Frequency Response Function Based Updating of a Laser Spot Welded Structure using Synthesised Frequency Response Function

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Abstract. Accurate analytical models of engineering structures are of paramount importance for dynamicists to be used in predicting the dynamic behaviour (frequency response function) of the structures. The finite element method (FEM) and the experimental modal analysis (EMA) have been known as powerful and useful methods that can be used to determine the frequency response function (FRF) of the structures. However, the finite element FRF are often not in good agreement with experimental FRF due to assumption properties in finite element (FE) model. Therefore, in order to have a reliable FE model of a structure, measured FRF obtained from the experimental modal analysis can be integrated with finite element FRF to reconcile the FE model and the procedures involved in the reconciliation is a model updating process. Prior performing the updating process, the experimental FRF must be in good quality to obtain accurate FE model results. One way to reduce noise data and eliminate suspicious modes in FRF data is to use the FRF synthesised method. The main goal of this study is to use frequency response function based updating to minimise the error of a laser spot welded structure by using FRF synthesised data. In this work, MSC Software and LMS Test Lab were used to predict and measured the FRF of laser spot welded structure. The results revealed that FRF based updating method is successfully reduced the correlation gap between synthesised FRF and predicted FRF.

Keywords: frequency response function, model updating, synthesised FRF, laser spot weld.

1. Introduction
A precise description of the dynamic behaviour of engineering structures is of paramount importance to the dynamist community. Usually, there is a great deal of uncertainty about the selection of suitable methods to be used for the analysis. This is because the time to market products is shrinking. Experimental analyses usually are very costly, and long-time consume to be performed as compared to numerical simulations using the finite element method which is one of the most versatile numerical methods [1-2]. However, it is found that the finite element results are frequently not in good agreement with experimental counterparts due to the invalid assumptions made in the finite element modelling.
One way to refine, correct or update the finite element model through which the dynamic behaviour of a structure is predicted using model updating methods [3-9].

The subject of model updating methods has received much attention from many researchers. In the modal based updating method, [10-12] have used natural frequency values as a reference for updating the finite element model. Furthermore, [13-14] successfully corrected the initial FE model of engineering structure by using frequency response function data. Although the FRF based updating method required more computational time and space to solve problems, this method is more reliable than modal based updating method as claimed by [15-16].

One of the major drawbacks of the FRF based updating method is the noisy data in experimental FRF that will usually affect the accuracy of the finite element model updating results. The FRF that are contaminated with noise may cause the numerical solutions are not able to differentiate between the actual resonance peaks and the spurious modes or the noisy amplitudes. Hence, this scenario has driven the authors to implement the FRF synthesized method to eliminate the noisy data, that can efficiently be used in FRF based model updating. This paper presents a method that can be used to minimise the error between finite element FRF and synthesised FRF of a laser spot welded structure using the FRF based updating method. The updating will be applied to the initial finite element model of the welded structure in light of the measured results. The updated frequency response function is validated with those obtained experimentally to evaluate the accuracy of the FE model.

2. Finite element modelling of the laser spot welded structure

The finite element model of the laser spot welded structure was constructed using commercial finite element software as shown in Figure 1. In this work, the structure was modelled using QUAD4 shell elements with thousands of elements and nodes. Convergence tests were performed to determine the appropriate size of the elements and the element type used in the development of the FE model. The hat shape plate and flat shape plate were connected using ACM2 elements connectors that are available in the software to represent laser spot welded joints. The structure is thin steel sheets which have the following properties: the Young’s modulus, $E = 210$ GPa, Poisson’s ratio, $\nu = 0.30$ and density, $\rho = 7500$ kg/m$^3$. The frequency response function of the finite element model of the structure was calculated using MSC. NASTRAN solver. In this research, the frequency of interest was starting from 0 to 900 Hz.

3. Experimental work of the laser spot welded structure

In this study, the experimental modal analysis was performed on the laser spot welded structure with the nominal thickness of 1.5 mm, length of 564 mm and width of 110 mm. The structure was suspended by using soft rubber bands and strings to simulate free-free boundary conditions. This is because there were no constrains involved in the finite element model. The high sensitivity of 10.73 mV/N impact hammer and three accelerometers with 10mV/g sensitivity were used to measure the frequency response function (FRF), natural frequencies and mode shapes of the laser spot welded structure. The responses from the impact hammer and the accelerometers were acquired and analyzed by using Leuven Measurement System (LMS) front-end. The selection of the excitation points and the locations of measurement points were decided based on the modal participation factor (MPF) calculated in the initial prediction of the
dynamic behaviour of the structure. The frequency bandwidth of interest was 0 to 900 Hz. The details of the configuration of the components and the test set up are available in [10]. In order to obtain an acceptable level of accuracy and minimize the noise in the data, the RMS averaging method was performed by exciting and testing the structure ten times.

