Joining Strategy Analysis of Structural Dynamic in Top Hat Plate of Dissimilar Materials

N.A. Nazri¹ and M.S.M. Sani¹,2*
¹Advanced Structural Integrity & Vibration Research (ASIVR), Faculty of Mechanical and Manufacturing Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia
²Automotive Engineering Centre, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

*Corresponding author: mshahrir@ump.edu.my

Abstract. Structural dynamic can be described as a study regarding analysis of model under exertion of dynamic loading. Joining in structure such as riveting, welding and soldering were strongly effects the structural dynamic properties. The aim of this paper is to conduct various joining strategy analysis in finite element software by using top hat plate structure in car as a model and result is compared with experimental data. Normal mode analysis with free-free boundary condition is applied. Resistance spot welding (RSW) technique is selected to weld flange part in top hat plate between dissimilar materials which is mild steel 1010 and stainless steel 304 with specified parameters applied. Modal testing via impact hammer test is carried out at the welded top hat plate for experimental analysis purpose. Correlation in between FEA and EMA results need to be conducted. By selecting identified parameters to execute model updating on the structure using sensitivity analysis method, the discrepancies in natural frequencies were reduced between FEA and EMA. CWELD element was chosen to represent weld model for spot weld joints due to its accurate prediction of frequencies and mode shapes compare to other weld modelling. As a closure, connection in structure parts play significant role in structural dynamics and model updating is one of successful method to lessen the discrepancies between FEA and EMA.

1.0 Introduction
The complex behaviour of joining elements holdings an important role in the whole dynamic characteristics, such as natural frequencies, mode shapes, and non-linear response features to external excitations [1]. It is necessary to evaluate the vibrational behaviour of the structure in order to prevent resonance fracture because of external dynamic loads [2]. Selecting proper joining method is a fundamental strategy in assembling structure with good performance. Various joining methods are existed in industry which has their own pros and cons. In between so abundance of manufacturing technologies, welding has been observed and confirmed as a key enabling technology to innovative and sustainable manufacturing [3] and resistance spot welding is one of the most popular method of welding metal sheets [4]. Pressure, heat and clamping duration are three main observed parameters to conduct resistance spot welding which are vary among different materials due to dissimilarities in mechanical properties. Previous study has reported that the time taken reflects how long current will flow in the joint, that is totally depends on the material type and also the thickness of material that needed to be weld [5].
This paper is attempted to conduct joining strategy of top hat structure using MSC Nastran Patran software and determine which joining is capable in resembling resistance spot welding joining. Modal parameters of the structure which is natural frequency and mode shapes are required to be analyzed from FEA and EMA and comparison will be carried out.

2. Finite Element Analysis

Finite element analysis can be defined as a computer simulation technique for modeling and analyzing the effect of the part or model built. This tool is very crucial to rectify the structure failure before manufacturing and test is carried on [6]. MSC Patran is utilized to conduct simulation for top hat structure. Completed geometry design is declared with respective material types and the properties can be seen in Table 1. Boundary condition is set to be free-free with normal mode analysis using SOL 103.

| Properties                  | Value      |
|-----------------------------|------------|
| Material properties (SUS304L) |            |
| Young’s modulus, E (GPa)     | 190        |
| Density (kg/m$^3$)           | 8000       |
| Poisson ratio                | 0.29       |
| Physical properties          |            |
| Length (mm)                  | 1004       |
| Width (mm)                   | 510        |
| Depth (mm)                   | 510        |

Four different joining strategies were implemented on top hat structure which is rigid body element (RBE), bar element (CBAR), weld element (CWELD) and beam element (CBEAM). Figure 1 shows how the joining methods were depicted. However, it is difficult to establish a sufficiently accurate dynamic FE model using FE modelling techniques and thus, lead to the development of modal updating [7-8].

![Diagram of Joining Methods in FEA](image_url)
3. Experimental Modal Analysis
Impact hammer testing is one of the methods to obtain modal parameters by giving excitation to the structure in the form of forces. Selected part in the structure is excited and the output response will be measured by accelerometers with the Fast Fourier Transform (FFT) analyzer and thus allow modal parameters to be extracted from the frequency response function (FRF) [10-11]. The selection of hammer tips is essential as the input excitation range of frequency is dominantly controlled by the hardness of the tip selected [10]. Springs were used to hang the structure in order to ensure the free-free boundary condition could be applied with 90° angle in between structure and hanger so that the free motion of vibration is not prevented. Figure 2 depicted the structure in hanging condition and the experiment setup. Roving accelerometer method is conducted while hammer is set to be fixed at one point. Frequency response function (FRF) and coherence graphs were observed for each excitation to ensure the data obtained is reliable.

