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# Design of experiment approach for stress assessment in saddle supported pressure vessels

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Abstract —*Horizontal pressure vessels supported with the saddles are subjected to high stresses near saddle vessel interface area. An accurate analysis of the local stresses and displacements of the vessels is thus of great importance. This paper aims to carry out the study of effect of design parameters in the stress distribution in vessel for saddle supported pressure vessel with industrial problem. The finite element analysis has been carried out in ANSYS 15.0 at actual loading condition of vessel and mesh convergence has been achieved. The design of experiment has been carried out by Taguchi method. L25 orthogonal array has been designed to carry out experimentation. Total 5 factors namely wear plate width ,saddle width, distance of saddle from head, saddle wrap angle and wear plate extension have been selected for the Taguchi experimentation. Further simulation has been carried out in ANSYS 15.0 for Taguchi experimentation. Main effect plots and Regression equations have been obtained. The suggested model can be used for predicting the values of stress and the effect of parameters on the stress distributions.*

***Keywords****-saddle supported vessels, Finite Element Analysis, Taguchi experimental design, L25 orthogonal Array, Regression Equation*

## I. INTRODUCTION

The horizontal pressure vessels are supported on saddles. Most of the pressure vessels are used in chemical industries. As the pressure vessels are always under severe loading conditions due to pressure, forces, moments, temperature in addition to exposure to chemical reactions. It is mandatory to design the Pressure vessel in compliance with the various codes. ASME code is predominantly used for design and fabrication of pressure vessel. As the code is very strict due to the safety aspects in general the design obtained by codes are not cost effective. In the present era of global competitions it is desirable that the designer should also look to reduce the factor of safety. The designer are required to apply latest design and analysis packages to maintain the safety along with reduction in cost.FEA and Design of Experiments can be effectively used to design a product along with consideration to safety and cost aspects. In horizontal saddle supported large pressure vessel the saddle horn area and the supports are having high stress values due to the membrane and bending stresses. The ASME CODE [3] does not give any guidelines for design of saddles. The saddles are designed empirically in accordance with the procedure given by Zick[11].

A precise study of the membrane and bending stresses and deformations of the vessel and saddle is critical and has obtained the attention to researchers. Ong [2] studied the horizontal storage vessel for circumferential stress for various configurations. Nash et al. [10] investigated the plastic collapse of horizontal saddle supported storage vessels along with parametric study. FEM has been applied effectively for finding stress distribution in saddle supported pressure vessel along with effect of individual parameters by Shafique M.A.Khan [13].Parametric analysis for horizontal vessel was performed by Finite element method and further results were compared with experimentation on small scale model by L.yang et al. [7]. Widera et al. [1] and K.Magnucki et al. [8] also performed study of horizontal pressure vessel for different range of various parameters with the help of finite element method.

With a consideration of above literature reviews that saddle supports have not been studied in great detail. This research aims to study the effect of various design parameters in the stress distribution in vessel for saddle supported pressure vessel with industrial problem. The case study of industrial pressure vessel has been taken and CAD model has been created with real geometry of pressure vessel. The model has been simulated with actual boundary conditions and finite element method has been applied in ANSYS 15.0 to analyze the effect of various parameters on the stress distributions in the pressure vessel. Taguchi method has been applied for design of experiment and regression equations have been developed for stress in the horn area.

## II. PROBLEM SETUP

### 2.1 Design Data

The case study has been taken with MetalFab Engineers Surat. The vessel has been designed as per code ASME SECTION VIII DIV. 1 [3] and following dimensions are obtained.

