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Finite Element Model of the Spot Welded Joints of Door in White (DIW)

Nor Irwan Abd Halim, Mohd Azmi Yunus, Salmiah Kasolang and Muhamad Norhisham Abdul Rani
Centre of Structural Dynamics and Control Engineering, Faculty of Mechanical Engineering,
Universiti Teknologi Mara (UiTM), 40450 Shah Alam, Selangor Darul Ehsan, Malaysia

Abstract: Welded joints are widely used in automotive industry in order to form a complete vehicle. The welded joints not only provide connections between components but are essential in controlling the dynamic characteristics of the vehicle. The dynamic characteristic of the vehicle is highly influenced on determining the level of car Noise, Vibration and Harshness (NVH) performance. Since, the characteristics of the welded joints plays a significant in the dynamic characteristics of vehicle structures, the accurate predictive models of the joints is vitally important. Hence, in this study, the feasibility of usage of connector elements such as ACM2, CWELD and CFAST on Door in White (DIW) structure is investigated. The study highlight on the influence and feasibility of each connector elements to produce correlated response with measured data. Correlation level between the predicted results and measured data were assessed through frequency deviation and MAC value.

Keywords: DIW, welded joints, dynamic characteristic, NVH, performance

INTRODUCTION

In automotive industry, Noise, Vibration and Harshness (NVH) performance not only contribute to the luxury level of the car but have always been an important issue closely related to reliability and quality of the vehicle. There are many sources of noise and vibration in a vehicle such as from the engine, tires and wind. However, certain cases the NVH characteristics are actually admired. For instance the door closing sound is often reflecting to vehicle quality by the customer perception. Therefore, a Door in White (DIW) must possess a good dynamic characteristics in order to control the noise and vibration performance and also associated with the customer expectation. The improvement of the noise and vibration of the DIW can be performed numerically by using finite element analysis and experimentally as early as the design stage.

The finite element analysis practically have been widely used and adopted by global automotive manufacturer in order to shorten the vehicle development timeline and to reduce the cost for the vehicle development programmed. However, the accuracy of the finite element model has always been questioned due to the fact that general assumption criteria are initially used during the development of the finite element model of the vehicle. Therefore, it is important to validate developed finite element models with measured data in order to ensure that appropriate models have been obtained. The complex behaviour of connecting elements such as bolt and weld joint plays an important role in the overall dynamic characteristics such as natural frequencies, mode shapes and nonlinear response characteristics to external excitations of the vehicle structure (Ibrahim and Pettit, 2005). Spot weld modelling in finite element can be described as complicated due to local effect existence of the weld area itself (geometrical irregularities, material homogeneity and weld defects) in actual condition (Palmonella *et al*., 2005). Although, there are lot of extensive studies on spot welded joints, very well establish procedure to design and verify spot welded structures in Finite Element (FE) is not yet available (Palmonella *et al*., 2004). In this study, the developed finite element model of the DIW structure and spot weld model will be investigated and compared with the experiment data in term of natural frequencies and mode shapes. This study also presented the feasibility of connector elements namely, ACM2, CWELD and CFAST on representing spot welds in DIW structure. On top of that, the advantages of these 3 connector elements (ACM2, CWELD and CFAST) in MSC NASTRAN generate weld elements which is independent of the mesh which have more flexibility to be used in modelling a large complex structure with many numbers of spot weld point. Furthermore, their independency behaviour significantly reduces computational effort, time and cost of finite element analysis.

Corresponding Author: Nor Irwan Abd Halim, Centre of Structural Dynamics and Control Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Mara (UiTM), 40450 Shah Alam, Selangor Darul Ehsan, Malaysia

MATERIALS AND METHODS

Joint connector elements: The DIW jointed structure are assembled by 87 number of spot weld points (inclusive of 2 and 3 layers) with the diameter of 5 mm. There are 3 difference spot welds joint technique have been used to model the DIW namely, ACM2, CWELD and CFAST.

ACM2 (or area contact model 2) weld model have been proposed by Heiserer et al. in year 1999. The model (Fig. 1) consist of combination of brick element (CHEXA8) connected to joint components using RBE3 connections. Used of RBE3 element give advantage on distributing load into surrounding shell nodes without increasing local stiffness as per normal rigid link. Several studies have shown good accuracy level upon usage of the weld element type (Krank *et al*., 2012; Alba *et al*., 2009). The second weld model type used in this study was CWELD elements (Fig. 2). Unlike ACM2 model which contain few elements combination in Nastran, CWELD have been introduce as specific connector's element. The weld element has been introduced by Fang in year of 2000. This element in MSC Nastran defines as weld or fastener connecting two surface patches or connections. In this study the "ELPAT" format were used to define a connection of two shell element patches A and B with shell element identification numbers SHIDA and SHIDB. The diameter D and material ID are defined on the PWELD property entry. Since then many research have been done using the CWELD connector's element as spot weld element in finite element code (Husain *et al*., 2010).

