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Finite Element Model Updating and Dynamic Design of Spot Welded Structures

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ABSTRACT

Spot welds are used extensively in the automotive industry to join panels and for construction of other sub-assemblies that contains several thousands of spot-welds, so it is not practical in structural analysis to model each and every spot weld joint in detail. So a simple Finite element (FE) model of spot-welds needs to be used. There is not much work reported on dynamic testing, correlation and updating of the spot welded structures. This work explores the use of FE model updating to improve the dynamic characteristics of the spot welded structures. A hat like structure, used in earlier studies, is built and experimental modal analysis done on the spot welded structure. An FE model for the hat structure is built and correlated mode pairs are identified and attempts are made to update the FE model. Structural dynamic modification studies have been carried out to evaluate the effectiveness of the updated FE model of the spot welded structure for dynamic design. It is found that the updated FE model predicts more accurately the changes in dynamic characteristics as compared to the original FE model. Effect of spot welds on natural frequencies and damping of the spot welded structures is also studied.

INTRODUCTION

Spot welding is one of the widely used methods for manufacture of thin sheet components, especially in mass-production industries such as the automobile industry. Spot welds are used extensively in the automobile industry to join panels and car bodies that contain thousands of spot welds. So it is not practical in structure analysis to model each and every spot weld joint in detail. Modeling spot welds is difficult, mainly because there are many local effects such as geometrical irregularities, residual stresses, material in homogeneities and defects due to the welding process that are not taken into account by finite element modeling. Mainly two types of spot weld models exist, those which required require the stress within the weld spot to be calculated and those that do not. In the first case very detailed models are necessary to compute a smooth stress field at the spot weld .A very detailed model produces a detailed and smooth stress field, but it will not necessarily accurately predict the stiffness of real spot welds and their effect on the rest of the structure [4]. Detailed models will produce apparently reliable stress fields, whereas they may poorly estimate the forces that are interchanged between the spot weld and the rest of the structure. In the second case the only requirement from the model is to simulate, as closely as possible, the stiffness (and mass) characteristics of the real spot welds and their influence on the rest of the structure. Simple models that use few elements need to be built. These simplified joint models must be able to produce same results as that of a more refined model [3]. Model updating based on vibration characteristics is an important tool to improve the accuracy of the finite element models. In this paper, dynamic design of a spot welded structure is presented. Following sections deal with finite element modeling, experimental modal analysis, and FE model updating and structural dynamic modifications on spot welded structure.

FE modeling of the spot-welded structure

A Hat structure that is spot-welded from one flat and other folded mild steel plate is fabricated for the experimental studies in this work. This structure has been used in another study [4]. A ‘‘single hat’’ structure (SH) is shown in Figure-1.The structure consists of a hat section made up of mild steel plates (density7800kg/m^3) joined together by spot welds at the flanges, and are designed to represent simplified models of the beams[1] used in the construction of car bodies, for example the roof pillars. Figure-2 shows the section of the hat structure plates that form the SH benchmark. The thickness of the plates is 1 mm and the structure has 12 spot welds 10.5 mm apart (Figure-3).

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Figure-1 Single hat (SH) structures

