CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

The efficient methods for the numerical prediction of dynamic characteristics of large, complex structures have been the subject of much investigation in the scientist and engineer communities. The finite element method has become the predominant method for numerically predicting structural behaviour and the results obtained are very useful for virtual product development. Nonetheless, constructing accurate finite element models for modern structures which are usually large and complex is not an easy task (Friswell & Mottershead, 2005). This is because the sort of structures requires a very large number of degrees of freedom to be accurately modelled and the accuracy of the methods improves as more elements are used.

An ample amount of Research work is going in the Aerospace Industries and numerous work has been done until 2014-15 including optimization techniques, use of computer aided modelling, simulation and FEMUP. Based on the above a literature review is presented here,

2.2 FINITE ELEMENT MODEL UPDATING

The elimination of some errors in the finite element models seems to be impossible even though well rounded selection of data including the use of practical and measured parameters in the process of constructing the finite element models is used. For the success of construction of reliable finite element models, comparative evaluation of both the predicted results and measured results is vital because the results of the comparison provides some insights into
the likely sources of errors in the finite element models. The requirement to improve the finite element models derived results with respect to those obtained from the tested models is a part of the model correlation process (Gyeongho Kim et al. 2014).

There are many techniques that have been developed through which the finite element models of structures are adjusted by varying the parameters of numerical models to fit the experimentally measured data (Eric M. Hernandez et al. 2013).

The reconciliation of finite element models with tested structure has become universally accepted method for constructing reliable finite element models through which the dynamic behaviour of structures can be fully investigated and significantly improved. The process of adjusting finite element models exits in a range of techniques. The simplest one can be performed by simply changing the values of model parameters of the finite element model, rerunning the analysis and comparing the updated results with the measured results. These repetitive processes may be stopped once a required correlation has been achieved (Babak Moaveni et al. 2012).

This type of finite element model adjustment significantly poses a challenge to the engineer not only to assess the level of improvement in the finite element model but also to ensure the rationale behind the changes made to the finite element model. On top of that, this trial and error approach seems to be inefficient because firstly a large of amount of unnecessary repetitive processes is required for the correlation and secondly this approach highly depends on the individual skills and intuition in the classification of the source of errors in the finite element model (Linda Mthembu et al. 2012).
In an era dominated by high technology, demands on the accuracy in predicting structural dynamic performance of large and complex structures, in particular in automotive and aerospace industry for safety and economic benefits, are surging. With increasing size and complexity of the structures involved, as a result, model updating has become more difficult to efficiently perform. Therefore systematic and efficient approaches are necessary. In the past few decades, vigorous effort has been made in order to improve the correlation between analytical model of structures and measured data through the application of modal data (Quan Yuan 2013).

One of the earliest attempts was published by Rodden (1967) who identified the structural influence coefficients via the application of measured natural frequencies and mode shapes of an effectively free-free ground vibration test.

While Berman & Flannelly (1971) were among the first authors who presented a systematic approach through which the improvement of stiffness and mass characteristics of a finite element model was performed. The improvement was only achieved through the mass matrix, but not through the stiffness matrix because in this case it did not resemble a true stiffness matrix.

Assuming that the mass matrix is correct in his proposed method, Baruch (1978) used Lagrange multipliers to update the stiffness matrix by minimising the discrepancy between the updated and analytical stiffness matrices. The same approach was employed by Berman & Nagy (1983) to updated the mass matrix of a large analytical model. However for the updated stiffness matrix, two additional constraint equations were included.

Wei (1980) and Caesar (1986) used the same approach proposed by Berman & Nagy (1983), for the investigation of the robustness of variations of these methods including looking into the possibility of the methods to be used to
affect structural changes and the applicability to be used in small and banded matrices only. It appears that all the aforementioned methods require no iteration in order to satisfy the desired matrices to all the constraint equations. The initiation of the development of model updating algorithms began in the 1970s as a result of increasing reliability and confidence in measurement technology. The iterative methods through which analytical models can be reconciled with measured data have become of interest to researchers since.

