Analysis of Plates Welded With Stiffeners under Harmonic Loading
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Abstract— In this paper we are going to study the structures of plate with spot welded stiffeners using Ansys(14.5) software under the loading conditions for Harmonic analysis. These structures mainly consists two parts i.e. Upper and lower part which are joint together using spot weld. Spot welding is most preferred and widely used method for joining the metal sheets in automotive and many other industrial assembly operations. The finite element (FE) modelling of plates with spot welded stiffened structures and its Harmonic analysis is research area of this paper. In FEA study, modal analysis method is used to find the natural frequencies of all test structural models.

Key words: Stiffeners, Harmonic Loading, Spot welding

I. INTRODUCTION

A spot weld is materialized by clamping the sheets with two pincers while applying a force and transmitting current. The electrical resistance of contacting sheets generates sufficient heat at the metal surfaces to melt the metal. Thus nugget develops and sheet metals are joined. Automotive bodies and many other structures are composed of metal sheets joined by spot welds. Spot weld joints provides localized connection thus lead to high stress concentration in the joined plates. Excessive stresses and premature failure occurs due to improper design.

A designer significantly concentrates the strength of component by introducing the changes in its geometry and weld patterns that will reduce the vibration of the structural models. Also increases the strength of the structures. Stiffeners are secondary plates or sections which are attached to beam webs or flanges to stiffen them against out of plane deformations. Longitudinal web stiffeners, which are aligned in the span direction and Transverse stiffeners, which are aligned normal to the span direction of the beam. The optimum design of geometry and weld patterns can be obtained optimal performance i.e. good strength to the composed structures.

II. LITERATURE REVIEW

In the literature, there are some studies about Vibration Analysis of stiffened shells and plates with stiffeners welded to them. Pravin Nana Jadhav [1], discussed about the effect of spot weld patterns and profiles of stiffeners on the vibration characteristics of plates with spot welded stiffeners. There are some studies about optimization of spot welded structures. Ahmet H Er`tas, Fazil O.Sonmez [2] optimized the spot welded plates for maximum fatigue life. They suggest that number of spot welds significantly affects the fatigue strength. Sheet thickness and material are studied to the strength requirements of the structures. The effect of the size of the welds diameter and pitch of the weld on the account of absorbed energy is studied [3].

The residual stresses produced in each nugget have significant effect on the natural frequency of the plate, where natural frequency increases when residual stresses are included. This effect varies depending on the boundary conditions of the plate and on the distribution of the weld spots [4].

Guidelines for spot welds CWELD and ACM2 are analysed and proposed [5]. The effect of laser spot welding technique and the design adjustments are studied [6–7]. The effect of growth in nugget size with spot welding has a great impact in natural frequencies of the model [8]. The behaviour of a spot welded structure under dynamic loads is strongly influenced by the number and locations of the resistance spot welds [9].

Some researchers have published regarding vibration analysis of stiffened laminated plates and shells. It was found that stiffeners profile and its arrangement have great effect on the natural frequencies and mode shapes of the plates. Experimental analysis of composed structures, including setup is studied to find the natural frequencies using FFT analyzer.

This study of harmonic analysis of plates with spot welded stiffeners includes study of spot weld arrangement and stiffener parameters such as profile, dimensions and arrangement. Good agreement of optimum design of structure due to FEA study.

III. DEFINITION OF HARMONIC RESPONSE ANALYSIS

Any sustained cyclic load will produce a sustained cyclic response (a harmonic response) in a structural system. Harmonic response analysis gives you the ability to predict the sustained dynamic behavior of your structures, thus enabling you to verify whether or not your designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations.

Three harmonic response analysis methods are available: full, reduced, and mode superposition. (A fourth, relatively expensive method is to do a transient dynamic analysis with the harmonic loads specified as time history loading functions. The ANSYS/Linear Plus program allows only the mode superposition method. Before we study the details of how to implement each of these methods, let’s explore the advantages and disadvantages of each method.

The full method is the easiest of the three methods. It uses the full system matrices to calculate the harmonic response (no matrix reduction). The matrices may be symmetric or unsymmetric. The advantages of the full method are: It is easy to use, because you don’t have to worry about choosing master degrees of freedom or mode shapes. It uses full matrices, so no mass matrix approximation is involved. It allows unsymmetric matrices, which are typical of such applications as acoustics and bearing problems. It calculates all displacements and stresses in a single pass. It accepts all types of loads: nodal forces imposed (nonzero) displacements, and element loads (pressures and temperatures).It allows effective use of solid model loads. A disadvantage of the full method is that no
prestressed option is available. Another disadvantage is that this method usually is more expensive than either of the other methods when you use the frontal solver. However, when you use the JCG solver or the ICCG solver, the full method can be very efficient.

