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EFFECT OF WELDING RESIDUAL STRESS ON NATURAL FREQUENCY OF STRUCTURES

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Abstract— ***Welding is one of the most reliable and efficient permanent metal joining processes in the industry. It is a well-established fact that structural integrity of components is substantially affected by the residual stresses when subjected to thermal and structural loads. Residual stress caused by welding is a matter of grave concern in all the industries. In this work, an experimental investigation is conducted to ascertain the effect of residual stress on the natural frequency of structures. The frequency of a cantilever beam is found using an accelerometer sensor, Data Acquisition (DAQ) device and Laboratory Virtual Instrument Engineering Workbench (LabVIEW) software. The experiment is done on multiple samples to ensure repeatability of measured data. For applying residual stress the cantilever beam is TIG welded and after welding the new natural frequency is found. A variation in the frequency due to the residual stresses is observed. For reducing this residual stress the cantilever beam is heat treated and the natural frequency is found again. Residual stresses resulting from welding are reduced by a post weld thermal stress relief heat treatment. The effect of residual stresses on natural frequency is experimentally determined. The model is also analyzed through engineering simulation software ANSYS.***

Keywords— ***Natural frequency, TIG welding, Residual stress, Heat distribution models, Stress relief.***

I. INTRODUCTION

When two plates are joined by welding, a very complex thermal cycle is applied to the weldment. Thermal energy applied results in irreversible elastic-plastic deformation and consequently gives rise to the residual stresses in and around fusion zone and heat affected zone (HAZ). It is a well-established fact that structural integrity of components is substantially affected by the residual stresses when subjected to thermal and structural loads. Presence of residual stresses may be beneficial or harmful for the structural components depending on the nature and magnitude of residual stresses. Two of the major problems of any welding process are residual stress and distortion. Residual stress and distortion continue to be important issues in shipbuilding and are still subject to large amounts of research.

II. OBJECTIVES

The frequency of a cantilever beam in this experiment is found using a accelerometer sensor, Data acquisition (DAQ) device and Lab VIEW software. The experiment is done on multiple samples to ensure repeatability of measured data. For applying residual stress the cantilever beam is TIG welded and after welding the new natural frequency is found. . A variation is observed in the frequency due to residual stress. . For removing this residual stress the cantilever beam is heat treated and then again the natural frequency is found. The effect of residual stresses on natural frequency is experimentally determined. The model is also analyzed using engineering simulation software ANSYS.

III. EXPERIMENTAL PROCEDURE

The Experimental analysis was started with two trials. First trial was with five equidimensional low carbon steel work pieces of dimensions 400mm long, 25mm width and 6mm of thickness and second trial carried out in five equidimensional low carbon steel work pieces of dimensions 300mm long, 25mm width and 3mm of thickness. First of all the natural frequency of all the work pieces was measured then each specimen was applied with a welding arc spot for 75s at the middle of the plate. By varying the current and keeping all other parameters constant, welding spots were produced on each plate using GTA welding machine. After the welding, the natural frequencies were different from those obtained before welding due to the presence of welding residual stresses and then heat treated in the furnace.

Fig. 1 Complete setup for finding natural frequency.

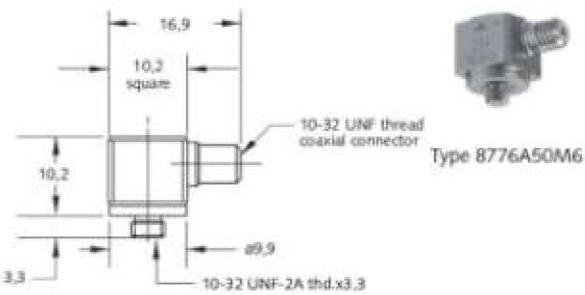

Fig. 2 Accelerometer

Fig. 1 shows the complete setup used in the lab for finding frequency which consists of accelerometer, DAQ and PC with Labview software. The image in Fig. 2 shows the accelerometer used for this experiment.