![Figure 2. Structure in hanging position and experiment setup](image)

4. Model Updating
Model updating is a process of adjusting certain parameters of the finite element model [12-13]. The purpose of modifying the parameter is to meet a better correlation between finite element model and experimental analysis. There are numerous methods of updating, and for this paper, optimization algorithm (SOL200) in NASTRAN software was utilized to perform model updating. For updating, sensitive parameters need to be identified through sensitivity analysis that was performed earlier before updating process. Model updating is such a procedure that updates the uncertainty parameters in the initial finite element model based on the experimental results so that a more refined model can be extracted [14].

5. Result and Discussion
Among four joining methods, one need to be selected which gives the lowest percentage of error when compared with EMA, as the joining seems to be the most reliable to represent spot weld in real tested structure. Data from Table 2 shows apparently the differences in percentage of error for natural frequencies when compared with EMA while Figure and Table 3 demonstrates the mode shapes for EMA and FEA with joining strategies respectively.

From the result, it can be seen obviously that CWELD contributes the least percentage of error while RBE experienced overestimation of natural frequencies. CBAR and CWELD both were capable of reducing the error. However, for mode shape prediction, CBAR gives the worst illustration of deflection while RBE gives the best demonstration of mode shapes when compared with EMA. Both CWELD and CBEAM experience a little failure in estimating the mode shape in fifth and sixth modes.
Table 2. Percentage of error between EMA and FEA for 4 types of modelling

| Modes | Natural Frequency | EMA | RBE | CBAR | Error % | CWELD | Error % | CBEAM | Error % |
|-------|------------------|-----|-----|------|---------|-------|---------|-------|---------|
| 1     |                  | 212 | 224 | 210  | 5.66    | 219   | 3.30    | 201   | 5.19    |
| 2     |                  | 261 | 302 | 271  | 15.71   | 265   | 1.53    | 251   | 3.83    |
| 3     |                  | 334 | 371 | 330  | 11.08   | 371   | 11.08   | 369   | 10.48   |
| 4     |                  | 383 | 385 | 353  | 0.52    | 378   | 1.31    | 382   | 0.26    |
| 5     |                  | 418 | 396 | 387  | 5.26    | 424   | 1.44    | 409   | 2.15    |
| 6     |                  | 443 | 462 | 455  | 4.29    | 436   | 1.58    | 457   | 3.16    |
| 7     |                  | 583 | 543 | 544  | 6.86    | 549   | 5.83    | 543   | 6.86    |
| 8     |                  | 715 | 659 | 658  | 7.83    | 650   | 9.09    | 658   | 7.97    |
| 9     |                  | 791 | 823 | 812  | 4.05    | 767   | 3.03    | 777   | 1.77    |
| 10    |                  | 944 | 986 | 980  | 4.45    | 984   | 4.24    | 983   | 4.13    |
|       | Total Average Error | 6.57 | 4.51 | 4.24 | 4.58 |

Figure 3. Mode shape of EMA
Table 3. Mode shapes of FEA

| Modes | Type of modelling |
|-------|-------------------|
| RBE   | CBAR              | CWELD            | CBEAM          |
| 1     | ![Mode 1](image1) | ![Mode 1](image2) | ![Mode 1](image3) |
| 2     | ![Mode 2](image4) | ![Mode 2](image5) | ![Mode 2](image6) |
| 3     | ![Mode 3](image7) | ![Mode 3](image8) | ![Mode 3](image9) |
| 4     | ![Mode 4](image10) | ![Mode 4](image11) | ![Mode 4](image12) |
| 5     | ![Mode 5](image13) | ![Mode 5](image14) | ![Mode 5](image15) |
| 6     | ![Mode 6](image16) | ![Mode 6](image17) | ![Mode 6](image18) |
| 7     | ![Mode 7](image19) | ![Mode 7](image20) | ![Mode 7](image21) |
| 8     | ![Mode 8](image22) | ![Mode 8](image23) | ![Mode 8](image24) |
| 9     | ![Mode 9](image25) | ![Mode 9](image26) | ![Mode 9](image27) |
| 10    | ![Mode 10](image28) | ![Mode 10](image29) | ![Mode 10](image30) |