The reduced method enables you to condense the problem size by using master degrees of freedom and reduced matrices. After the displacements at the master DOF have been calculated, the solution can be expanded to the original full DOF set. The advantages of this method are it is faster and less expensive compared to the full method when you are using the frontal solver. Prestressing effects can be included. The disadvantages of the reduced method are the initial solution calculates only the displacements at the master DOF. A second step, known as the expansion pass, is required for a complete displacement, stress, and force solution. (However, the expansion pass might be optional for some applications.) Element loads (pressures, temperatures, etc.) cannot be applied. All loads must be applied at user defined master degrees of freedom. (This limits the use of solid model loads.)

The mode superposition method sums factored mode shapes (eigenvectors) from a modal analysis to calculate the structure's response. Its advantages are, it is faster and less expensive than either the reduced or the full method for many problems. Element loads applied in the preceding modal analysis can be applied in the harmonic response analysis via the LVSCALE command. It allows solutions to be clustered about the structure's natural frequencies. This results in a smoother, more accurate tracing of the response curve. Prestressing effects can be included. It accepts modal damping (damping ratio as a function of frequency). Disadvantages of the mode superposition method are, Imposed (nonzero) displacements cannot be applied. When you are using Power Dynamics for the modal analysis, initial conditions cannot have previously applied loads.

IV. USES FOR HARMONIC RESPONSE ANALYSIS

Harmonic response analysis is a technique used to determine the steady state response of a linear structure to loads that vary sinusoidal (harmonically) with time. The idea is to calculate the structure's response at several frequencies and obtain a graph of some response quantity (usually displacements) versus frequency. "Peak" responses are then identified on the graph and stresses reviewed at those peak frequencies. This analysis technique calculates only the steady state, forced vibrations of a structure. The transient vibrations, which occur at the beginning of the excitation, are not accounted for in a harmonic response analysis.

V. DESCRIPTION OF STRUCTURAL MODELS

A. Section view of structure 1

B. Section view of structure 2
C. Section view of structure 3

![Diagram of structure 3]

D. Section view of structure 4

![Diagram of structure 4]

The various spot weld patterns to be tested are given below,

(a) Weld pattern P1

(b) Weld pattern P2

VI. Finite Element Analysis

<table>
<thead>
<tr>
<th>Design of experiment</th>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
<th>Section 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern 1</td>
<td>M1P1</td>
<td>M2P1</td>
<td>M3P1</td>
<td>M4P1</td>
</tr>
<tr>
<td>Pattern 2</td>
<td>M1P2</td>
<td>M2P2</td>
<td>M3P2</td>
<td>M4P2</td>
</tr>
</tbody>
</table>

Table 1: Procedure of Experiment

Harmonic analysis is conducted in the range of the natural frequencies of the models with a constant loading i.e. harmonic loading. Thus to perform the harmonic analysis we need to perform the modal analysis and obtain the natural frequencies of the models. The Material properties of Steel are used, all the design date are in units mm.

A. Modal Analysis of Structural Models:

Modal analysis is used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. Modes are inherent properties of structure and are determined by material properties (mass, damping and stiffness), and boundary conditions of the structure. Each mode is defined by natural frequency, mode shape (modal parameters). If either the material properties or the boundary conditions of a structure change its modes will change. Also natural frequencies are different due to different vibrations. This study includes the different structures. So, material properties and boundary conditions are different. Thus analysis of structures is carried out by observing natural frequencies of the same structures.