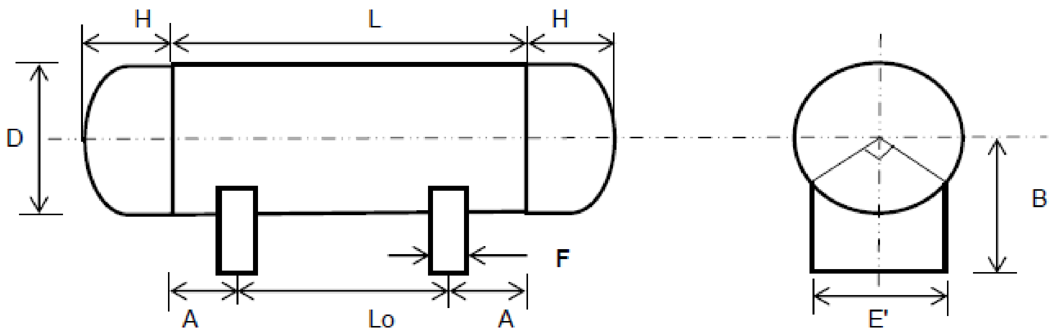


***Figure 1. Vessel Geometry***

***Table 1. Vessel and Saddle Design Data***

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | Vessel Design pressure | P | 6.3 $Kg/cm^2$ | Centre height of Vessel | B | 2000 |
| 2 | Joint Efficiency (Full X ray) | E | 1 | Included Angle of Saddle | 2Ɵ | 140 |
| 3 | Vessel Diameter OD | D | 3024 mm | Saddle width | E' | 2850 |
| 4 | Length of Vessel (Tan to Tan) | L | 8000 mm | Saddle Breadth | F | 300 |
| 5 | Dished End height H | H | 762 mm | Wear/Pad Plate thickness | tw | 16 |
| 6 | CC distance between saddle | Lo | 6600 mm | Density of medium to be stored | ρ | 985 $kg/cm^2$ |
| 7 | Max. Overhang of Vessel from Saddle | X | 1462 mm | Vessel Tangent line from Saddle | A | 700 |
| 8 | Shell Thickness | ts | 12 | Weight of Vessel | W | 12200 kg |
| 9 | Dished End Thickness | te | 12 | Content weight | Wt | 53264 kg |
| 10 | Volumetric Capacity of Vessel | V | 63.62 | Operating weight | Wo | 65464 kg |

**2.2 Finite element analysis**

The geometry has been created in Creo parametric and further exported to ANSYS 15.0 for finite element analysis. The element type selected for the FEA is 8 node brick elements for ANSYS Library. The vessel has been applied boundary condition as shown in figure 4 as per the design data by applying internal and hydrostatic pressure. Both the saddles have been considered as fixed support. The weight of vessel is considered also for the analysis purpose.

