Finite Element Model Updating of Composite Structures for Automobiles

Dissertation-II

Submitted in partial fulfillment of the requirement for the award of degree

Of

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By

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Under the guidance of

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CERTIFICATE

I hereby certify that the work being presented in the dissertation entitled **“Finite Element Model Updating of Composite Structures for Automobiles”** in partial fulfillment of the requirement of the award of the Degree of master of technology and submitted to the Department of Mechanical Engineering of Lovely Professional University, Phagwara, is an authentic record of my own work carried out under the supervision of **Mr. Varun Panwar,** Assistant Professor, Department of Mechanical Engineering, Lovely Professional University, Punjab, **Dr. Ashok Kumar**, Research fellow, Centre for Infocomm Technology, School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore and **Mr. Nitin Chauhan**, Assistant Professor, Department of Mechanical Engineering, Lovely Professional University, Punjab. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

28-11-2017

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Abstract

In this work, finite element model updating of composite beam will be carried out. The finite element model of the composite beam will be simulated using MATLAB. Finite element model updating is the technique to improve the simulated finite element model from the experimental data. There are different types of errors in the finite element model such as geometry, property error, boundary condition, and error in joints. A lot of work has been done on isotropic materials like steel, aluminium etc. Finite element model updating of the composites structures is proposed in this study along with different orientation of the fibre.

Acknowledgement

This Dissertation-1 with title "Finite Element Model Updating of Composite Structures for Automobiles" wouldn't have come so far without the esteemed efforts and guidance of few persons. I feel extremely pleased to thank Mr. Varun Panwar, Assistant Professor, Department of Mechanical Engineering, Lovely Professional University, Punjab, Dr. Ashok Kumar, Research fellow, Centre for Infocomm Technology, School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore and Mr. Nitin Chauhan, Assistant Professor, Department of Mechanical Engineering, Lovely Professional University, Punjab for their guidance and untiring efforts.

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Declaration

I hereby declare that I am doing the Dissertation-1 titled "Finite Element Model Updating of Composite Structures for Automobiles" under the guidance if Mr. Varun Panwar, Assistant Professor, Department of Mechanical Engineering, Lovely Professional University, Punjab. I am knowledgeable of the penalties for plagiarism fabrication and unacknowledged syndication and declare that this project is free of any these.

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Chapter 1

Introduction

The title ‘Finite Element Model Updating of Composites Structures for Automobiles’ consists of updating the mechanical properties and fibre orientation of composite beam. There are two parts each of them is briefly explained:

1.1 Finite Element Model Updating

This is a updating technique which gives more accurate results related to measured data than the other initial models. Finite element updating is consist of finite element and updating, former one is a method which divides the large problem into smaller ones and thus we can get accurate solution for thermal problem, structural problem, fluid flow problem, etc. and later one is a word which means to bring something new either by adding some new information or by making any corrections.

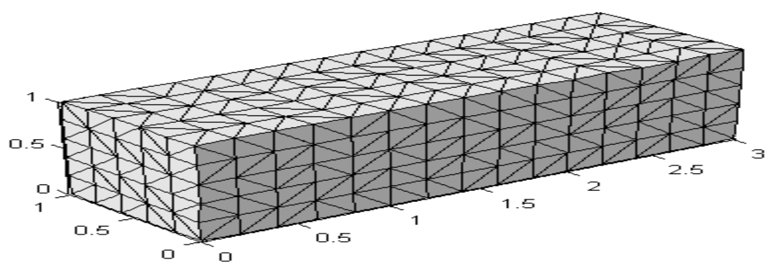


Figure 1: Finite Element Meshing [1]

Those smaller parts of the large problem are known as finite elements. Now the question is how does it work? This technique requires the boundary conditions to get the partial differential equations and forms the system of algebraic equations. In this solution, we get the value of unknown parameter at discrete points over the domain. More closer of these points results in better accuracy in solution of whole system.