<table>
<thead>
<tr>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
<th>Mode 4</th>
<th>Mode 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1P1</td>
<td>5.64</td>
<td>7.8</td>
<td>8.5</td>
<td>11.47</td>
</tr>
<tr>
<td>M1P2</td>
<td>5.52</td>
<td>7.32</td>
<td>7.88</td>
<td>11.39</td>
</tr>
<tr>
<td>M2P1</td>
<td>4.63</td>
<td>9.93</td>
<td>10.69</td>
<td>12.01</td>
</tr>
<tr>
<td>M2P2</td>
<td>4.54</td>
<td>8.17</td>
<td>8.45</td>
<td>8.77</td>
</tr>
<tr>
<td>M3P1</td>
<td>3.45</td>
<td>8.98</td>
<td>9.45</td>
<td>9.84</td>
</tr>
<tr>
<td>M3P2</td>
<td>3.85</td>
<td>9.15</td>
<td>9.78</td>
<td>10.02</td>
</tr>
<tr>
<td>M4P1</td>
<td>5.48</td>
<td>8.78</td>
<td>9.81</td>
<td>12.11</td>
</tr>
<tr>
<td>M4P2</td>
<td>5.28</td>
<td>8.5</td>
<td>10.02</td>
<td>12.5</td>
</tr>
</tbody>
</table>

Now the natural frequencies are determined and can be proceeded for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis.

This paper deals with the behavior of these plates when the load is given harmonically, a constant cyclic load of 1000N, in its Y-axis direction with a 2% damping ratio.
The above graphs show the variation of four stiffener models with the variation in welding patterns. The first five modes are considered to process harmonic analysis for a cyclic load of 1000N.

B. Harmonic Analysis of Structural Models

In the literature, work by Ahmet H. Ertas, Fazıl O. Sonmez gives the permissible load range of these structural models as 1000-3000N. This work of harmonic analysis is followed by applying this load cyclically i.e. harmonic loading and amplitude values along the direction of applied load i.e. Y-axis direction.

Consider the first structural model and first pattern and within the range of its natural frequencies under a harmonic loading of 1000N the amplitude values with 50 sub steps and through using Sparse Solver equation, The graphical comparison of amplitude to DOF solution are as following.

<table>
<thead>
<tr>
<th>Frequency (in HZ)</th>
<th>M1P1</th>
<th>M1P2</th>
<th>M2P1</th>
<th>M2P2</th>
<th>M3P1</th>
<th>M3P2</th>
<th>M4P1</th>
<th>M4P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.22</td>
<td>7.84</td>
<td>10.691</td>
<td>9.82</td>
<td>3.58</td>
<td>3.58</td>
<td>9.76</td>
<td>9.76</td>
<td></td>
</tr>
<tr>
<td>Amplitude (in mm)</td>
<td>235.84</td>
<td>324.15</td>
<td>851.81</td>
<td>1541.49</td>
<td>152.4</td>
<td>162.35</td>
<td>134.37</td>
<td>133.63</td>
</tr>
</tbody>
</table>

Table 3: Results of Harmonic Analysis
Analysis of Plates Welded With Stiffeners under Harmonic Loading
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Table 4 A: for models 1 and 2 with two patterns

<table>
<thead>
<tr>
<th>MODEL/PATTERN</th>
<th>M1P1</th>
<th>M1P2</th>
<th>M2P1</th>
<th>M2P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (in HZ)</td>
<td>5.64</td>
<td>17.22</td>
<td>5.52</td>
<td>16.07</td>
</tr>
<tr>
<td>Stress (N/m2)</td>
<td>69.93</td>
<td>15857</td>
<td>2679.19</td>
<td>6195.82</td>
</tr>
</tbody>
</table>

Table 4 B: for models 3 and 4 with two patterns

<table>
<thead>
<tr>
<th>MODEL/PATTERN</th>
<th>M3P1</th>
<th>M3P2</th>
<th>M4P1</th>
<th>M4P2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (in HZ)</td>
<td>3.45</td>
<td>10.4</td>
<td>3.45</td>
<td>10.33</td>
</tr>
<tr>
<td>Stress(N/m2)</td>
<td>611.406</td>
<td>660.3</td>
<td>603.83</td>
<td>668.03</td>
</tr>
</tbody>
</table>

Table 4: Stresses at Peak frequencies

Graph 5: Minimum frequencies vs Stress

Graph 6: Maximum Frequencies vs Stress

VII. CONCLUSION

The natural frequencies of the structural models by changing the spot weld patterns are determined. These results are further used in conducting a harmonic analysis for a permissible load of 1000N [2] and the maximum amplitudes i.e. displacements in the Y-axis direction, of the structural models are determined within the range of their natural frequencies. The maximum stress values at those peak frequencies are tabulated. For the required range of allowable displacement in the solid structure and the allowable natural frequency without making the system in to resonance the structural model and its weld pattern are selected.

REFERENCES