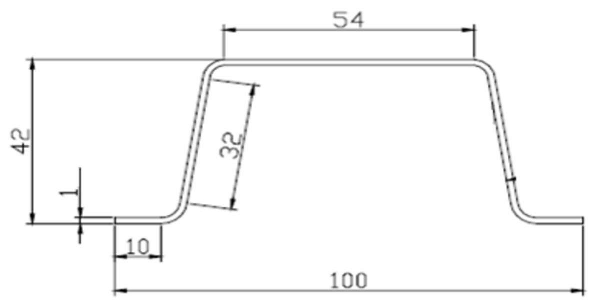


Figure 2- Section view single hat structure

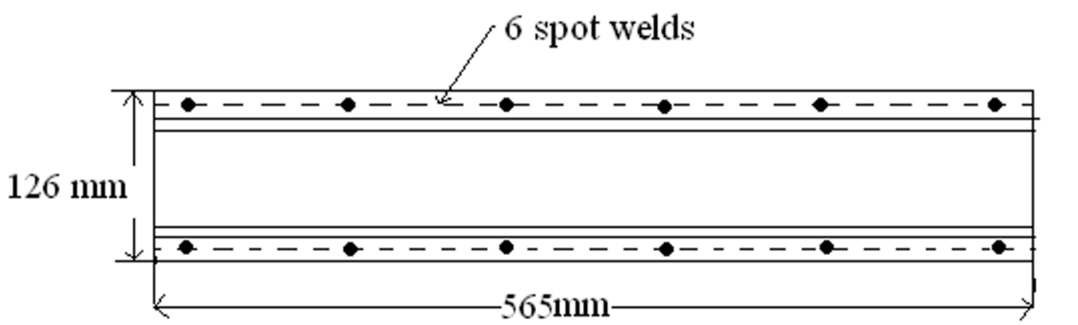


Figure -3 Top view of single hat structure (SH)

Finite element model of the hat structure is built in ANSYS [7] taking four nodded quadrilateral shell elements for the hat surface and beam elements for the spot weld. For applying the beam element at the spot weld location the surface should be concurrently meshed so that the node connecting the two ends of the beam lie perpendicular to each other. Since during actual spot welding the region around the spot weld become rigid. This rigid region is also created in the FE model by using constraint equation. One master node, which is same as the node at which beam element is placed and six slave nodes around the master node, is selected to create six constraint equations. Modal analysis is done in ANSYS to get the natural frequencies and mode shapes through FEA.

Experimental Modal Analysis (EMA) on spot-welded structure.

Spot welded structure is suspended at the two ends with elastic tapes to ensure the free-free condition. Experimental modal analysis (EMA) is done on the SP structure with 36 measurement points. A single axis accelerometer is mounted at location 12 as shown in figure 5 for reference. Excitation is given by impact force using modal hammer. The analysis is done by moving hammer to different locations. The data is recorded using Experimental setup that is shown in Figure-4.