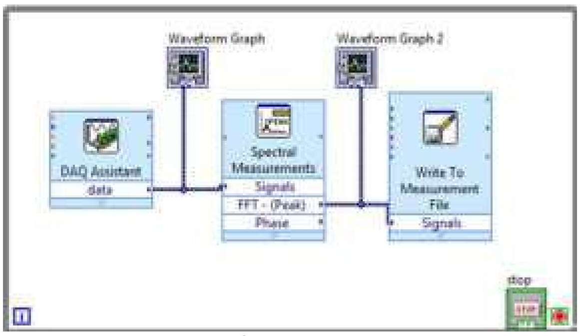

Fig.3 Diagram used for experimental setup in Labview.

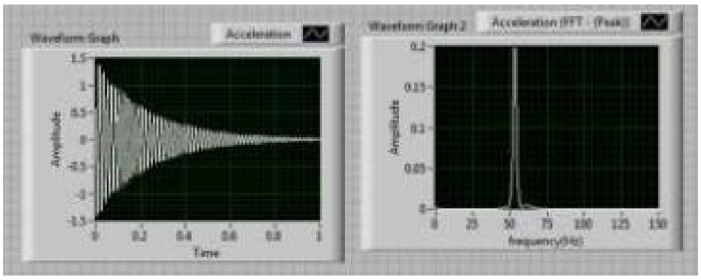

Fig. 4 Output window in Labview

For finding natural frequency block diagram shown in the Fig. 3 is used in Labview software. Fig. 4 shows the output window, which give the frequency-time plot and amplitude-time plot. Here we require peak value of frequency only.

IV. MATHEMATICAL MODELING

In order to avoid the complex formulations for representing welding arc, heat distribution functions are put forward. A distribution function will give the spatial distribution of heat flux over the work piece. Goldak's heat distribution model (double ellipsoidal model) is used in this analysis. This model is composed from two ellipsoidal heat sources where one defines the heat input in the front and the other in the rear part of the ellipsoid. The geometric representation of model is shown in Fig.5 where η is the welding efficiency, U is the welding voltage, I is the welding current, a, b and c are the heat distribution parameters. v is the welding seed, and t is the time.

$$Q(x,y,z,t) = \frac{\eta U I 6\sqrt{3}}{\Pi abc\sqrt{\Pi}} \exp\left(-3(z/a)^2 - 3(y/b)^2 - 3((x+vt)/c)^2\right)$$

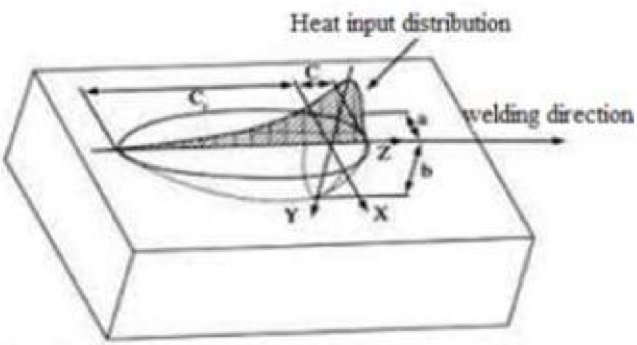

Fig. 5 Goldak heat distribution model in the form of double ellipsoid

V. FEM MODELING

A FEM model developed using ANSYS is used to find out residual stress distribution during GTAW spot welding of low carbon steel. FEM software ANSYS 13 is used for the analysis. The Fig. 6 shows the 3D finite element model of the work piece of thickness 3mm width 12.5mm and length 300mm. Fig. 7 shows refined mesh at weld line and fixing of cantilever beam.