Collins et al. (1974) formulated and demonstrated a method for the statistical identification of a structure. Through the proposed method they maintained the specific finite element character of the model and used values of the structural properties originally assigned to model by the engineer as the starting point. The original property values were modified to make the model characteristics conform to the experimental data.

Chen & Garba (1980) considered more measurements than parameters in computing the new eigenvalues and eigenvectors of the spacecraft structure by introducing extra constraints to turn the parameter estimation problem into an over determined set of equations.

Dascotte & Vanhonacker (1989) discussed and demonstrated the results of the updated analytical model that achieved through the application of the eigen sensitivity approach using weighted least square solutions. The drawback of the suggested approach is that engineering intuition and judgement are required to determine the proper value of the weights. In recent years, modal updating based on optimization scheme has become one of the predominant approaches used in automotive industry. This approach allows a number of model parameters to be systematically adjusted with respect to the measured modal parameters in order to minimize the objective function defined. The adjustment of the model parameters are performed iteratively in which
perturbation to the model parameters is altered at each iteration with respect to the objective function. While the objective function is defined in the form of the differences in modal parameters between the predicted and measured results. There are several papers that extensively discussed and demonstrated the results obtained from model updating using optimization approach.

Zabel & Brehm (2009) suggested that the selection of appropriate optimization algorithm for particular analysis problem is essential. This is to avoid presenting the issue of local extrema in the objective function defined. On top of that, they also concluded that the objective function has to be sensitive to updating parameters which requires a certain smoothness.

Model updating based optimisation scheme was tested by Bakira et al. (2007) on a finite element model of actual residential multi-storey building in Turkey and successfully used the scheme to detect and localise the damage on the building. Generally, frequency-domain model updating can be mathematically categorised in two groups, firstly direct methods and secondly iterative methods. Usually the former tends to have low computational expenditure, however, the updated models do not always represent physically meaningful results (Friswell & Mottershead, 1995). On the other hand, the latter requires higher computational effort due to repeated solutions. The updated models via iterative methods will always represent physically meaningful if their convergence is achieved (Caesar 1987).

A good introduction on the subject was presented by Imregun, (1992), including a discussion of practical bounds of the algorithms in general terms.

Furthermore mathematical approach and comprehensive surveys, were presented by Natke (1998), Imregun & Visser (1991), Mottershead & Friswell (2005). The latest survey was given by (Mottershead et al. 2010).
Meanwhile a comprehensive textbook on finite element model updating is available in Friswell & Mottershead (2005).

2.3 DIRECT METHODS OF FEMUP

The earliest generation of algorithms produced the methods often referred to as direct methods. These methods can be directly employed by taking derivatives with respect to structural system matrices to be updated and the updated system matrices are obtained in a single step. The resulting updated structural system matrices will reproduce the measured data exactly and lead to imperfect analysis results if the updated model is used for succeeding analysis. The unavoidable phenomenon happens because the updated system matrices lose their original characters from being sparse and only contain non zero elements in a band along the leading diagonal to a fully populated and also reflected little physical meaning. None of the direct methods, however, gives particularly satisfactory results as the updated structural system matrices have little practical value. Baruch (1978) and Berman & Nagy (1983) are the first advocates who employed these methods. However, Mottershead & Friswell (1993) in their survey mentioned that Berman concluded that it is impossible to identify a physically meaningful model through a direct approach. On top of that, these methods require a very high quality of experimental data which seems to be completely difficult to achieve for complex structures. Therefore iterative methods or optimization methods have great advantages that outweigh all the drawbacks of direct methods. The following section outlines iterative methods which are the methods used in this research work. None of direct methods have received general acceptance, due to certain shortcomings, although many have been successfully applied to specific problems. A review of the previous research and existing procedures can be found in Allemang & Visser (1991); Maia & Silva (1997) and Dascotte (2007).
2.4 ITERATIVE METHODS OF FEMUP