3.1. The synthesised frequency response function

One way to determine the frequency response function (FRF) of a component is by calculating an FRF synthesis based on the number of mode shapes and natural frequencies of the components. The equation of the synthesised FRF [13] is expressed by

\[
H_{syn}(\omega_k) = \sum_{i=1}^{N} \frac{\bar{\{\phi\}_i}(\bar{\{\phi\}_i}^T T_E)}{\omega_{n_i}^2 - \omega_k^2 + j^2 \xi_i \omega_{n_i}\omega_k} \tag{1}
\]

where \(N\) is the number of calculated modes, \(\{\bar{\phi}\}_i\) is the \(i\)th mass normalized mode shape, \(\omega_{n_i}\) is the \(i\)th natural frequency and \(\xi_i\) is the \(i\)th modal damping ratio. In this research, the synthesised FRF was used as a reference data in model updating method.

4. FRF based model updating

The updating of the initial finite element model was attempted using NASTRAN Solution 200 software. The objective of FRF based updating is to minimise the discrepancies between the finite element FRF and experimental FRFs by improving the parameters of the FE model in light of measured data to an acceptable level of accuracy. The finite element frequency response function must be corrected using the min-imisation of output residue at any frequencies using the equation below;

\[
\min \sum_{j=1}^{m} \left( \frac{T_{j}^{FE}}{T_{j}^{exp}} - 1 \right)^2 \tag{2}
\]

where \(T_{j}^{FE}\) is the \(i\)th predicted frequency response function and \(T_{j}^{exp}\) represents the \(i\)th measured frequency response function.

5. Results and discussion

The objective of this paper is to minimise the error between finite element FRF and synthesised FRF using FRF based updating method. The synthesised FRF was calculated using Equation 2 starting from 0 to 900 Hz which contains ten modes. The comparison of synthesised FRF and original experimental FRF are presented in Figure 2 below. The synthesised FRF has successfully removed spurious mode (marked with red circle) between mode seven and mode eight. In addition, the noisy data in the frequency less than 400 Hz has also been successfully reduced. Hence, the synthesised FRF will be used as a reference data to correct the initial finite element FRF.
Figure 2. Graph of comparison between original experimental FRF and synthesized FRF

The computed initial finite element FRF as shown in Figure 3 shows huge discrepancies as against the synthesized FRF. The discrepancies may arise from erroneous assumptions about the model properties used in the initial model. In addition, the discrepancies may come from the simplification in modelling of the joints to represent the actual joints without considering the effects of the process of assembling the substructures. Therefore, the initial finite element model needs to be corrected to improve the accuracy of the model. However, it seems to be impossible to manually adjust the predefined model properties of the initial finite element model without using a systematic updating method. This study aimed to systematically correct the predefined model properties of the initial finite element model in the light of experimental data using the frequency response function (FRF) based model updating method.

Figure 3. Graph of comparison between initial FE FRF and synthesized FRF

The potential updating parameters were selected from the finite element model to systematically modify the parameters until the predicted FRF is closed to measure FRF. Prior performing model updating process, the sensitivity method is carried out using Nastran codes. It was found that the responses which are the FRF are more sensitive to the Young’s modulus and Poisson’s ratio of the hat and plate as well as all model properties of the heat affected zones. The minimisation process of the
The parameter changes of the finite element model are tabulated in Table 1. From the results, Young’s Modulus of heat affected zone shows huge difference from the actual value which is from 210 GPa to 241.4 GPa. This means that the HAZ regions are harder than any other regions. All updated parameter values are within the acceptable level of steel properties. In addition, the updated values are in line with the results presented in the previous studies [9,10,13].
6. Conclusions
The attempt to predict and correct the frequency response function (FRF) of the laser spot welded structure using the FRF based updating method have been discussed. The results of updating the initial FE model of the structure are presented. The finite element method and experimental modal analysis have successfully used to determine the FRF of the laser spot welded structure. In addition, the synthesised FRF was successfully used to replace experimental FRF in the FRF based model updating method. Using the synthesized FRF in the FRF based model updating has proven to be successful in significantly improving the quality of the FE FRF against the measured FRF. Therefore, this method has a high potential to be used for various applications of FRF based model updating with noisy data and spurious modes are of great concern to the dynamicist community.

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