By considering all joints modelling for spot weld, it can be stated that generally all modelling strategy can be modelled when matching mesh was implemented to the structure [15]. For model updating purpose, RBE that represent weld joints do not have both geometrical and material properties which disallowed the updating purpose compare to CBAR, CWELD and CBEAM that contains significant parameters in modelling of weld that can be used to be update. From these comparisons, it is found that the natural frequency of CWELD is more tempting to approach EMA compare to other two models, so the CWELD element is selected to represent spot weld joining and will be proceed to model updating method to improve the correlation between numerical and experimental counterparts.

5.1 Sensitivity Analysis and Model Updating Result
It is essential to choice those updating parameters which will be most effective in producing a genuine improvement in the modelling of the structure [16-18]. Sensitivity analysis is a one step behind model updating which allowing the procedure of selecting sensitive parameters for updating. Sensitivity of
parameters can be identified from F06 file in NASTRAN by giving huge values for the most sensitive parameters while the lowest values depicted the least sensitive and not suggested for updating purpose. Initially, six parameters were chosen to undergo sensitivity analysis, and the sensitivity of top five natural frequencies were tabulated in Table 4 below.

| Output Type | Young Modulus (Mild steel) | Young Modulus (Stainless steel) | Young Modulus (Weld Joint) | Density (Mild steel) | Density (Stainless steel) | Diameter (Weld Joint) |
|-------------|-----------------------------|----------------------------------|-----------------------------|----------------------|---------------------------|-----------------------|
| NF1         | 7.05                        | 108.6                            | -5.01E-7                    | -18.7                | -102.4                    | -5.03E-7              |
| NF2         | 93.8                        | 35.8                             | 3.28E-7                     | -85.8                | -31.3                     | 5.87E-8               |
| NF3         | 132.5                       | 56.3                             | -2.15E-7                    | -104.5               | -73.2                     | 6.54E-7               |
| NF4         | 8.63                        | 198.2                            | -5.98E-8                    | -13.7                | -209.7                    | -3.82E-8              |
| NF5         | 166.7                       | 45.9                             | -1.67E-7                    | -122.5               | -76.7                     | 7.23E-7               |

From the table tabulated, it can be seen clearly that parameters related to weld joints does not sensitive enough to contribute in updating. Based on the table, by neglecting the negative signs, Young modulus and density for both materials were seems to gives effect on updating strongly as they were considered sensitive. To be clear, four parameters were selected for updating which are Young Modulus for mild steel, Young Modulus for stainless steel, density for mild steel and last but not least, density for stainless steel. Table 5 presented the initial and updated result of FEA.

| Modes | EMA (Hz) | Initial FEA of CWELD | Updated FEA of CWELD | Error (%) | Error (%) |
|-------|----------|-----------------------|-----------------------|-----------|-----------|
| 1     | 212      | 219                   | 214                   | 3.77      | 0.94      |
| 2     | 261      | 265                   | 261                   | 1.53      | 0.00      |
| 3     | 334      | 371                   | 344                   | 10.48     | 2.99      |
| 4     | 383      | 378                   | 367                   | 0         | 4.18      |
| 5     | 418      | 424                   | 416                   | 0.72      | 0.48      |
| Total Average Error | 2.75 | 1.72 | |

Regards to the table displayed, percentage of error was successfully deducted from 2.75% to 1.72% and this result proved the ability of model updating to reduce the discrepancy between FEA and EMA. It is also verified that four selected parameters significantly affect the behaviour of model. The changes in value for updated parameters are shown in Table 6.

| Parameter | Initial value (i) | Updated value (ii) | Deviation | (ii-i)/|i| |
|-----------|-------------------|-------------------|-----------|------|---|
| Young Modulus of mild steel (GPa) | 200               | 224               | 0.12      |
| Young Modulus of stainless steel (GPa) | 190               | 161.5             | 0.15      |
| Density of mild steel (kg/m³) | 8000              | 9200              | 0.15      |
| Density of stainless steel (kg/m³) | 8030              | 8110              | 0.01      |
6. Conclusion
As a summary, this study has dealt with joining strategy of FEA on modelling spot weld connection for forecasting the structural behaviour. Four types of joining have been simulated which is RBE, CBAR, CWELD and CBEAM and each of them shows dissimilarities in the results of natural frequency and mode shapes. CWELD joining has been agreed to be selected as the most reliable model of spot weld as the natural frequencies of CWELD give the lowest error to EMA besides the prediction of mode shapes does not differ in many modes. Model updating was carried out by updating four sensitive parameters which is Young Modulus of mild steel and stainless steel, and density for both materials. After model updating is run, the result shows that the percentage of error was successfully lessen and achieve the goal of updating.