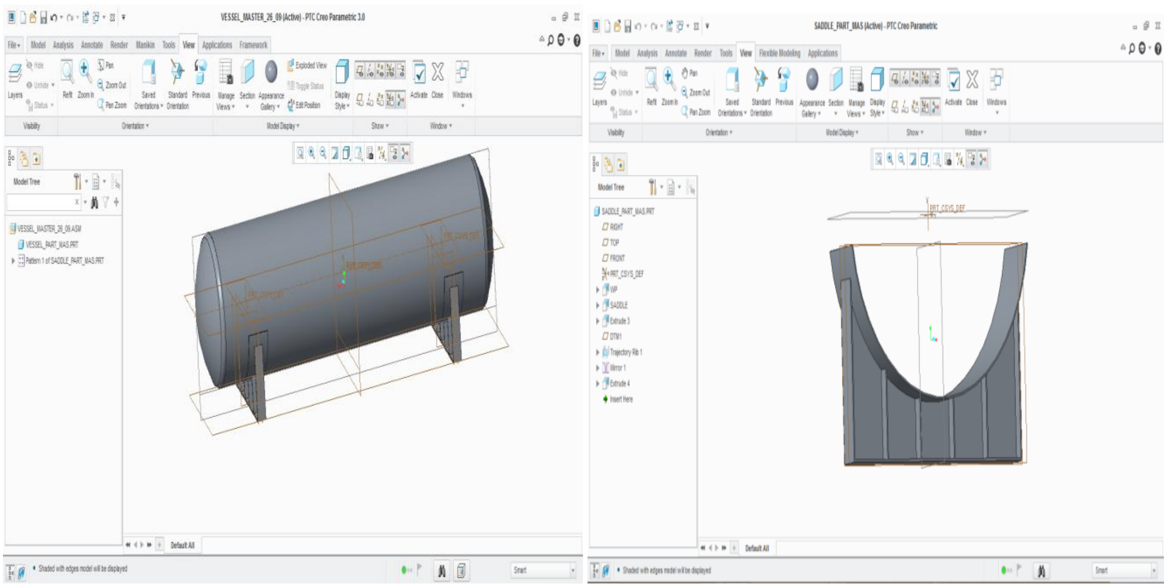

***Figure 2. CAD Model of Vessel with saddle***

 

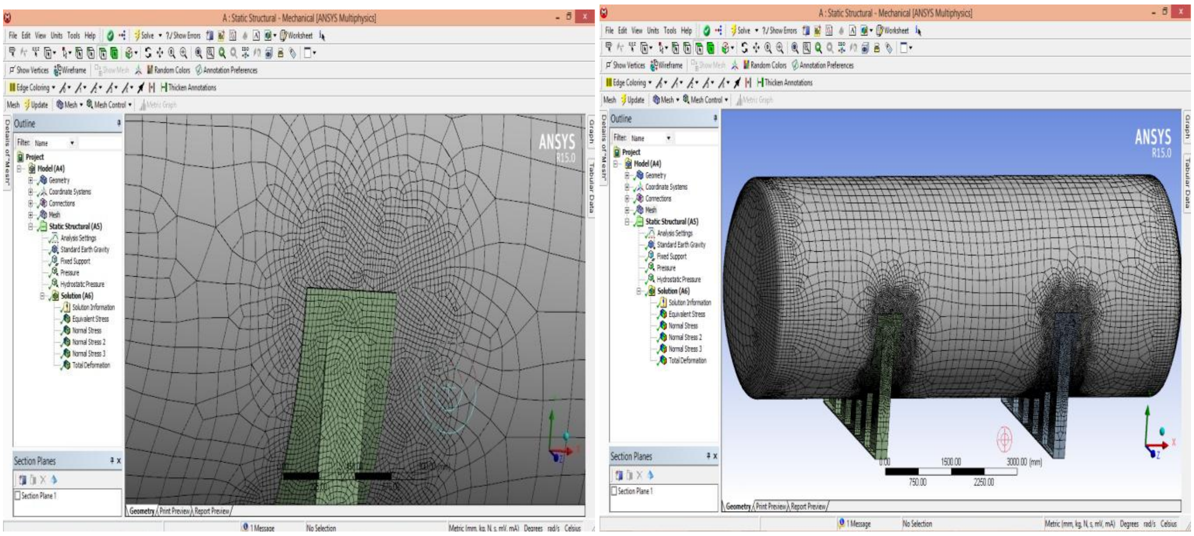


*Figure 3. Meshing*

The vessel has been simulated as shown in figure 4 for the boundary condition of internal pressure of 0.6178 Mpa and hydrostatic pressure of the fluid along with the self weight of the vessel. Further mesh convergence has been done before achieving the element size for all the simulation as shown in the figure 3. The solver converges to a less than 5 % error for all the solutions so the results are reliable from prediction point of view.

