Design and Analysis Aspects of Pressure Vessel with Quick Lock Door

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Abstract— An autoclave is the pressure vessel used for curing the composite material at an elevated pressure and temperature. In general, autoclaves are provided with an opening almost equal to shell diameter for the ease of loading and unloading of the components that need to be processes. This shell opening need to be closed and locked quickly by means of doors and flanges. In this project the spherical dished door is employed for closing the shell opening and a very simple and effective type of innovative sliding flanges are used for quick lock. These innovative flanges with door can be mainly used for large size of autoclave where the vessel diameter is more than 6 meters and also even it is applicable for small size autoclave. The process of closing and locking of the door should be as quick as possible to reduce the operation time. In this project, with a single arrangement both closing and locking happens simultaneously, there by simplifying the overall system. In this project the complete design of pressure vessel (Autoclave) with sliding flanges is carried out and each parts of autoclave is modeled and assembled through a software solid edge ST6. And also finite element modeling and analysis of autoclave with sliding flanges has been carried out using HYPERMESH v11.0 and MSC/NASTRAN is used as a solver. A main aim of carrying out the finite element modeling and analysis for the autoclave is to check whether the complete autoclave is able to withstand the design pressure load are not.

Key words: Autoclave, Sliding Flanges, Quick Lock, Closing and Locking, Design and Finite Element Analysis

I. INTRODUCTION

A. Autoclave with Locking System

In general the pressure vessel consist of cylindrical shell or vessel where one end of shell is closed permanently by means of rear dish and other end will be opened for loading and unloading the composite material for the curing processes. When the composite material is loaded inside the shell through the opening provided, it is necessary that this opening has to be closed by means of door before starting the curing process. So once the complete shell opening is closed by means of introducing the door, it is necessary to lock the door with effective sealing in order to maintain the required pressure within the shell for curing the composite.

In general for small size of autoclave, a very simple door can be employed. However because of small scale autoclave a weight of door can be very less, therefore the door can be handled either by manually or by using small systems. Whereas as a size of autoclave increase gradually, the size of door which will also increases, therefore the corresponding weight of door which will also increase. However designing a very simple and effective type of door locking system for large size of autoclave is a big task for design engineer.

B. Door Locking System

In this autoclave, the door is closed and locked quickly by providing a simple sliding flange. For the door locking and unlocking, two flanges where employed, one of the flange is welded to the shell called as shell flange and other flange is welded to the door called as door flange. Each flange has a flange–teeth combination.

However for locking the door, the door has to be closed. The closing of the door is obtained by using a davit arm mechanism, slider, davit mast, rotary link with bearing arrangement, suspension arm and guide way.

The slider will be sliding forward and backward in the davit arm, during opening and closing operation of the door. Davit arm will rotate freely by motor and gear arrangement by withstanding the total weight of door with door flange, suspension arm, rotary link, and slider. The davit arm is mounted on the davit mast by the bearing arrangement; so that the free rotation of arm is obtained. The guide way is provided in such a way that the door can be rotate in a pre-defined path.

During door closing operation, the door teeth will be entering into shell flange and shell teeth will be entering into door flange as shown in Figure 1.3, once the teeth’s and flanges are in complete contact the door will be locked. In this autoclave the door closing and locking takes place simultaneously and also the time required to complete this operation is very less.

C. Advantages of Door Locking System

- Simultaneously the door will be closed and locked therefore the time required to complete this operation is less.
- Since 360 degree of contact between the flanges is achieved so there is no need of compensation of flange thickness.
- Proper alignment of door flange with shell flange is not needed after closing and before locking of the door.
- Machining cost required for the flanges can be reduced.

Fig. 1: Complete geometry model of Autoclave
II. OBJECTIVES
- To design and obtain an effective and innovative locking system in the autoclave.
- To design a door efficiently and handle high pressure with effective sealing.
- Providing of simple opening of autoclave door without effort for the operator.
- To obtain effective door handling system for operating the autoclave door.
- Doing solid modeling and motion study of design.

III. MATERIAL PROPERTIES

<table>
<thead>
<tr>
<th></th>
<th>SA 516</th>
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<td></td>
<td>GRADE70 (plate, Carbon Steel)</td>
<td>GRADE2 (Forging, Carbon Steel)</td>
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<tr>
<td>Young’s Modulus</td>
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<td>Yield Strength</td>
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<td>Allowable Stress</td>
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<td>125 MPa</td>
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<tr>
<td>Poisson’s ratio</td>
<td>0.3</td>
<td>0.3</td>
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IV. GEOMETRY OF AUTOCLAVE

After the design calculation the geometry considered for the autoclave are,

Autoclave shell: Considering a cylindrical steel shell of 5.5 m diameter, 7 m length and thickness of 18 mm through which the composite material is loaded for curing process.