There are many advantages of finite element method:

i. We can get accurate solution of complex geometry
ii. Easy representation of the total solution
iii. We can also find the resultant properties of two or more dissimilar material
iv. It also notice local effects

1.1.1 History of FEM

Finite element method was developed to solve complex structures problem basically in aeronautical engineering and civil engineering. In 1940, R. Courant and H. Hrennikoff play an important role for the development of this method. Then K. Feng presented a method to solve partial differential equation based on the computations of dam constructions. This method was named as the finite difference based on variation principle. **[2]**

1.2 Composites

In this thesis, I am going to deal with composite structures more specifically composite beams. For that first, we need to know about composite materials. Composite material as the name suggests, it is formed by combining two or more constituent which should have different chemical or physical properties. One constituent is called reinforced material or fibre and other one is called matrix in which fibre is embedded. This newly formed material have different characteristics with those individual components and known as composite material. These individual components remain separate and can be at different orientation with each other within the finished structure.

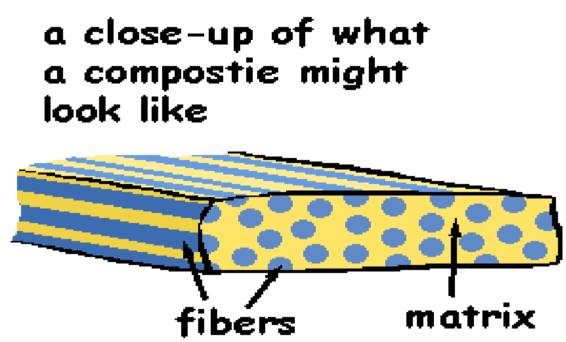


Figure 2: Composite Material [3]

There are some advanced composite materials such as ‘Kevlar + epoxy’, ‘graphite + epoxy’, and ‘boron + aluminium’ which have very high strength to weight ratio. These advanced materials have the application in aerospace industry and commercial industry. In this era, composite material has many applications such as in designing of bridges, structures, and building, etc. Composite materials also used in transport's vehicle and its accessories.

A composite material has the following properties:

i. It is homogeneous at macroscopic level and heterogeneous at microscopic level.
ii. It has high strength, high stiffness, and high toughness
iii. It results in reduced weight and reduced cost.

Composite has two constituents one is reinforcement such as fibre, it improves the properties of composites and another one is matrix, it is used as support to and protection of fibres. It also helps to transfer stresses between broken fibres. Composites have the applications in many fields such as in Aerospace, Missiles, Railway Carrier, Medical, Sports Equipment, Military, etc.

1.2.1 History of Composites

The composites have existed from 10000BC. Straw brick composite was used as construction material at that time, It was the combination of reinforced and clay. It could not serve the function when it was used as individual. In 4000BC, a composite material was developed names as fibrous and it was used in writing materials. In 1500BC, reinforcing mud walls was used in-house. In 1200BC, Mongols invented modern composite bow. The bow consists of several materials such as bamboo, wood, antler, and horn, etc. Main body was made of horn and antler, this result in more flexibility. Egyptian drew coarse fibres from heat softened glass to make the containers. In 20^{th} century, boat and aircraft were made of glass composites when glass fibres reinforced resins. These are also called as glass fibres. Development of new fibres such as carbon, boron, etc., results in increased application of composite. Ceramic and composite is the new composite system. It is very light in weight and has high strength. **[4]**

Chapter 2

Scope of the study

Modern technology and innovation leads to complex geometry of structures and it's used in complicated environment. And monolithic metal and its alloy does not always meet the demands of these advanced technology that's why it is required to combined two or more material to meet the demand of these technologies. In case of airlines, the mass need to be reduced without decrement in their stiffness and strength which is possible by using composite materials. One can say that if we use composite material in aeroplane, it will result in increase in cost. But it is not like that, use of composite can reduce the number of parts used in aeroplane and saving in fuel cost which ultimately result in more profit.

And still, experiment is going on to find new composite materials to improve the structures. Take an example of satellite used in space, there working temperature changes between 90℃ to -155℃. This means stable benches and trusses are required which are used in satellite. Also, these temperature changes results in limitation of low thermal expansion. A monolithic metal cannot meet this demand that's why composite specifically 'graphite + epoxy' is used in satellite.