The main idea of iterative methods is to use sensitivity based methods in improving the correlation between the predicted and measured eigenvalues and eigenvectors. This is because sensitivity based methods have capability of reproducing the correct measured modal parameters. Almost all sensitivity based methods compute a sensitivity matrix by considering the partial derivatives of modal parameters with respect to structural parameters via truncated Taylor's expansion (Imregun & Visser, 1991). The variation of analytical response due to parameter variations can be expressed as a Taylor's series expansion limited to the first two terms (David-West et al., 2010) applied the method for updating a thin wall enclosure and the updated model showed good correlation with the experimentally derived data. On the other hand, these features are not all that important in models for dynamic analysis where the overall stiffness and mass play a much more important role in the determination of structural characteristics. Although the models for limit capacity analysis is an important issue in spot welds, however the topic will not be thoroughly reviewed as it is not the objective of this research work that focuses on spot weld modelling for dynamic analysis. Detailed information on the topic of models for limit capacity was elaborated and presented in several papers such as Chang et al. (1999); Chang et al. (2000); Deng et al. (2000); Radaj (1989); Radaj & Zhang (1995); Zang & Richter (2000) and Xu & Deng (2004); Roberto (2008) and Pal & Chattopadhyay (2011).

Study of dynamic characteristics of structures is usually treated as a global issue rather than a local issue owing to the fact that eigenproblem is typically a function of the structural mass and stiffness and of the boundary conditions as well. However, when it comes to investigating eigenproblem of welded structures, emphasis should not only be on modelling work of the structure but also be on spot weld modelling. This is because the properties and
characteristics of spot welds play a significant role in the dynamic behaviour of welded structures. In other words, dynamic characteristics of numerical models of welded structures highly depend on the quality and reliability of spot weld model. The well accepted alternative method for modelling spot welds in the past few decades was to use coincident nodes approach through which the nodes were coincident at boundary between the welded components (Lardeur et al., 2000). However, since early 1990s single beam models have been commonly used in modelling spot welds in industries. Rigid bar and elastic rod element are categorised into these single beam models. They are used to connect between two nodes of adjoining meshed sheets and their descriptions of connection and usage are available in (MSC.NASTRAN 2010).

Meanwhile, Donders et al. (2005) particularly in one of the sections of their paper, discussed the accuracy of results calculated from spot weld connections modeled as single beam elements. However, none of the aforementioned attempts to use single beam elements to model spot welds had produced satisfactory results of dynamic behaviour of welded structures. Common conclusions made in their studies were that spot weld connections modelled as single beam elements would only produce unsatisfactory results in comparison with those experimentally observed and the drawbacks of single beam elements representing the physical spot welds lie in several factors.

In Abdul Rani et al. (2011) the investigation revealed that the key parameters, namely the properties of materials, elements and patches that have been widely used by many researchers for the improvement in the finite element models were found to be insufficient for improving the initial finite element model in the study. The cause for the discrepancy was discovered to be the initial stress arising in the welding process and a new updating parameter was used successfully in the end to produce very good results by the updated finite element model. They also suggested that structures with large spans (walls or
floors for example) made from thin metal sheets are susceptible to initial curvature and/or initial stress and they should be accounted for in updating the finite element models of these structures.

2.5 MODEL UPDATING USING ANN

Artificial Neural Networks (ANN) has been used in mechanical engineering problems since the early 1990's. The main areas of concentration have been control, identification, and damage detection. And the results are mostly limited to computer simulations. There has been a significant amount of work on FE model updating by neural network over the past few years and several hundred papers have been published. Mottershead et al. (2011) gave extensive reviews of the various model updating methods that have been developed. The state-of-the-art in model updating technology has long been based on modal-based model updating procedures as these are, in general, numerically more robust and better suited to cope with larger applications.

Hashash et al. (2004) used ANN for model updating, the alternative approaches for model updating. ANN is used to represent the mapping between frequency domain data and model parameters. Once trained, the neural network quickly yields accurate estimates of the model parameters based on the frequency domain response of the structure. Since the process of estimating the model parameters is fast (of the order of tenths of a second), this technique can be used to adjust the control law acting on the structure in real-time as long as parameter variations are slow enough to allow for the updating of the system.