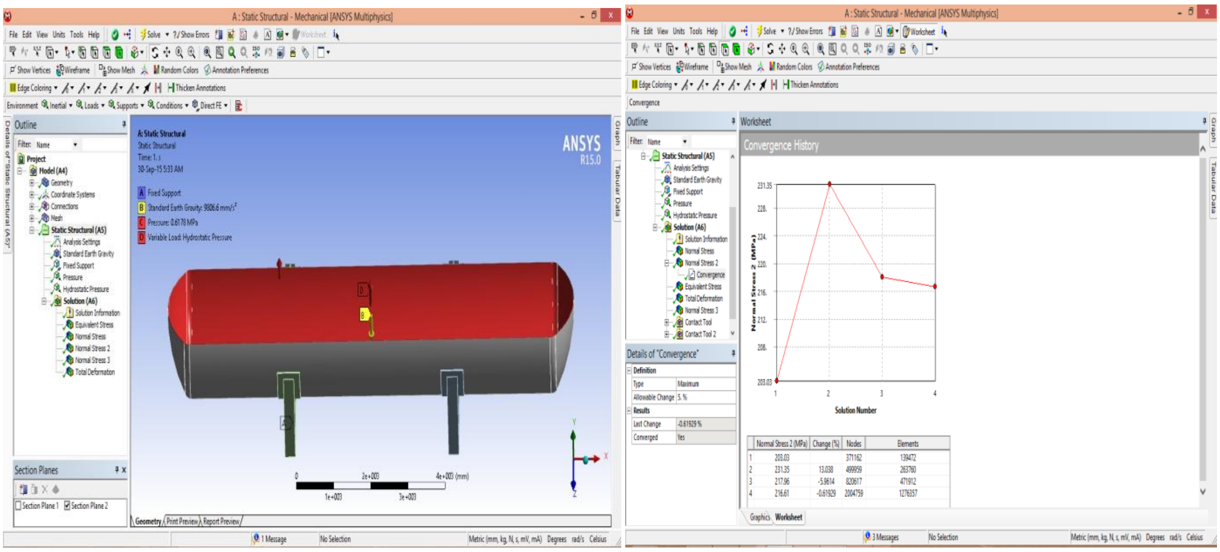


*Figure 4.Boundary conditions and Convergence*

## III. DESIGN OF EXPERIMENTATION

Various mathematical modeling techniques are available to find the response of various parameters. Design of Experiments is a versatile method for mathematical modeling. The classical methods are difficult to handle in addition to complex in nature. In classical method large numbers of experiments are required to be performed. To counter these difficulties, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. The TAGUCHI method has been for finding the influence of and its significance. To carry out Designing following parameters were considered as discussed previous with its range as mentioned in table.

### 3.1. Factors

The factors as shown in table 2 have been shortlisted to evaluate the effect and the range has been selected from the references Ong [2], tooth [6], Abbasi [9], Nash [10] and in consultation with industry experts so as to make the study more effective.

 

*Table 2. Design parameters*

| Sr | Parameter | | Min Value | Max Value |
|---|---|---|---|---|
| 1 | Saddle angle(degree) | ϴ | 120 | 180 |
| 2 | Extension of wear plate(degree) | ϕ | 6 | 20 |
| 3 | Distance of saddle from head(mm) | a | 350 mm | 2000 mm |
| 4 | Wear plate width(mm) | w | 300 mm | 700 mm |
| 5 | Saddle width(mm) | b | 150 mm | 400 mm |

**3.2. Experimental Design**

As per Taguchi method the following L25 orthogonal array has been designed to carry out experimentation.