The strength of composite is high because of thin diameter fibre. Due to inherent flaws reduces the actual strength of any material from the theoretical strength. These flaws can be removed by using thin diameter of fibre.

As there is a lot of application of composite materials so I decided to work on the field of composites.

Chapter 3

Review of Literatures

Y. Sumi et.al 1998 [5]: Proposed a numerical simulation approach for predicting the patterns of growing cracks in heterogeneous material. They used the Schwartz-Neumann alternating procedure and took the help of first-order perturbation solution. In the mean, they find that crack pattern is affected by the surrounding heterogeneous materials with combination of other growing cracks.

Jesiel Cunha et.al 1999 [6]: Described the dynamic test to identify the stiffness of composite material. They compared and enlisted the advantages over other. The several other properties can also be identified simultaneously. This non-destructive type procedure is adapted well for anisotropic composite materials. The result of this procedure is so accurate that it can be directly implemented as input data in finite element codes.

Q. Chen et.al 2000 [7]: Developed integral finite elements and said that it is very powerful tool. These are helpful for complete dynamic analysis of elastic-viscoelastic materials. They compared it with the finite element meshing method and said that it will give quick and more accurate result. But they use these elements with optimization technique. And with combination, they can make optimal design for viscoelastically damped structure in order to control the vibration and noise.

Yiu-Yin Lee et.al 2001 [8]: Presented a multimode time-domain modal formulation for the non-linear vibration of composite plates. This formulation used the modal coordinate transformation to reduce the number of non-linear differential equation. With this one can easily determine the minimum number of linear modes which is necessary to get the accurate non-linear frequency results. This formulation also used the FEM to deal with boundary condition and complex geometry.

Victor Y. Perel et.al 2002 [9]: Developed a model-supported method to detect the failure occurred due to repeated loading in composite beam. When piezoelectric actuators are attached on composite beam, effect of transverse shear deformation can also be taken into account. With the use of parameter accounted for delamination, finite element model can give more accurate result combined with damage identification. Predictions of frequencies which were computed showed good compliance with experimental results.

A. Pavic et.al 2003 [10]: Performed modal testing of a unique floor structure made of HSC. They also compared the finite element model result with manual model updating result like natural frequency and mode shapes. They found the changes in stiffness of cracked and uncracked states of floor using FE model updating. They also found that even if the floor is heavily cracked, the floor retains their shape that is linear and did not damp under low-level excitation.

T. Lauwagie et.al 2004 [11]: Developed a non-destructive testing method to assess the in-plane elastic properties, for each individual layer. A multi-model updating technique is used to get these properties from the resonance frequencies of suspended plates. This technique is necessary to confirm the uniqueness of the obtained properties. And with the help of finite element model's database on can get the properties of different layers.

Narasimalu Srikanth et.al 2005 [12]: Determine the damping loss factor of composites with the help of cell model based on FEM. This occurs due to the existence of plastic zone. Cooling from extrusion temperature to room temperature results in thermal mismatch due to that plastic zone is produced. This result is verified with impact based suspended beam experiments. It can be seen from numerical result that damping loss factor increases with weight percentage of Ti added.

G. Steenackers et.al 2006 [13]: Developed an automated model updating approach. They find the resonance frequency of aluminium plate using this approach. This approach can take multiple updating parameters. It was shown that considering measurement uncertainty gave more accurate result. They perform several experiment and come to the conclusion that results were affected by fineness of mesh, very fine mesh gave more accurate result while number of mode taken into consideration did not affected much in the result especially when number of mode was taken five or more than five.

Bijaya Jaishi et.al 2007 [14]: Used the multi-objective optimization technique to reduce the difficulty of evaluating the individual objective function. Eigenfrequency residuals and modal strain energy residuals are taken as two objective functions. It was seen that this technique is robust by simulating the simply supported beam with FE model updating and can detect the damaged elements. They successfully applied this technique on Girder Bridge.