Ali Mohamed Nezhad et al. (2014) present application of ANN for updating of a mathematical model of the structure based on dynamic parameters. ANN, which predict the value of selected stiffness or concentrated masses on basis of Frequency Response Function (FRF), have been built. Preceding an
update, the FRF is compressed in order to reduce the number of input values necessary for updating.

C Chang et al. (2002) proposed model updating methodology based on an adaptive neural network (NN) model. The adaptive NN updating procedure is applied to a suspension bridge model and verified both numerically and experimentally. The NN model has a feed forward architecture and is first trained off-line using some training data that are obtained from finite-element analyses and contain modal parameters as inputs and structural parameters as outputs. The results indicate that by adaptively training the NN model and iteratively adjusting the structural parameters, it is possible to reduce the differences between the measured and the predicted frequencies from a maximum of 17% to 7% for the first eight vertical modes.

HOU Ying-ke et.al. (2010) made an attempt to investigate the galling failure in SMF operations under different conditions via finite element analysis and experimental tests. A further objective was to develop a numerical methodology to study the galling failure problem in SMF processes. Major factors that influence the galling failure, including material properties of the sliding couples, process parameters and frictional coefficient are modelled in finite element analysis (FEA) model. A methodology using finite element analysis has been developed to investigate the galling problem in SMF processes. The accuracy and reliability of the methodology is validated by the experiment.

2.6 PERFORMING SENSITIVE ANALYSIS

J. E. Mottershead et al. (2009) suggest that the sensitivity method is applied to update finite element models of welded joints and the boundary condition of a cantilever plate. Careful parameterization is found to be critical in updating joints and boundary conditions, and the merits of geometric parameters
are given special consideration. The use of nodal offset dimensions results in an updated model of the welded joint with physical interpretation. Similarly the “rigid” boundary in a cantilever plate is successfully updated using the effective length of the elements closest to the joint. In all cases an improvement on the analytical natural frequencies is demonstrated.

S. V. Modak et al. (2013) proposed “the updating of a finite element model of a structure using measured modal data and its subsequent use for predicting the effects of structural modifications with a reasonable accuracy”. An updated model is obtained by employing a method of model updating based on the constrained optimization. Structural modifications in terms of mass and beam modifications are then introduced to evaluate the updated model for its usefulness in dynamic design.

A. Gopichand et al. (2013) states the need for rapid, inexpensive assessment of these sensitivities exists at all design stages. During the design of large, complex space structures, the structural analyst needs to understand the sensitivity of transient load predictions to uncertainties in critical structural vibration modes and forcing inputs. These questions arise both early in the design cycle, when models are simple and unrefined, and in the later stages of design, when models can be very complex and expensive to analyze.

2.7 SELECTION OF UPDATING PARAMETER

Gyeong-Ho Kim et al. (2014) proposed multi-objective optimization technique for several objective terms simultaneously. Also the success of finite element model updating depends heavily on the selection of updating parameters. In order to avoid an ill conditioned numerical problem, the number of updating parameters should be kept as small as possible. Such parameters should be selected with the aim of correcting modelling errors and modal properties of interest should be sensitive to them. When the selected parameters
are inadequate, then the updated model becomes unsatisfactory or unrealistic. An improved method to guide the parameter selection is suggested.

**2.8 GENERATION OF TRAINING SAMPLES**

C. C. Chang et al. (2002) investigate the use of orthogonal arrays for the sample selection. A comparison between the orthogonal array method and other methods are also addressed in his study. In developing an iterative neural network technique for model updating of structures, it has been shown that the number of training samples required increases exponentially as the number of parameters to be updated increases. Training the neural network using these samples becomes a time-consuming task. The results of using orthogonal array (OA) indicates that the orthogonal arrays method can significantly reduce the number of training samples without affecting too much the accuracy of the neural network prediction.