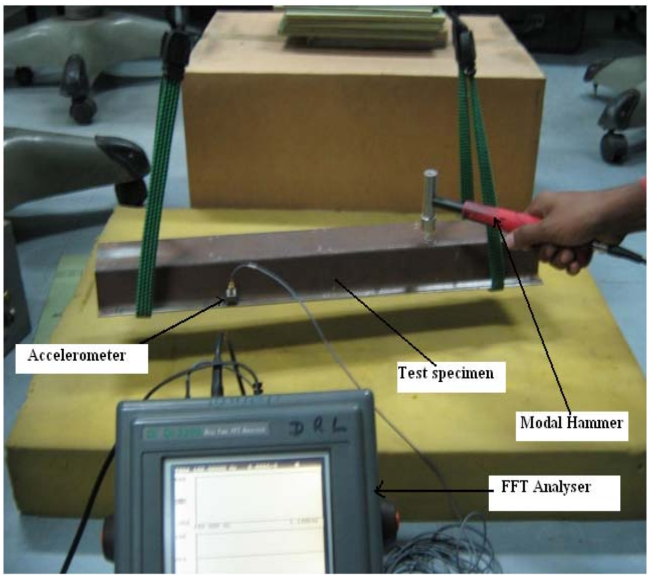


Figure-4 Experimental Set- up

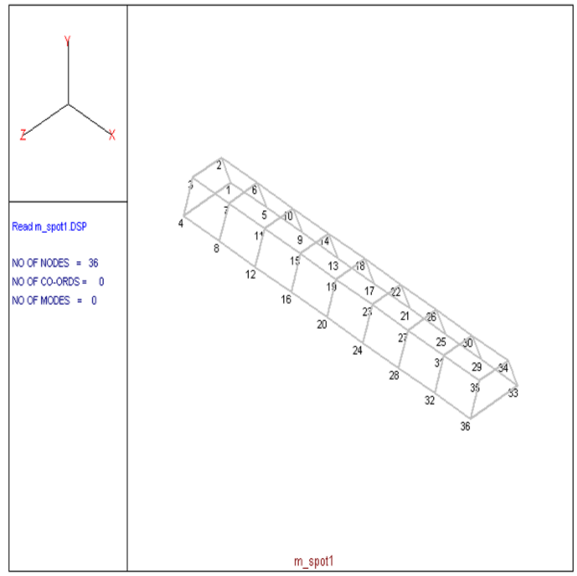


Figure-5 Hat structure showing the measurement points

Table 1 Natural frequencies and damping factor obtained from EMA

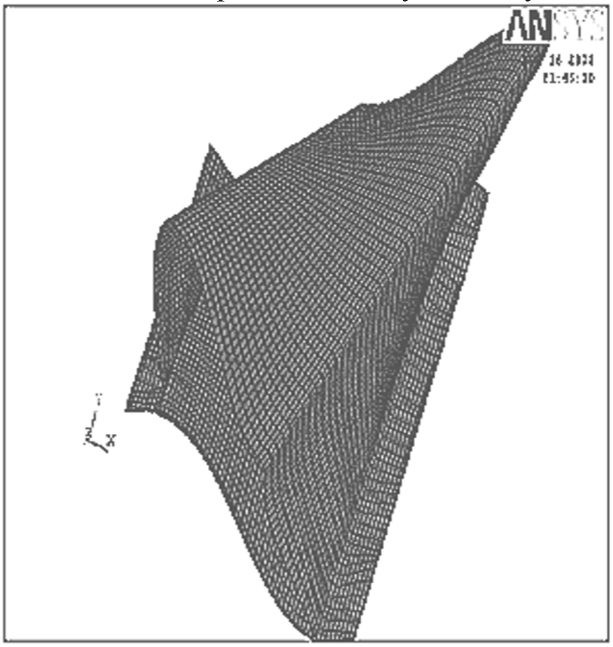
Mode no	EMA frequency (Hz)	Damping	Comments
1	380.1	0.0107	1st Twisting
2	397.3	0.0089	2nd Twisting
3	533.5	0.0062	Bending of hat and base mode
4	627.4	0.0043	1st Base mode
5	671	0.0053	2nd Base mode
6	748	0.0086	3rd Base mode
7	860.4	0.0091	Bending mode
8	924.4	0.0073	4th Base mode
9	994	0.0078	Twisting of hat and base mode

Comparison of experimental and numerical results

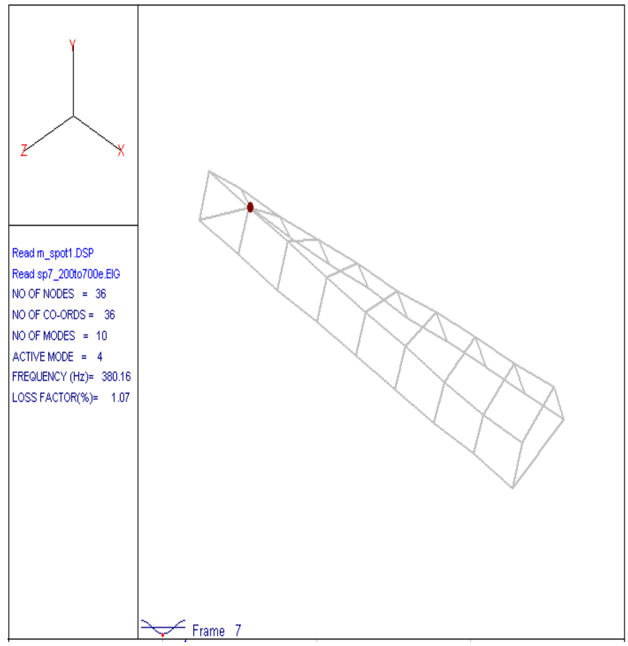
The results obtained from FE model of spot welded structure are compared with EMA results to find out the correlated mode pairs. A considerable difference between the FEA and EMA frequencies is found for higher modes. Figure-6 shows the comparison of finite element mode shapes obtained from ANSYS [7] and the experimental mode shapes obtained by analysis of measured FRFs in ICATS [5]