B. Paluch et.al 2008 [15]: Explained a procedure to get the optimal design structure of composite material. They used the genetic algorithm and finite element programme together for this case. In this paper it both method is explained briefly. They also considered two examples for the explanation of approach. This method results in weight saving which is caused by extra freedom in structure and this is caused by optimal ply orientation and variable thickness.

Hendrik Schlune et.al 2009 [16]: Proposed a methodology which aims to use manual model refinement to eliminate the simplification of inaccurate modelling. Then non-linear optimization technique is used to find the parameter. They found that use of non-linear model gives more accurate result, this concept was developed by applying this methodology to single-arch bridge. Four multi-response objective functions were tested and gave the statement that accuracy in eigenfrequency does not result in improved model for static analysis.

Giuseppe Chellini et.al 2010 [17]: Analyzed the damage of a steel-concrete composite frame. They used vibration measurement in finite element model technique to analyze the damage. And performed the same operation for three different damage level for different structure. They focused on beam-to-column joints and used the damage detection technique which occurs due to earthquake.

Wei-Xin Ren et.al 2010 [18]: Developed a finite element updating technique based on response surface. They used civil engineering structures in structural dynamics for this purpose. They chose the important updating parameter and developed the quadratic polynomial response surface. Proposed procedure was described by simulated simply supported beam and tested under vibrational conditions. This method was found easy and converged fast with response surface compared to sensitivity based finite element model.

S.R. Shiradhonkar et.al 2011 [19]: Worked on damage detection. They used vibration measurement occurs during strong earthquake by noting down the recorded response and got the result using finite element updating technique. Response was estimated by interpolating it in time domain. They also noticed that sensitivity technique and system identification technique. And they came up with new idea of strong column-weak beam in building design.

Nader M. Okasha et.al 2012 [20]: Proposed and illustrated a technique to find the reliability of older bridges. It uses strain data as input parameter obtained from crawl tests. Updating of resistant parameter was done by using finite element technique. To analyze the reliability of structure an incremental non-linear analysis which considered both limiting stress and serviceability was proposed. Updating parameter gives more accurate result than initial deterioration model.

Xiangqian Li et.al 2013 [21]: Presented a Weibull model which uses two-parameter. This approach helps to find the fibre dominated failure. It was noticed that these failure produced from the location where the maximum stresses exist. These stress distribution varies and is discontinuous due to the damage produced. They performed four-point bending test and good result for fibre tensile failure. This result was compared with simple analytical solution in finite element analysis and found good result for size-effect on strain to failure.

B. Rahmani et.al 2013 [22]: They proposed a numerical analysis approach to improve finite element model updating technique that is Regularized model updating. And they got that this approach results in more accurate extraction of mechanical properties of composite. They validated this approach by performing several experiments. The sensitivity of this algorithm is measured at different measured noise level and got that this algorithm is better than FEMU for random noise.

S.V. Modak 2014 [23]: Established a direct matrix updating formulation for vibroacoustic finite element models. By using this formulation, there will be no effect on symmetry after the updating of the mass and stiffness matrix of both structural and acoustic parts. Updating using the proposed method was exhibited on a simple rectangular-box cavity with a flexible plate. It was instituted that the updated vibroacoustic model exactly reproduces the coupled natural frequencies and the eigenvectors used in updating. The updated model also predicts the frequency response well over the frequency range spanned by the modes used in updating.

Subrata Chakrabort et.al 2014 [24]: Suggested an efficient Moving Least-Squares Method (MLSM) based adaptive Response Surface Method (RSM) to approximate the FE response of structures for FEMU of large complex structures. This eliminates the complexity of repeated FE solution for obtaining structural response and their sensitivities which are required for solving the FEMU problems. A comparative evaluation was being made between the MLSM based RSM and the usually accepted LSM based approach of FEMU. In general, both the LSM and MLSM based RSM approach of FEMU algorithms can update the model parameters successfully. However, the MLSM based RSM identifies the model parameters better than the LSM based RSM, specifically when the model parameters are away from its baseline values.