Rear dish and door dish: Rear end of shell is closed by means of ellipsoidal dish of thickness 20 mm and front end of shell is closed by spherical dish door of 25 mm thickness.

Shell flange and door flange: A shell flange of 222 mm thickness and door flange of 170 mm thickness is used for locking the door.

V. FINITE ELEMENT MODELING AND ANALYSIS

The finite element modeling of autoclave has been carried out by generating the mid-surface for each of the parts. The discretization of the complete model of the autoclave is carried out in HYPERMESH v11.0. The element used for the FE modeling is CQUAD4 shell element. And RBE2 rigid element is used between the flanges to transfer the load. A main aim of carrying out the finite element modeling and analysis for the autoclave is to check whether the complete autoclave is able to withstand the design pressure load (7.7 bar) are not.

VI. RESULTS AND DISCUSSION

The analysis of the discretized autoclave model has been carried out in MSC NASTRAN after assigning the material properties, boundary conditions and external load.

A. Self-Weight Comparison

Weight comparison of autoclave as per strength of material calculation and finite element analysis is carried out, weight of autoclave as per SOM is 42.6 tonne and as per FEA is 41.29 tonne, both the weight are approximately same. Density of the steel assigned for the complete autoclave is 7.850*10^{-9} tonne/mm$^3$.

B. Validation of the FE Model

The hoop stress in the autoclave shell, corresponding to the design internal pressure of 7.7 bar is as shown in Figure 4. A hoop stress from finite element analysis is 128.7 MPa and analytical data (strength of material approach) is 128.368 MPa. The finite element analysis data for this comparison is taken away from the shell-door assembly in order to avoid the local effects.

C. Displacement Pattern of Autoclave

The displacement pattern in the autoclave shell is as shown in below Fig 5, the maximum displacement is observed in door dome in the direction of Y-axis (i.e. longitudinal direction) of magnitude -3.82 mm and the minimum displacement is observed in front saddle in the direction of X-axis of magnitude 1.505e-4 mm.
D. Von-Mises Stress Distribution

The von-Mises stress state or equivalent stress at the inside surface of the autoclave is shown in Fig 6(a). From the Figure, it is seen that the maximum stress in the door at Location A is in the order of 162 MPa which is more than the allowable stress of 132 MPa, but the average stress at Location A is around 106 MPa < 132 MPa.

The von-Mises stress state on the outside surface of the autoclave is shown in the Fig 6(b). From the Figure, it can be seen that the maximum stress in the door at Location B is in the order of 85 MPa.

E. Top View of Fe Model of Autoclave with Location C and Location D

Figure 7 shows the top view of autoclave by indicating the location C and location D in the shell flange-door teeth assembly and door flange-shell teeth assembly respectively. The following section shows the details of the stress plot at location C and location D.

F. Von-Mises Stress State at Location C

The details of the stress plot is given at the Location C on the inside surface of the shell flange-door teeth assembly is as shown in Fig 8(a). The maximum equivalent stress in the shell flange-door teeth assembly is in order of 124 MPa which is less than the allowable stress of 125 MPa.

The details of the stress plot are given at the location C on the outside surface of the shell flange-door teeth assembly is as shown in Fig 8(b). The maximum equivalent stress in the shell flange-door teeth assembly is 123 MPa which is less than the allowable stress of 125 MPa.
G. Von-Mises Stress State at Location D

The details of the stress plot is given at the Location D on the inside surface of the door flange-shell teeth assembly as shown in Fig 9(a). The maximum equivalent stress in the door flange-shell teeth assembly is in the order of 121.9 MPa which is less than the allowable stress of 125 MPa.

![Fig. 9(a): Stress distribution at location D (Inner surface)](image)

The details of the stress plot are given at the Location D on the outside surface of the door flange-shell teeth assembly as shown in Fig 6.7 (b). The maximum equivalent stress in the door flange-shell teeth assembly is 94.2 MPa which is less than the allowable stress of 125 MPa.

![Fig. 9(b): Stress distribution at location D (outer surface)](image)

VII. CONCLUSIONS

- The flanges have been designed for the toothless locking mechanism in the autoclave. This design helps in reducing the machining cost.
- The finite element analysis of the toothless autoclave has been carried out in the MSC NASTRAN. The analysis results are validated with the SOM calculations. The analytical result of hoop stress on the autoclave shell is 128.368 MPa which is approximately same as that of the SOM calculation of 128.7 MPa.
- The maximum equivalent stress distribution in the shell flange-door teeth assembly and door flange-shell teeth assembly is less (i.e. 124 MPa) and the stress are well within the allowable stress limit of 125 MPa.
- Locally high stress is observed on the inside surface of autoclave door dome (i.e.162 MPa), but the average stress distribution on the door dome is in the order of 106 MPa which is well within the allowable stress limit of 132 MPa.

REFERENCE

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