Mode shapes obtained by FE analysis

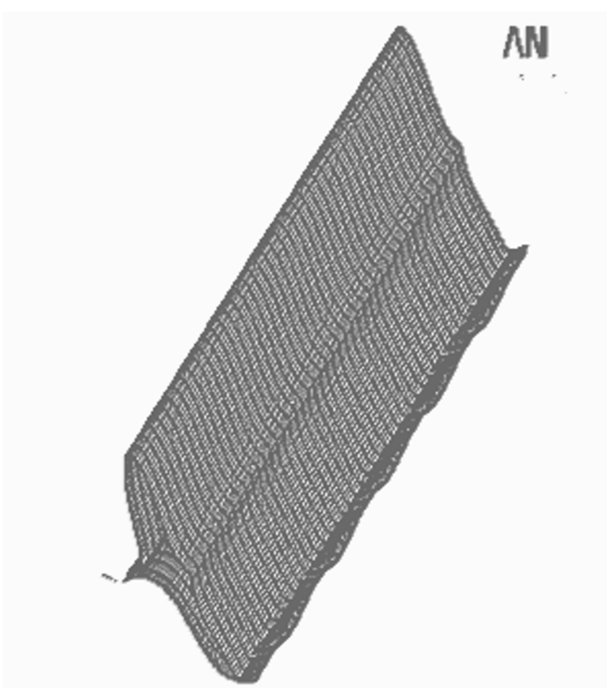
Mode shape obtained by experiment



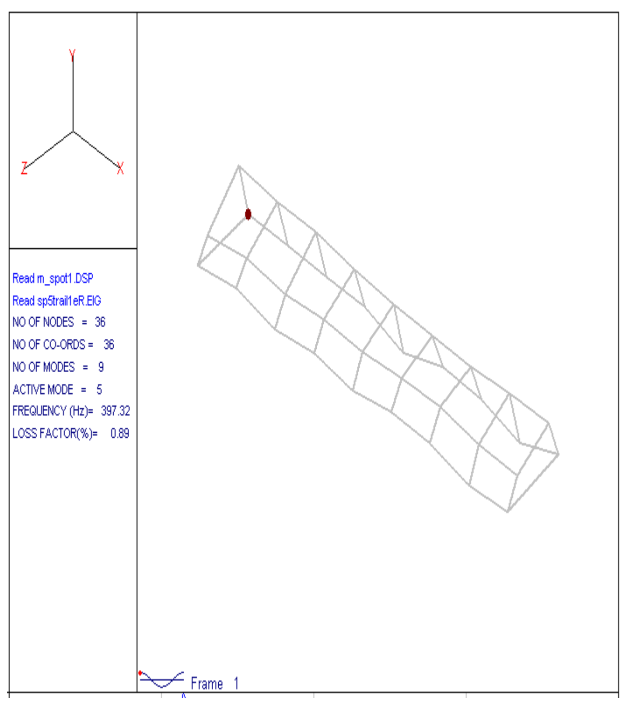
Mode 1 at 386.7Hz (twisting)



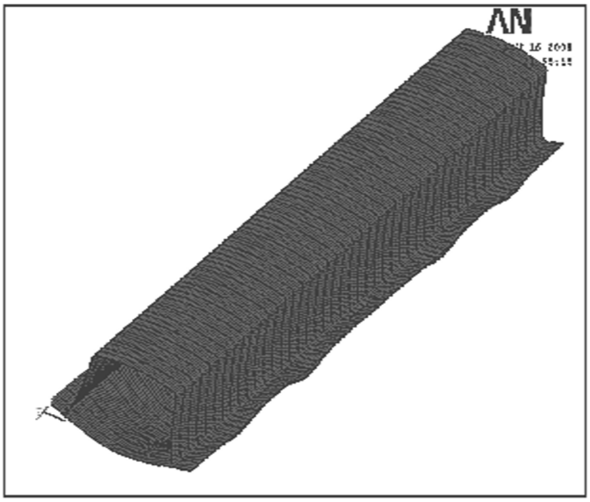
Mode 1 at 380.1Hz (twisting)