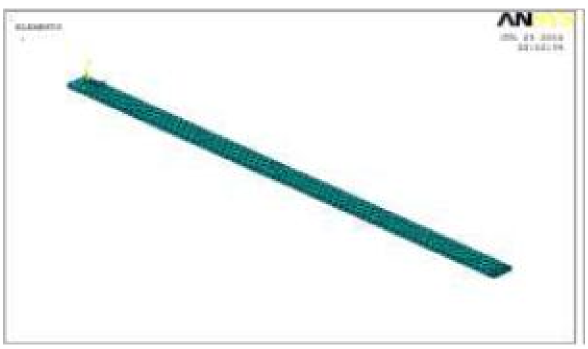

Fig. 6 3D meshed model used in analysis.

Fig. 7 Refined mesh and fixing.

All sides of plate are assumed to be open to atmosphere and the combined convective and radiative heat transfer coefficient used by W.H Kim is given by:

$$h = 2.14 \times 10^{-3} \times 0.8 \times T^{1.61}$$

The material properties of low carbon steel are calculated using relation represented by S.E. Chidiac et al. The element used for meshing is a 20 noded brick element with temperature as one degree of freedom. Using APDL coding, subroutine was written for calculating heat flux and other properties based on temperature.

VI. RESULT AND DISCUSSION

The heat source is assumed to be concentrated at the origin for 75seconds and then allowed to cool for 5000s. After welding there is an increase in the frequency. Mathematical modeling of Geo Yongi also suggest that if there is welding residual stress, there is an increase in the frequencies. Fig. 8 and Fig. 9 shows the comparison in frequency before and after welding, heat treatment. Heat treatment is done in the specimen for removing residual stress. Frequencies obtained after heat treatment appear to be very near to the frequencies obtained before welding. Hence we can conclude that heat treatment is effective in removing welding residual stress.