Cheon-Hong Min et.al 2014 [25]: Presented a new technique for the analysis of damped structures. This technique comprises of three steps each of them are different techniques which need to be executed one by one in order to get accurate updating of damped structure. Sensitivity based technique was executed first with natural and zero frequencies then Improved Reduced System was used to decrease DOF, finally damping matrix is needed to complete the proposed approach. Matrix can be determined by damping ratio.

S.V. Modak 2014 [26]: Recommended a Model updating using uncorrelated modes (MUUM) method. Existing iterative methods of model updating allow updating using the correlated mode pairs which is identified based on a prior step of establishing one to one correspondence between the FE model modes and modes identified through a model test. This paper identified the limitation of these methods since it then means that the experimental modes that are left uncorrelated cannot be used in the process of model updating even when they form valid know pieces of information about the structure. The proposed method involves minimization of an objective function that is based on both the correlated mode pairs as well as uncorrelated mode pairs, to estimate the updating parameters iteratively. Two numerical examples based on a beam structure and a third one on a more complex F-shape structure were presented to demonstrate the working of the method and to show that even in the presence of uncorrelated modes the proposed method had the ability to yield the correct pairing of the modes. The robustness of the method was examined to execute updating in the presence of simulated noise.

B. Raja Mohamed Rabi et.al 2015 [27]: Came up with the new thought that to minimize the difference between analytical and measured results. For this using orthogonal array, they determined optimal values of experimental parameter. They worked on space vehicle model and able to gain the desired task to minimize the difference between analytical and measured result by training neural network model with adjusting the structural parameter.

Asim Kumar Mishra et.al 2015 [28]: Found the constituent level fibre and matrix elastic properties of fibre reinforced plastic composite plates. They used an inverse eigen-sensitivity algorithm which minimization the error function. The function is defined as a weighted difference of mode-shapes and eigenvalues. This experiment was executed on laminated unidirectional composite plate structure. And they used finite element software ABAQUS to find eigen properties.

S.V. Modak 2015 [29]: Proposed a method to update the finite element models using uncorrelated modes. The method covers the conventional inverse eigen-sensitivity method, which requires correlated mode pairs to allow uncorrelated modes to be used in updating process. Experimental and numerical reports were presented to validate the proposed method. Updating parameter can be correctly determined by using the numerical method studies. It was noticed that, in the framework of the proposed method, the uncorrelated known correctly before updating tend to automatically choose the correct experimental counterparts at the end of the updating process. The method was tested successfully to perform updating of an experimental plate structure. This proposed method was effective to deal with uncorrelated modes in model updating.

Asim Kumar Mishra et.al 2016 [30]: Worked on to find ship panels which is made of fibre reinforced plastic. As the time goes on material degraded that's why they decided to find properties of that material so for this they proposed a inverse identification technique based on vibration. They implemented inverse eigensensitivity method with gradient-based optimization. They performed a lot of simulation and found that if boundary elasticity is ignored, it will result in inaccurate material properties. The proposed technique is robust even the input data contains random noise. They focused specifically on fibre and matrix because changes in material properties due to degradation occur at constituent level.

Guillaume Rosenzveig et.al 2016 [31]: Simulated the assembly process of large and light-weight aeronautical structures. The idea was to update the stiffness and mass properties of FE model grounded on measurements taken on the assembly line during the assembly process. They used CAD model for perfect geometry and for mass properties they used refined mesh and applied the boundary conditions on the model. This method was based on the minimization of cost function.

Nestor R. Polanco et.al 2016 [32]: Studied the composite behaviour of operational bridge decks with uncertain shear connectors. They implemented a sequential sensitivity based weighted least-squares solution. They used acceleration measurement instead of strain measurement and analyzed the shear connectors. The gap of this paper was that only stiffness of the deck can be assessed, not much can be learned regarding its ultimate static capacity.

J.T. Wang et.al 2017 [33]: Proposed an acceleration model updating method based on FRF. Kriging model which is metamodel was used to reduce solving time as there was reduced number of training samples and taken the boundary condition into account. They said that analytical FRFs and experimental FRFs are almost same. This method was tested on a composite of honeycomb sandwich beam and it was successfully implemented.