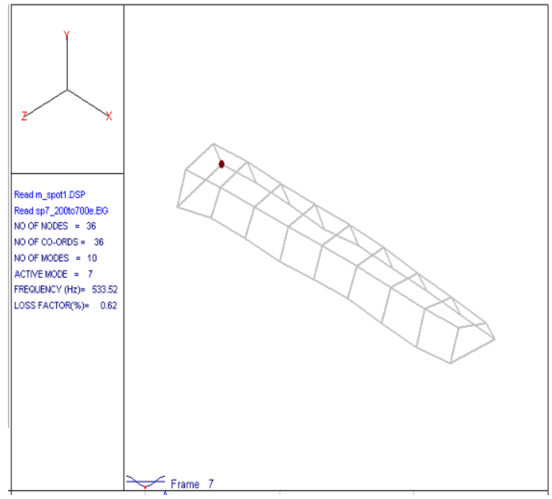
Mode 2 at 409.4Hz (twisting)



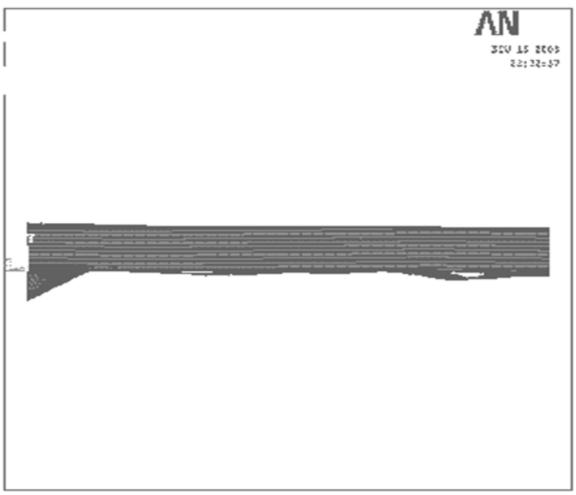
Mode 2 at 497.3Hz (twisting)



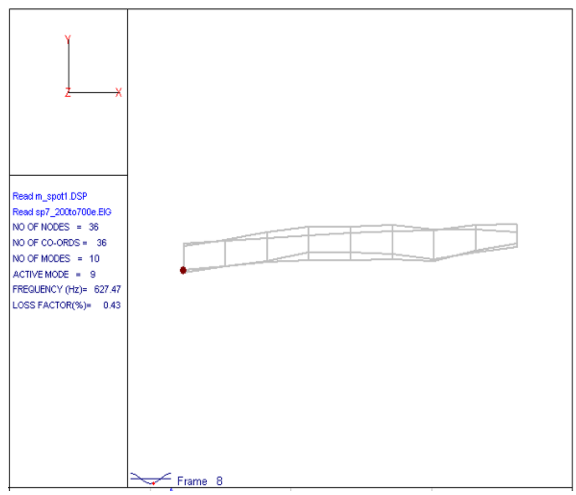
Mode 3 at 516.6 Hz (bending and base mode)



Mode 3 at 533.5 Hz (bending and base mode)

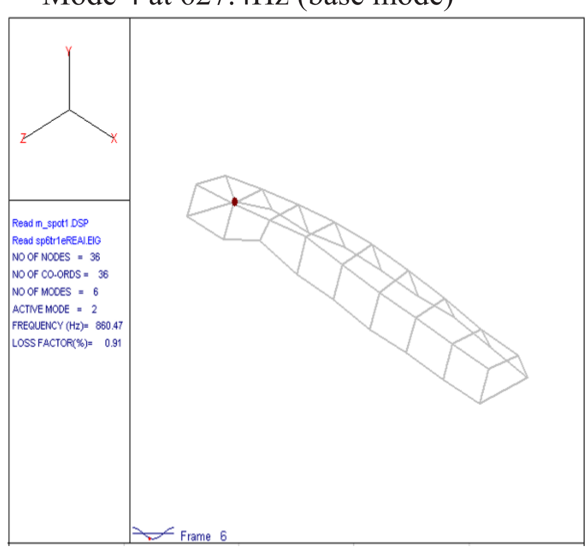


Mode 4 at 648.8 Hz (base mode)