Acknowledgments
The authors of this paper would like to acknowledge a great support and encouragement by focus group of Advanced Structural Integrity of Vibration Research (ASIVR), Universiti Malaysia Pahang (UMP) for providing all the equipment used for this work Fundamental Research Grant Scheme (FRGS/1/2017/TK03/UMP/02-19) – RDU 170123.

References
[1] Ibrahim R A and Pettit C L 2005 Uncertainties and dynamic problems of bolted joints and other fasteners, Journal of Sound and Vibration 279 (3) 857-936.
[2] Lee Y S, Yang M S, Kim H S and Kim J H 2002 A study on the free vibration of the joined cylindrical–spherical shell structures Computers & Structures 80 (27) 2405-2414.
[3] Martinsen K, Hu S. J and Carlson B E 2015 Joining of dissimilar materials CIRP Annals - Manufacturing Technology 64 (2) 679-699.
[4] Ambroziak A and Korzeniowski M 2010 Using Resistance Spot Welding for Joining Aluminium Elements in Automotive Industry Archives of Civil and Mechanical Engineering 10 (1) 5-13.
[5] Aslanlar S 2006 The effect of nucleus size on mechanical properties in electrical resistance spot welding of sheets used in automotive industry Materials & Design 27 (2) 125-131.
[6] Sani M S M, Nazri N A, Zahari S N, Abdullah N A Z and Priyandoko G 2016 Dynamic Study of Bicycle Frame Structure IOP Conf. Ser. Mater. Sci. Eng. 160 012009
[7] Guo N, Yang Z, Jia Y and Wang L 2016 Model updating using correlation analysis of strain frequency response function Mechanical Systems and Signal Processing 70 (Supplement C) 284-299.
[8] Abdullah N A Z, Sani M S M, Hussain N A, Rahman M M and Zaman I 2017 Dynamics properties of a Go-kart chassis structure and its prediction improvement using model updating approach International Journal of Automotive and Mechanical Engineering (IJAME) 14 3887-97
[9] Nazri N A and Sani M S M 2017 Finite element normal mode analysis of resistance welding jointed of dissimilar plate hat structure IOP Conf. Ser. Mater. Sci. Eng 257(1) 012059
[10] Avitabile P 2001 Experimental Modal Analysis J Sound Vib. 35(1) 20–31.
[11] Izham M H M, Abdullah N A Z, Zahari S N and Sani M S M 2017 Structural dynamic investigation of frame structure with bolted joints MATEC Web of Conferences 90 (01043).
[12] Mottershead J E, Link M and Friswell M I 2011 The sensitivity method in finite element model updating: A tutorial Mech. Syst. Signal Process. 25 2275–96
[13] Sani M S M, Abdullah N A Z, Zahari S N, Siregar J P and Rahman M M 2016 Finite element model updating of natural fibre reinforced composite structure in structural dynamics MATEC Web of Conferences 83 (03007)
[14] Ren W X and Chen H B 2010 Finite element model updating in structural dynamics by using the response surface method Engineering Structures 32 (8) 2455-2465.
[15] Zahari S N, Sani M S M and Ishak M 2017 Finite element modelling and updating of friction stir welding (FSW) joint for vibration analysis MATEC Web of Conferences 90 (01021)
[16] Zahari S N, Zakaria A A R, Sani M S M and Bujang I 2016 A review on Model updating of joint structure for dynamic analysis purpose MATEC Web of Conferences 74 (00023)
[17] Friswell M I and Mottershead J E 1995 Finite element model updating in structural dynamics, 1st ed. (Springer Science & Business Media, The Netherlands).
[18] Fouzi M S M, Jelani K M, Nazri N A and Sani M S M 2018 Finite Element Modelling and Updating of Welded Thin-Walled Beam International Journal of Automotive and Mechanical Engineering (IJAME) 15(4) 5874-89