*Table 3. Taguchi L25 orthogonal array with results*

| Exp. No. | Saddle angle(degree) | Extension of wear plate(degree) | Dist of saddle from head | Wear plate width | Saddle width | Response 1 (s1 Mpa) on vessel near wear plate | Response 2 (s2 - Mpa) on vessel at midspan |
|---|---|---|---|---|---|---|---|
| **1** | 130 | 6 | 600 | 300 | 160 | 92.9 | 37.51 |
| **2** | 130 | 9 | 900 | 400 | 220 | 99.2 | 35.03 |
| **3** | 130 | 12 | 1200 | 500 | 280 | 148.14 | 32.699 |
| **4** | 130 | 15 | 1500 | 600 | 340 | 120.7 | 30.818 |
| **5** | 130 | 18 | 1800 | 700 | 400 | 175.52 | 30.557 |
| **6** | 140 | 6 | 900 | 500 | 340 | 114.35 | 34.415 |
| **7** | 140 | 9 | 1200 | 600 | 400 | 128.38 | 32.117 |
| **8** | 140 | 12 | 1500 | 700 | 160 | 117.72 | 33.877 |
| **9** | 140 | 15 | 1800 | 300 | 220 | 141.36 | 32.93 |
| **10** | 140 | 18 | 600 | 400 | 280 | 123.38 | 36.507 |
| **11** | 150 | 6 | 1200 | 700 | 220 | 129.9 | 35.147 |
| **12** | 150 | 9 | 1500 | 300 | 280 | 135.71 | 34.327 |
| **13** | 150 | 12 | 1800 | 400 | 340 | 120.49 | 32.577 |
| **14** | 150 | 15 | 600 | 500 | 400 | 159.64 | 33.745 |
| **15** | 150 | 18 | 900 | 600 | 160 | 133.2 | 36.561 |
| **16** | 160 | 6 | 1500 | 400 | 400 | 118.19 | 32.367 |
| **17** | 160 | 9 | 1800 | 500 | 160 | 129.75 | 34.631 |
| **18** | 160 | 12 | 600 | 600 | 220 | 140.74 | 37.679 |
| **19** | 160 | 15 | 900 | 700 | 280 | 113.61 | 35.471 |
| **20** | 160 | 18 | 1200 | 300 | 340 | 125.91 | 35.214 |
| **21** | 170 | 6 | 1800 | 600 | 280 | 126.11 | 32.794 |
| **22** | 170 | 9 | 600 | 700 | 340 | 134.84 | 35.083 |
| **23** | 170 | 12 | 900 | 300 | 400 | 123.21 | 35.651 |
| **24** | 170 | 15 | 1200 | 400 | 160 | 123.74 | 36.842 |
| **25** | 170 | 18 | 1500 | 500 | 220 | 131.74 | 34.836 |

## IV. RESULTS AND DISCUSSIONS

The main effect plots and analysis of variance are obtained as in figure 5 and the table 4.The R-Sq value of the model is 79.87 % which implies that model is significant. Further the regression equation is obtained as follows.

Response 1(stress 1) = 61.3 + 0.019 Saddle angle(degree) + 1.65 Extension of wear plate(degree) + 0.00826 Dist of saddle from head + 0.0338 Wear plate width+ 0.0629 Saddle width

 