L. Venugopal et al. (2012) proposed that Taguchi method is an efficient problem solving tool which can upgrade/improve the performance of the product, process, design and system with a significant slash in experimental time and cost. This method that combines the experimental design theory and quality loss function concept has been applied for carrying out robust design of processes and products and solving several complex problems in manufacturing industries. Further, this technique determines the most influential parameters in the overall performance. The optimum process parameters obtained from the Taguchi method are insensitive to the variation in environmental condition and other noise factors. The number of experiments increases with the increase of process parameters.

H. Arfa & R. Bahloul (2012) in his research to solve this complexity, the Taguchi method uses a special design of orthogonal array to study the entire process parameter space with a small number of experiments only. Taguchi
defines three categories of quality characteristics in the analysis of Signal/Noise(S/N) ratio, i.e. the lower-the-better, the larger-the-better and the nominal -the-better. The S/N ratio for each of process parameter is computed based on S/N analysis. Regardless of the category of the quality characteristics, a larger S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of process parameter is the level of highest S/N ratio. Furthermore, a statistical analysis of variance (ANOVA) can be performed to see which process parameter is statistically significant for each quality characteristics.

Davidson, et al.(2012) Taguchi method is one of the optimization techniques that could be applied to optimize input welding parameters. Optimization of process parameters is the key step in the Taguchi method in achieving high quality without increasing the cost. This is because optimization of process parameters can improve performance characteristics.

G. L. Damoulis & E. Gomes(2009) analysed that the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. This is particularly true when the number of the process parameters increases, leading to a large number of experiments have to be carried out. To solve this task, Taguchi method with a special design of orthogonal arrays can be used to study the entire process parameter space with a small number of experiments only.

2.9 TRAINING OF THE ANN

Y.M.A. Hashash et al. (2004) propose the model updating methodology based on an adaptive neural network. In his studies he used feed forward architecture for updating the model tuning. In addition he states “The ANN model has a feed forward architecture and is first trained off-line using some training data that are obtained from finite element analysis and contain
model properties as inputs and structural parameters as outputs. The ANN model is then adaptively retrained on-line during the model updating process in order to eliminate the difference between the measured and the predicted modal parameters”.

J.F. Carvalho et al. (2008) carried out the simulation of metal forming processes using the FEM, which opens doors to solving new and more complex problems using alternative approaches, such as inverse methodologies/problems. In this paper two types of inverse problems were presented and discussed: the parameter identification and the shape optimization problems. The aim of the first type of problems is to evaluate the input parameters for material constitutive models that would lead to the most accurate results compared to physical experiments. The second category involves determining the initial geometry of a given specimen in order to provide the desired final geometry after the forming process. The purpose of this work is to formulate these inverse problems as an optimization problem and introduce a straightforward methodology of process optimization in metal forming. To reach this goal, an integrated optimization approach, using a finite element code together with a numerical optimization program, was developed.

M.H.A. Bonte et al. (2008) in their investigation used FEM simulations for processes. More recently, coupling FEM simulations to mathematical optimization techniques has shown the potential to make a further giant contribution to product improvement and cost reduction.

2.10 SUMMARY

Modelling work on space structures, bolted joints, welded joints, model updating methods, sub structuring synthesis schemes has been reviewed in this chapter. It appears that the versatility of the finite element method has made it the most popular numerical method used for structural performance
analysis. However, in all cases, the results calculated from the method which is developed based on assumptions, may produce a large discrepancy from experimentally observed results. For the predicted results of FEMs to correlate as closely as possible with the measured results, systematic adjustments must be made to minimize the errors introduced to the models. The FEMUP method has become the accepted method for the reconciliation.

There are two major groups of frequency domain of model updating methods: the first is direct model updating methods and the second is iterative model updating methods. However the latter has superseded the former because the physically meaning updating parameters can be directly identified and then used for further applications. In addition, the iterative methods can benefit from optimization techniques which are readily available in commercial software like MSC. NASTRAN.