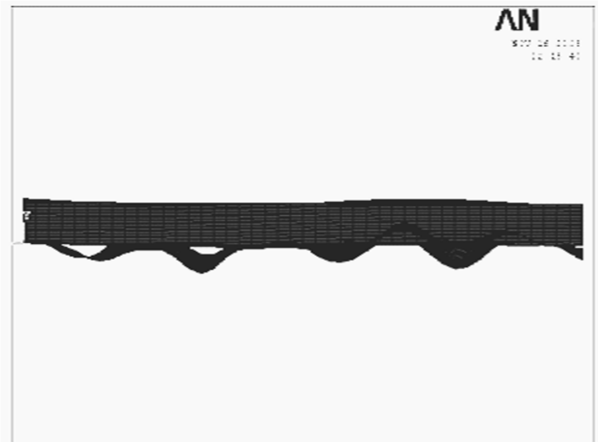


Mode 4 at 627.4Hz (base mode)

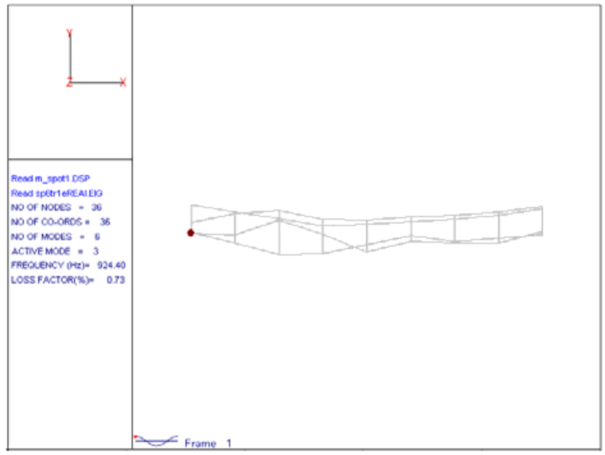
Mode 5 at 873.3 Hz (bending)



Mode 5 at 860.4Hz (bending)



Mode 6 at 1008.9 Hz (base mode)



Mode 6 at 924.4Hz (base mode)

Figure 6 Comparison of FE and experimental modes

The updating of FE model is carried out in FEM-Tools software [6]. Young's modulus and moment of inertia of the beam elements are taken as the updating parameters. Percentage change in young's modulus of the beam element after updating is found to be 90%.The large change in young's modulus represents an equivalent reduction in the stiffness of the spot welded structure.

Table 2 shows the comparison of natural frequencies, obtained through EMA, initial FE model and Updated FE model. Here both the parameters are chosen for updating.

Table 2 comparison of original and updated model

Mode	Natural Freq. (Hz)			% Error	
	EMA	FEA (original)	FEA (Updated)	FEA (original)	FEA (Updated)
1	380.1	386.7	386.2	1.73	1.59
2	397.3	409.4	409	3.06	2.96
3	533.5	516.6	512	-3.16	-4.02
4	627.4	648.8	639.8	3.40	1.98
5	860.4	873.3	867.2	1.49	0.78
6	924.4	1008.9	967.7	9.15	4.68
Average (% error)				2.61	0.78

Table 3 shows the comparison of average and maximum error in natural frequency of updated and original FE model. Moment of inertia has not much effect on the updating. So diameter can be varying in the spot welded structure. So, for the further analysis young's modulus has been taken as the updating parameter.