Farhad Adel et.al 2017 [34]: Represented a simple model for predicting the dynamic behaviour of the bolted joints in hybrid structures. These regions are known as joint affected region (JAR). Natural frequencies of JAR was computed and compared to model test result. Then the FE model was updated grounded on the genetic by minimizing the difference between analytical model and test result.

Chapter 4

Objective of the Study

A lot of works have been done on damage detection analysis of composite materials, column, bridges, and many researchers proposed different types of updating technique and optimization technique, some papers compares between different updating technique, some papers studied the response of surfaces subjected to dynamic loading, some papers discuss about crack propagation, some papers interested in aging of heavy structures and some of these works have also been performed on composite materials. After reviewing number of papers, I decided to work on finite element updating of composite materials thus made the following objectives:

Objective 1:

Modeling of finite element of composite structure using the 'MATLAB', simulation software.

Objective 2:

Modal analysis of the composite structure. Include error such as boundary condition and material properties in the FE model of the composite structure. By using finite element model updating technique, the error in the finite model should be removed.

Objective 3:

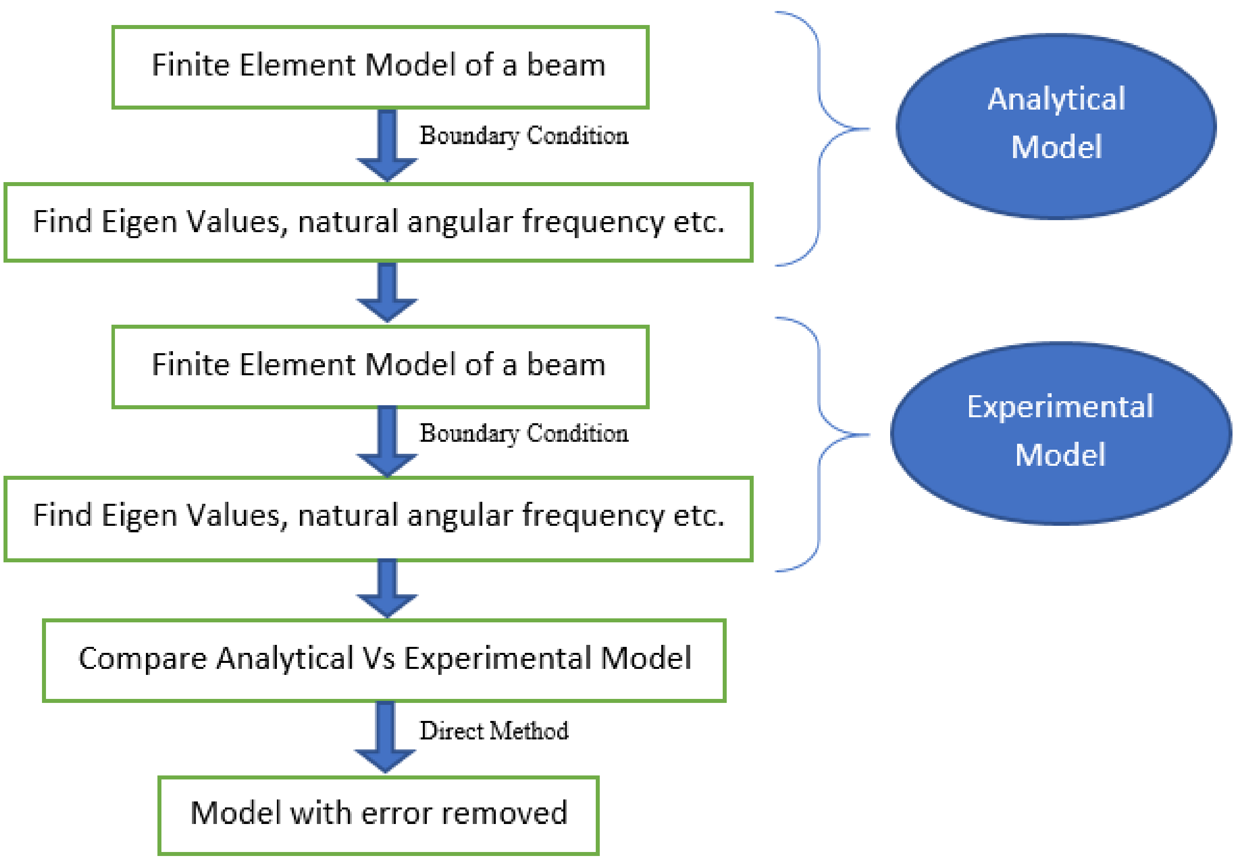
Inclusion of error can also be in the form of different fibre orientation in finite element model of the composite structure. And by using finite element model updating technique, the error in fibre orientation should be removed.