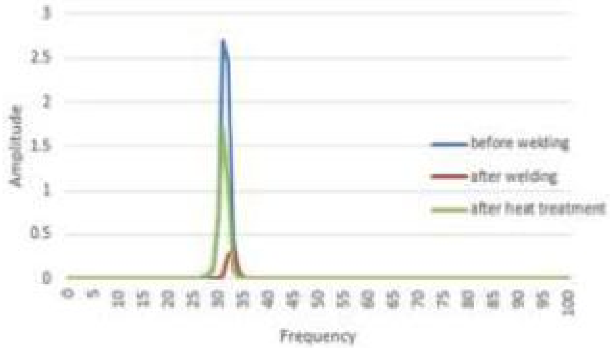

Fig. 8 Comparison in frequency after heat treatment in trial 1

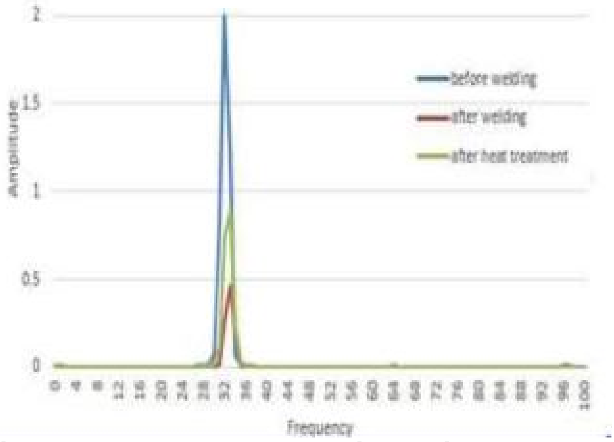

Fig.9 Result in trial 2

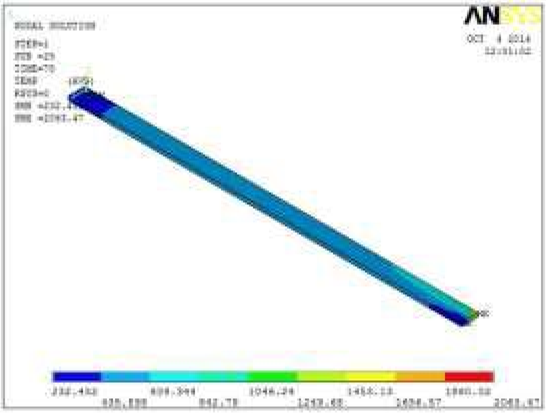

Fig.10 FEM analysis result at 75th second welding completed

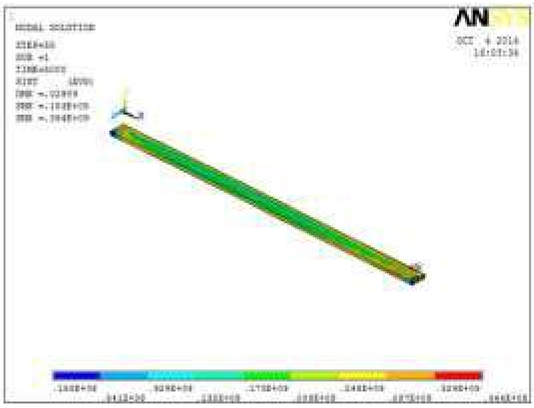

Fig. 11 Residual stress after welding

Fig. 10 shows weld at 75th second, where welding is completed to the end of the beam and shows temperature distribution. Fig. 11 shows the maximum and minimum value of residual stress after welding, the value lies in the range of yield strength of low carbon steel. From this the presence of residual stress after welding have been verified.

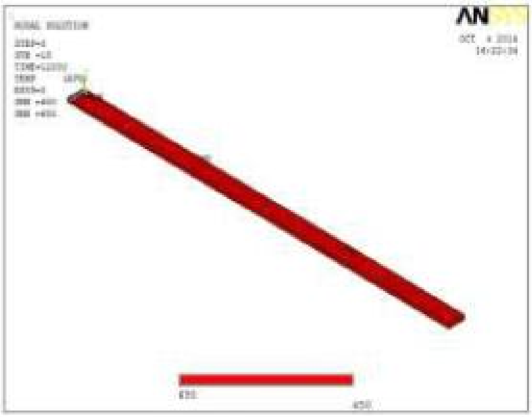

Fig. 12 heat treatment at 650°C.

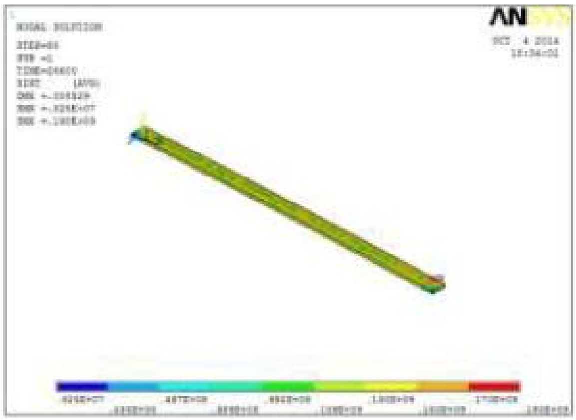

Fig. 13 Residual stress after heat treatment

The temperatures recommended for stress relieving low carbon steels are 595° C to 675° C. In Fig. 12 shows the heat treatment of metal at temperature of 650° C. Heat treatment done for 2hrs at 650° C and cooled for 4hrs. Fig. 13 shows the reduced effect of residual stress distribution after the heat treatment. FEA results shows that after heat treatment residual stress value decreased and shows that post weld heat treatment is effective in removal of residual stresses.

VII. CONCLUSION

Aim of the project is to ascertain the effect of welding residual stress on natural frequency. A detailed study was conducted on Labview software and for block diagram was generated. TIG welding is considered as the most suitable method for carrying out experimental analysis since it causes least structural variation. Experimental study was completed with two trials and proved that frequency increased due to welding residual stress. FEM modeling of the cantilever beam is done and a sequential thermo-mechanical coupled analysis is performed and the temperature distribution is obtained for the welded specimen. Residual stress have been found using FEA and it is found to be increasing after welding which further decreases after heat treatment.

VIII. ACKNOWLEDGMENT

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