Table 3 Average and maximum error in the updated model

Percentage Error (%)	Young's modulus (%)		Moment of inertia (%)		Both young's modulus and Moment of inertia (%)	
	updated	original	updated	original	updated	original
Average error	1.14	2.61	1.91	2.61	0.78	2.61
Maximum error	7.12	9.15	6.9	9.15	4.68	9.15

Structural Dynamic Modification (SDM) of the spot-welded structure

Model updating techniques are used to update a finite element model of a structure so that an updated model predicts more accurately the dynamics of a structure. The dynamic design using an updated model requires that the model predict the change in the dynamic characteristics due to potential modification with reasonable accuracy [2]. The updated model obtained by matching the natural frequencies is then used for predicting the effects of potential design modifications made to the structure. With this purpose the structural modification in the form of mass and change in number of spot welds are considered.

Mass modification

A mass modification is introduced by attaching a mass of 70 gram at a distance of three-fourth of the length on the top surface as shown in Figure-7.The mass modification is also introduced analytically in the updated model. A comparison of the modified modal data as predicted by the updated model and that of the experimental data is done.

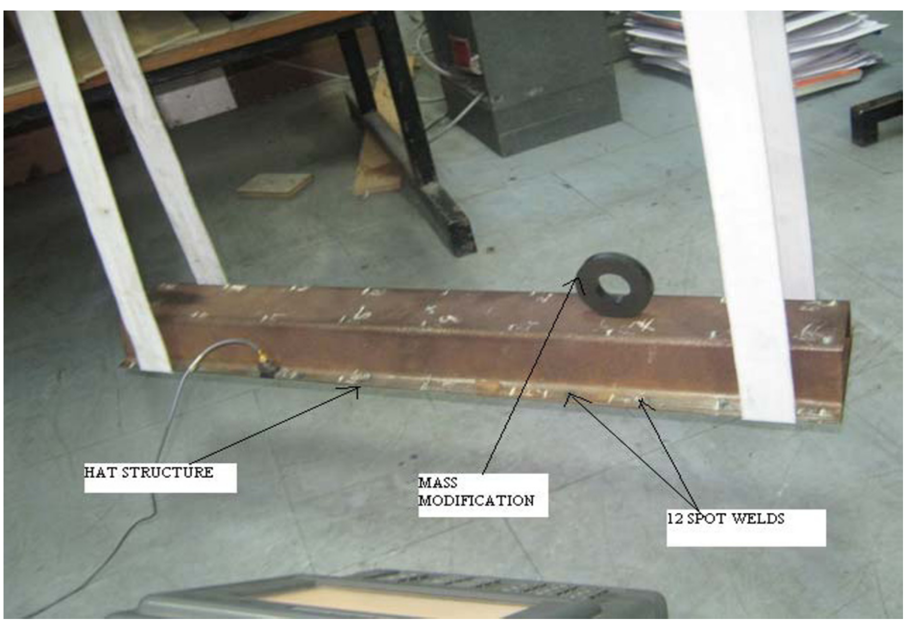


Figure 7 EMA set up with mass modification

Comparison of modified natural frequency of the updated model and that of the experimental data is shown in Table 4.It is observed that the predicted dynamic characteristics (natural frequency) on the basis of updated model are reasonably closer to the measured characteristics for the modified structure. The average error in the original FE model is 4.17% while in the updated model it is reduced to 2.25%. It is seen that in the third mode the results are not satisfactory as the original FE model behaves good in this case. Also, in the fourth mode there is very little change or no change in the natural frequency due to addition of lumped mass.

Table 4 Percentage Error predicted in FE model and updated model

Mode	EMA freq. Before SDM (Hz)	EMA freq. After SDM (Hz)	Original FE freq. After SDM (Hz)	(%) error	Updated FE freq. After SDM (Hz)	(%) error
1	380.1	331.4	379.2	14.42	350.6	5.79
2	397.3	388.2	398.7	2.7	390.9	0.69
3	533.5	505.6	508.1	0.49	498.5	1.4
4	627.4	625.4	648.6	3.79	634.1	1.39
5	860.4	853.6	827	-3.1	854.8	0.14
6	924.4	939	1002.5	6.76	977.5	4.1
Avg(% error)				4.17		2.25

Structural dynamic modification due to variation in number of spot weld

Number of spot weld increased to 22

In order to predict the change in dynamic characteristics of the spot welded structure variation in number of spot welds is done. 10 more number of spot welds is created on the hat structure, 5 on each side of the flanges .Now total no of spot welds become 22 i.e., 11 on each side of the single hat structure. The increase in number of spot weld is also introduced analytically in the updated model. A comparison of the modified modal data as predicted by the updated model and that of the experimental data is done. It is observed that the predicted dynamic characteristics (here it is only natural frequency) on the basis of the updated model are reasonably closer to the measured characteristics for the modified structure.