Chapter 5

Research Methodology

- All the research work will be done using MATLAB which is a simulation software.
- For updating the model, Direct method will be used
- Direct method has two steps
  i. Update mass matrix
  ii. Update stiffness matrix
- Simulated finite element model can be improved by Finite element model updating technique from the experimental data.

4.1 Flow Chart



4.1.1 Comparison between Analytical Vs Experimental model

- Analytical model is error model and experimental model is correct model.
- Following figure is just an example of comparison between updated and simulated frequency response function (FRF) model.

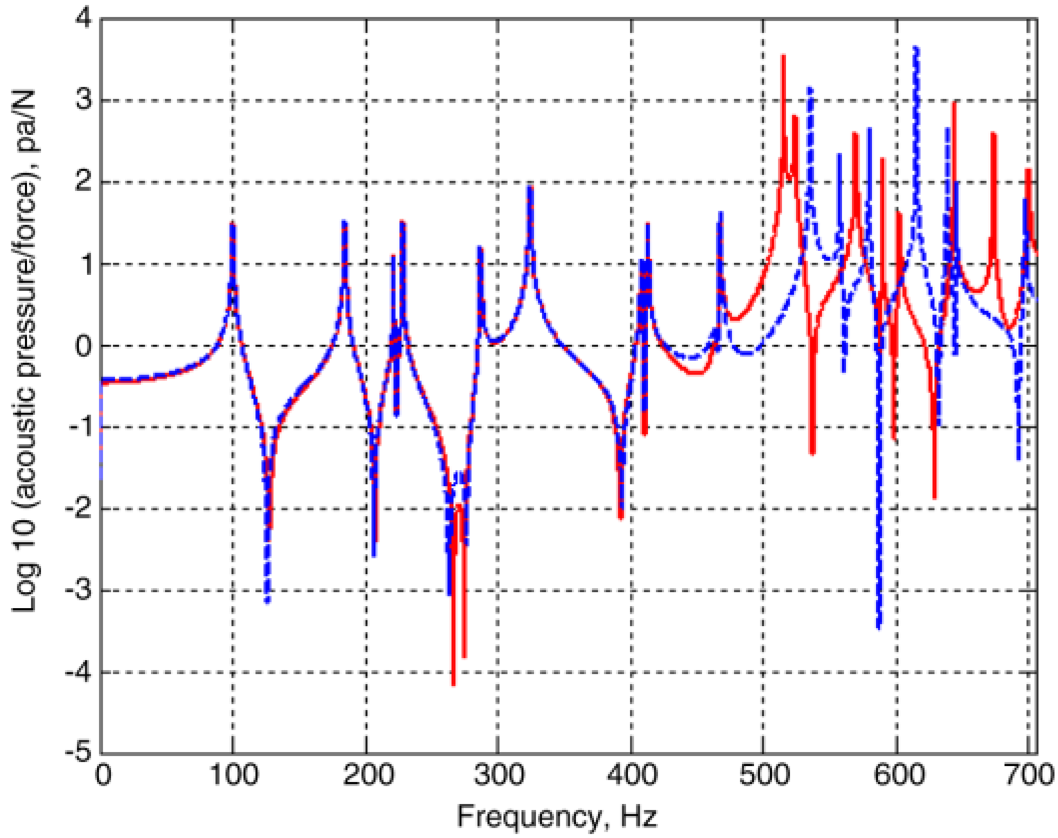


Figure 3: Overlay of updated and simulated FRF model [35]

4.2 Expected Research Outcomes

- By using finite element model updating technique the error should be removed.
- It should tell the actual orientation of fibres
- It should tell the correct mechanical properties such as modulus of elasticity, density etc.
- Both analytical and experimental model should completely overlap on each other in above graph.