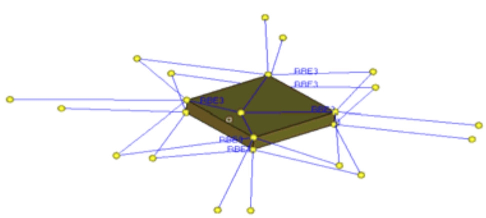

Fig. 1: Area Contact Model 2 (ACM2)

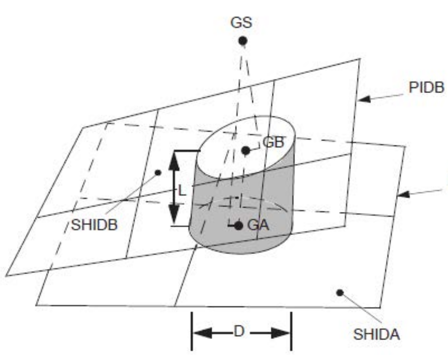

Fig. 2: CWELD element model

Another weld model used in the study was CFAST elements. CFAST element was first introduced in 2005 by MSC Nastran. The element consider as enhancement of CWELD element. In contrast to CWELD element, no materials ID defines on PFAST property entry with additional input of translational and rotational stiffness value were required to be define by user. Similar to CWELD, "ELPAT" format were used in this analysis to define a connection of two shell element patches A and B with shell element identification numbers SHIDA and SHIDB.

Theory overview: From mechanical engineering point of view, any components or systems can be represented by 3 basic elements such as mass, stiffness and damping. Natural frequencies (eigenvalue) and undamped mode shape (eigenvectors) were considered as basic design property of the structure.

In mathematical formulation, natural frequency and mode shape govern by reduced form on equation of motion whereas no damping and any applied loading been considered. This is basically an equation of motion for undamped free vibration and can be expressed as:

$$[M]\ddot{x} + [C]\dot{x} + [K]x = f(t) \quad (1)$$

The system is lightly damped and subjected to free vibration therefore, $[C]\dot{x} = 0$ and $f(t) = 0$. Therefore, the equation can be arranged and expressed in Eigen Solution equation of motion as:

$$[M]\ddot{x} + [K]x = 0 \quad (2)$$

The K and M matrices are simplified of the complete assembly of stiffness and mass:

$$(K - \lambda M)\varnothing = 0 \quad (3)$$

Corresponding to each natural frequency is an eigenvector, representing the contribution of the displacement coordinates.

Door in White (DIW) Model: In this study, the DIW was designed using CAD. Meanwhile, the finite element software of ALTAIR HyperMesh and MSC NASTRAN solver with SOL103 used to calculate the eigenvalue and

Fig. 3: FE model of DIW structure

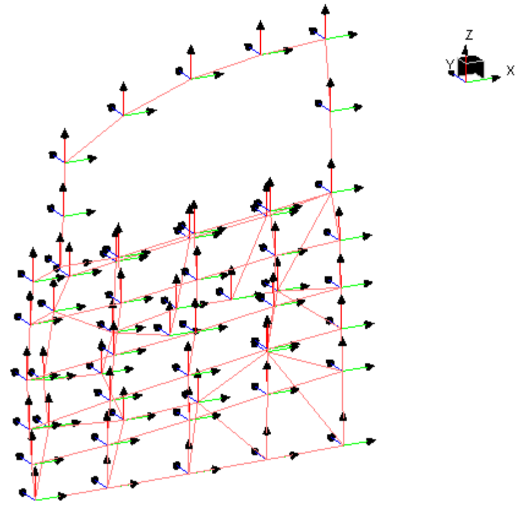

Fig. 4: DIW model with measurement degree of freedom

eigenvectors of the DIW with free-free boundary condition. There are DIW model 34782 CQUAD4 elements and 1518 CTRIA elements with average size of 7 to 8 mm as shown in Fig. 3.

