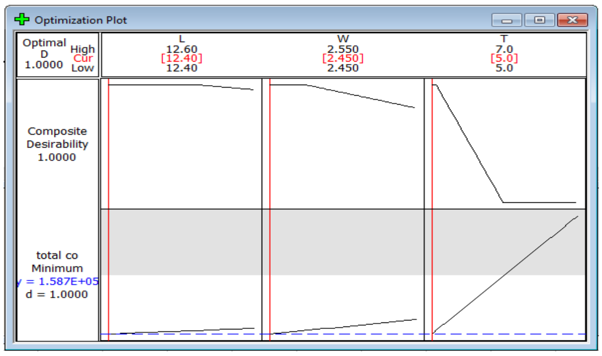

Fig.(d) optimization plot

Fig. 5 Plots

Table 6 DOE values for the cost

Sr. No.	L	W	T	Weight	Sheet cost	Mfg Cost	Other	Total Cost
1.	12.5	2.5	5	156.25	61328.125	45996.09	55000	162324.22
2.	12.5	2.5	6	187.5	73593.75	55195.31	55000	183789.06
3.	12.5	2.55	6	191.25	75065.625	56299.22	55000	186364.84
4.	12.4	2.5	6	186	73005	54753.75	55000	182758.75
5.	12.5	2.5	7	218.75	85859.375	64394.53	55000	205253.91
6.	12.5	2.45	6	183.75	72121.875	54091.41	55000	181213.28
7.	12.5	2.5	6	187.5	73593.75	55195.31	55000	183789.06
8.	12.6	2.5	6	189	74182.5	55636.88	55000	184819.38
9.	12.4	2.45	7	212.66	83469.05	62601.79	55000	201070.84
10.	12.5	2.5	6	187.5	73593.75	55195.31	55000	183789.06
11.	12.6	2.45	7	216.09	84815.325	63611.49	55000	203426.82
12.	12.4	2.55	7	221.34	86875.95	65156.96	55000	207032.91
13.	12.4	2.45	5	151.9	59620.75	44715.56	55000	159336.31
14.	12.6	2.55	5	160.65	63055.125	47291.34	55000	165346.47
15.	12.5	2.5	6	187.5	73593.75	55195.31	55000	183789.06
16.	12.4	2.55	5	158.1	62054.25	46540.69	55000	163594.94
17.	12.6	2.45	5	154.35	60582.375	45436.78	55000	161019.16
18.	12.5	2.5	6	187.5	73593.75	55195.31	55000	183789.06
19.	12.6	2.55	7	224.91	88277.175	66207.88	55000	209485.06
20.	12.5	2.5	6	187.5	73593.75	55195.31	55000	183789.06

RESULT & DISCUSSION:

a) Main effect Plot for strength:

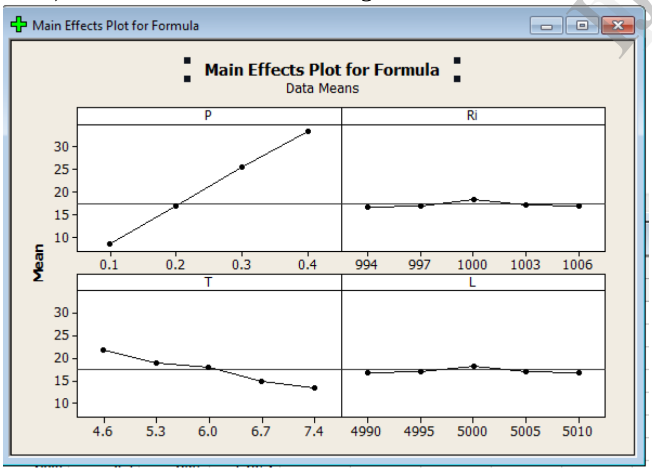

Fig. 6 Main effect plot for stress

From the main effect plot of hoop stress it is clear that the pressure is the main parameter to be considered in the design of pressure for considering
the stress. Pressure affects very rapidly on hoop stress. As thickness increases the stress decrease

Length and radius are comparatively insignificant parameters.

b) Main effect Plot for cost:

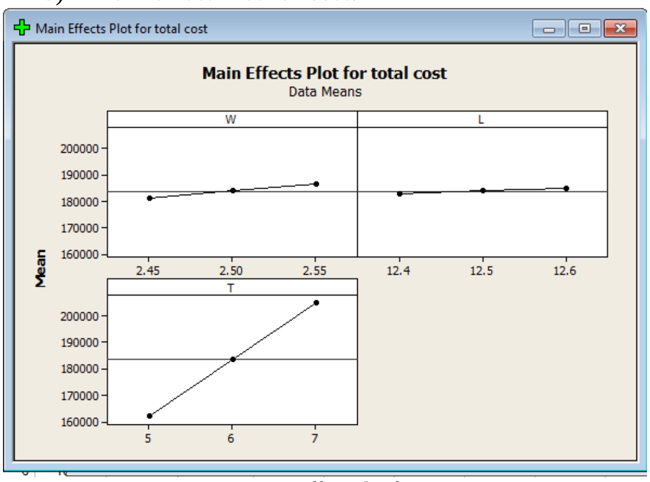

Fig. 7 Main effect plot for cost

From the main effect plot of cost it is clear that the thickness is the main parameter to be considered in the design stage for the cost calculation. Width and length are comparatively less signifcant.

CONCLUSION:

1. Non linear relationship is obtained between the tolerance, strength and cost.
2. Manufacturing tolerances plays very important role at the design stage of pressure vessel.
3. Pressure and thickness are the significant parameters which affects on the hoop stress of pressure vessel.
4. Thickness is affecting on the cost of pressure vessel.

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