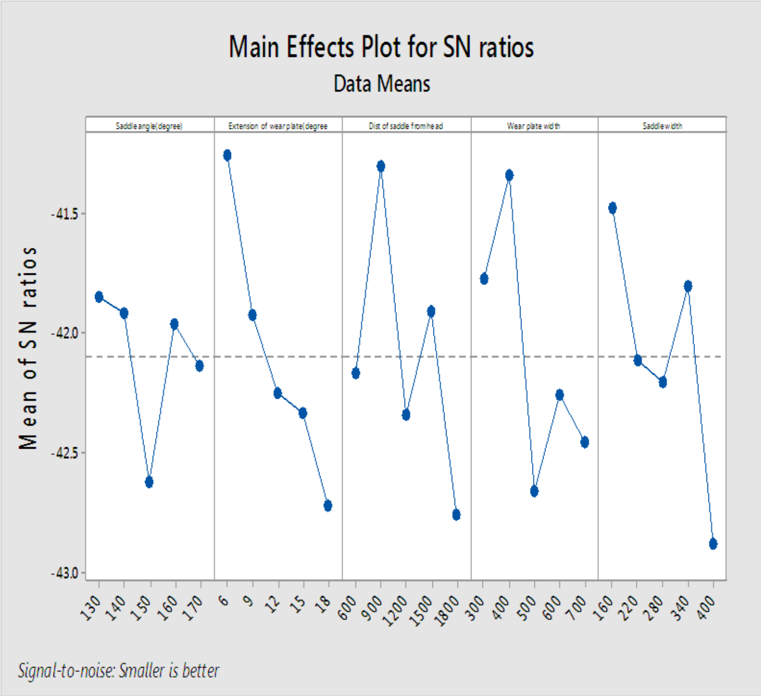


***Figure 5. Main effect plot for stress 1.***

***Table 4. ANNOVA for Stress 1.***

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Saddle angle(degree) | 4 | 1.947 | 0.4867 | 0.31 | 0.860 |
| Extension of wear plate(degree) | 4 | 6.042 | 1.5104 | 0.96 | 0.517 |
| Dist of saddle from head | 4 | 5.845 | 1.4612 | 0.92 | 0.529 |
| Wear plate width | 4 | 5.800 | 1.4499 | 0.92 | 0.532 |
| Saddle width | 4 | 5.458 | 1.3645 | 0.86 | 0.555 |

The main effect plots and analysis of variance for Response 2 (stress at vessel midspan)are obtained as in figure 6 and the table 5.The R-Sq value of the model is 97.82 % which implies that model is significant. The regression equation is obtained as follows.

Response 2(stress2) = 35.8 + 0.0459 Saddle angle (degree) + 0.0117 Extension of wear plate (degree) - 0.00298 Dist of saddle from head - 0.00282 Wear plate width- 0.0124 Saddle width

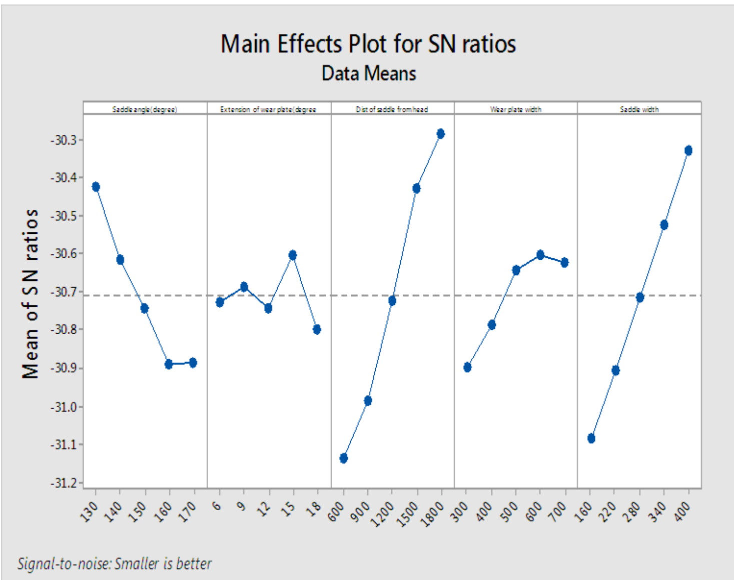


***Figure 6. Main effect plots for stress 2.***

 

***Table 5. ANOVA for stress 2***

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Saddle angle(degree) | 4 | 0.7803 | 0.19508 | 6.24 | 0.052 |
| Extension of wear plate(degree) | 4 | 0.1040 | 0.02600 | 0.83 | 0.569 |
| Dist of saddle from head (mm) | 4 | 2.6053 | 0.65132 | 20.83 | 0.006 |
| Wear plate width(mm) | 4 | 0.3235 | 0.08088 | 2.59 | 0.190 |
| Saddle width (mm) | 4 | 1.7981 | 0.44951 | 14.38 | 0.012 |

## V. CONCLUSIONS

The Taguchi method can be effectively used along with finite element method to investigate the stress distribution in the pressure vessel. The regression equations of both the responses suggest that the wear plate extension is most significant factor and the wrap angle has moderate effect on the stress contribution. Further one can use these models for selection of various design parameters to minimize the stress in the pressure vessel.

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