Chapter 6

Proposed Work Plan with Timelines

Research work started from the month of February 2017 and is expected to be completed before the month of May 2018. Work Plane is made to make sure that the research work should run smooth and can be finished before due date. It helps student to manage the time between the research work and other subject. The proposed work plan and timelines till now is shown by the following Gantt chart.

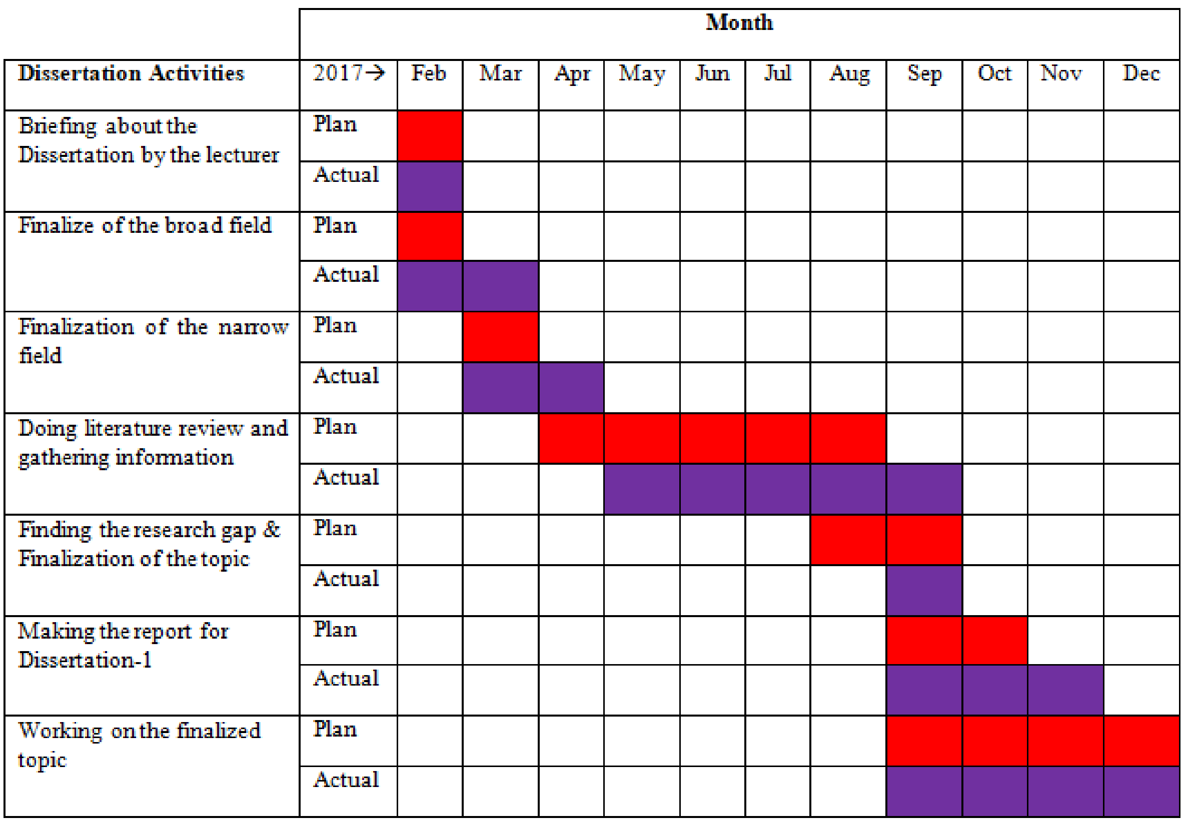


Figure 4: Gantt chart

It can be seen that most of the time consumed in literature review around four months as it is the crucial part of the research work in order to find the gap in the desired field of work. After the completion of the research-work results can be discussed and validated.

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