RESULTS AND DISCUSSION

Test planning: Sufficient frequency range must be chosen in order to excite all the first ten elastic modes of the DIW. Initial information such as mode shape and frequency from finite element results were used to determine the best position of accelerometer during Experimental Modal Analysis (EMA). Series of selected measurement degree of freedom location (Fig. 4) were selected. Modal Assurance Criterion (MAC) used to evaluate the quality of the chosen measurement locations. Diagonal values close to 1 express the ability of the chosen location to replicate similar mode with simulation models (Fig. 5). MAC can be defines as a scalar constant relating linearity between two modal vectors (Allemang, 2003). It is widely been used to measure the correlation between test and finite element model. In the case of test planning preparation, reduced FE mode shape from created set measurement degree of freedom points were used. The governing equation for Modal Assurance Criterion (MAC) is given in Eq. 4:

$$\text{MAC}\left(\{\psi\}_{test}, \{\psi\}_{fe}\right) = \frac{\left|\{\psi\}^{*T}_{test}\{\psi\}_{fe}\right|^2}{\left|\left(\{\psi\}^{*T}_{test}\{\psi\}_{test}\right)\left(\{\psi\}^{*T}_{test}\{\psi\}_{fe}\right)\right|}$$

Where:

$\{\Psi\}_{test}$ = Modal vector for test mode
$\{\Psi\}_{fe}$ = Modal vector for FE mode
$\{\Psi\}^{*T}_{test}$ = Transpose of test modal vector
$\{\Psi\}^{*T}_{test}$ = Transpose of FE modal vector

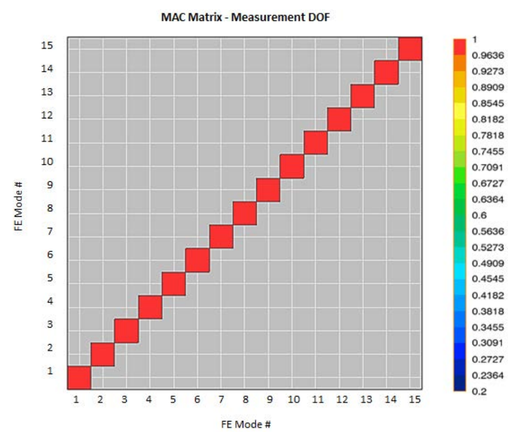

Fig. 5: MAC matrix of analytical mode response at measurement degree of freedom

Test setup: The DIW test sample were hanged using elastic bungee cord (Fig. 6) as to ensure experimental test arrangement represent free-free boundary condition similar to simulation model setup.

Roving hammer technique was applied to analyse the modal behaviour of DIW structure. Single fixed tri-axial accelerometer fixed to be function as reference signal. Subsequently the impact hammer was roved around previously selected 54 measurement degree of freedom locations and all translational acceleration response at the reference point were measured and recorded natural frequency of DIW based on measured Frequency Response Function (FRF). LMS data acquisition and LMS Test Lab Software used to process the measured load and signal response. PolyMAX curved fitting procedure then used to identify.

The results obtain from experimental results were compared to predicted results of the finite element models. Accuracy level of DIW finite element model with all 3 difference spot weld connectors of ACM2, CWELD and CFAST were investigated. Frequency deviation and MAC values of corresponding mode shape (mode pairing) between EMA and finite element were used to evaluate the finite element model quality.

Initial correlation for the DIW study is summarized by Table 1 and for quality of mode correlation, Fig. 7-9 is