Comparison of modified natural frequency of the updated model and that of the experimental data in case of 22 spot welds is shown in Table 5 When no .of spot welds are increased to 22 there is increase in the natural frequency of the structure due to increase in stiffness of the structure. The increase in natural frequency is well predicted by the updated FE model .The percentage error in the first twisting mode is reduced to .027% from 1.18 as predicted by original FE model. In first bending mode the error predicted by original FE model is 3.69% which are reduced to 0.67% in case of updated FE model. The average error in original FE model is 3.02% which is reduced to 1.59% in updated FE model.

Table 5 Percentage Error predicted in FE model and updated model with 22 spot welds

Mode no	EMA freq. Before SDM (Hz)	EMA freq. After SDM (Hz)	Original FE freq. After SDM (Hz)	(%) error	Updated Freq SDM (Hz)	Error (%) updated
1	380.1	400.1	404.9	1.18	400.2	0.027
2	397.3	443.7	434.5	-2.07	431.8	-2.66
3	627.4	631.1	655	3.79	639.8	1.39
4	860.4	860.2	892	3.69	866	0.67
5	924.4	963.9	1046.9	8.53	1046.2	8.53
Avg (error)				3.02		1.59

Number of spot weld increased to 42

Comparison of modified natural frequency of the updated model and that of the experimental data in case of 42 spot welds is shown in table 6. When no .of spot welds are increased to 42 there is increase in the natural frequency of the structure due to increase in stiffness of the structure. The increase in natural frequency is well predicted by the updated FE model .The percentage error in the first twisting mode is reduced to 1.02 from 3.7 as predicted by original FE model. The average error in original FE model is 11.15% which are reduced to 6.6% in updated FE model. Maximum error is reduced to 5.27% from 15.49%.

Table 6 Percentage Error predicted in FE model and updated model with 42 spot welds.

Mode no	EMA freq. Before SDM (Hz)	EMA freq. After SDM (Hz)	Original FE freq. After SDM (Hz)	% error	Updated Freq SDM (Hz)	Error (%) updated
1	380.1	404.4	419.4	3.7	400.27	1.02
2	627.4	622.2	718.6	15.49	655	5.27
3	860.4	863.8	987.1	14.27	980.5	3.51
4	924.4	966	1092.7	13	1090.4	12.8
Avg (%error)				11.15		6.6

Table 7 shows the change in damping due to change in number of spot welds. Due to increase in number of spot welds the damping of the spot welded structure has increased in some modes. Increase in damping due to increase in number of spot-welds is useful as then the overall vibration response and the also the radiated noise inside and outside the vehicle will be lower.

Table 7 Damping comparison of the spot welded structure

EMA12spot weld	Damping	EMA 22spot weld	Damping	EMA 42spot weld	Damping
380.1	0.00107	400.16	0.0111	404.4	0.0097
533.5	0.0062	521.4	0.0135	521.2	0.0127
627.4	0.0043	631.1	0.0108	622.2	0.0323
860.4	0.0091	860.2	0.0133	863.8	0.0125
924.4	0.0073	963.9	0.0040	966	0.0030

Conclusion

In this paper correlation, updating and structural modification studies on a spot-welded structure are carried out. Based on studies of model updating of spot welded structure, it is concluded that the updating of spot welded model has the potential to improve the accuracy of spot welded structure. Model updating is attempted through several updating parameters choices. The updated spot weld model can be used reliably for predicting the effect of structural modification. It is observed that as the number of spot welds is increased the natural frequency of the structure is increased. The damping is also seen to increase for most of the mode.

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