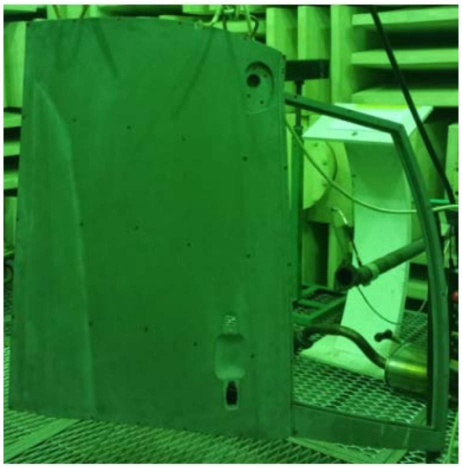

Fig. 6: EMA setup for DIW

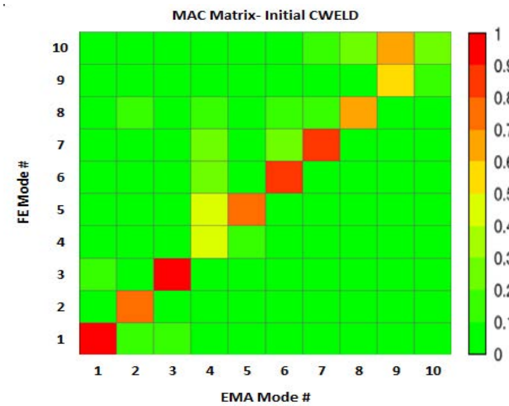

Fig. 8: MAC analysis for CWELD connector model

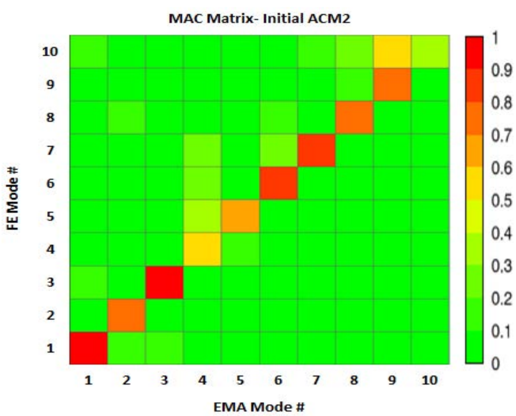

Fig. 7: MAC analysis for ACM connector model

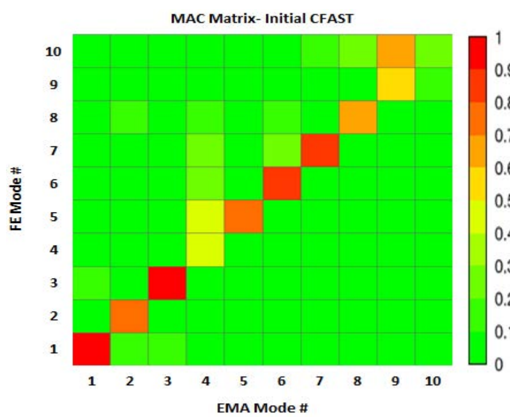

Fig. 9: MAC analysis for CFAST connector model

Table 1: Comparison of initial finding on difference weld connector element

		ACM2			CWELD			CFAST		
Mode	Test data (Hz)	Initial FE (Hz)	Relative error (%)	MAC	Initial FE (Hz)	Relative error (%)	MAC	Initial FE (Hz)	Relative error (%)	MAC
1	38.5	38.7	0.52	0.99	38.4	0.26	0.99	38.3	0.52	0.99
2	48.2	47.8	0.83	0.79	47.2	2.07	0.78	46.9	2.70	0.78
3	54.1	54.7	1.11	0.90	54.3	0.37	0.91	54.2	0.18	0.91
4	63.4	63.9	0.79	0.54	63.3	0.16	0.48	63.2	0.32	0.46
5	65.6	66.4	1.22	0.69	66.2	0.91	0.71	66.1	0.76	0.72
6	67.5	69.7	3.26	0.88	69.5	2.96	0.88	69.4	2.81	0.88
7	73.8	75.9	2.85	0.82	75.4	2.17	0.81	75.4	2.17	0.81
8	77.5	77.4	0.13	0.72	76.6	1.16	0.65	76.3	1.55	0.65
9	82.6	85.0	2.91	0.71	84.3	2.06	0.56	84.1	1.82	0.52
10	85.5	87.0	1.75	0.31	86.6	1.29	0.24	86.5	1.17	0.22
Total error (%)			15.36			13.41			14.00	

CFAST were investigated. Frequency deviation and MAC referred. In general MAC value >0.7 can be said as well correlated mode shape while value <0.5 described as poor correlated mode. CWELD model show the lowest total relative error summation (13.41%) followed by CFAST (14.00%) and ACM2 Model (15.36%). Largest relative error for all the 3 joints model contributed from Mode 6, 7 and 9. Lowest MAC recorded for Mode 10 in all the 3 joints model. It also can be seen that for all the 3 models, ACM2 produce the best MAC response. The entire 3 weld model shows less than 5% frequency deviation against experimental results for each calculated natural frequency.

CONCLUSSION

The DIW model with 3 different weld element have been analysed numerically and experimentally. Relative error and MAC value have been determine and compared in term of natural frequencies and mode shapes. All the errors between the predicted model and the experimental data are highly contributed from invalid assumption of material and properties at initial finite element model. In later stage, the finite element model of the connector elements are required to be updated in order to minimize discrepancies (frequency deviation, mode switching, low MAC value) against experimental data. On top of that, sensitivities study needs to be done in order to determine most influence parameter for updating process. Possibilities to produce good level of correlation in terms of natural frequencies and mode shapes suggested that all 3 spot weld models used (ACM2, CWELD and CFAST) have good capabilities to be used as spot weld connectors element in finite element model.

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