ASSESSING CONTROL PARAMETERS FOR VIBRATION IN A COMPOSITE MATERIAL FOR ALIGNING ITS CHARACTERISTIC BEHAVIOR WHILE RESPONDING TO INTENDED FUNCTION

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ABSTRACT:

The use of composite material for advanced engineering applications makes it imperative to assess its behavior in the scope and domain of NVH. This research work aims to evaluate the response in order to enhance its use for the intended function. In cases, where the occurrence of resonance is undesired for the function, the same needs to be negated by controlling the influential parameters leading to the characteristics of vibration for the component or the sub-assembly. The first mode and the others that follow indicate the natural frequencies at which the response of the material tends to be higher. The tendency to resonate over the operating frequency or working range could be controlled by altering the Eigen value by assigning a different level for control parameters. The mass, stiffness and damping could be varied to realize suitable Eigen value and Eigen vector for the function. The work shall focus on identifying significant control parameters for vibrational characteristics and the effect of altering these parameters. The performance of the composite material in the context of vibration analysis shall be evaluated for offering recommendation of a set of levels for the configuration under study.

KEYWORDS: *NVH, FEA analysis, composite material, vibration*

I. INTRODUCTION

Many engineering structures or structural components such as aircraft wings, helicopter blades, and space structures are commonly modeled as beams. Because of unique electromechanical characteristics, light in weight, high corrosion resistance, good electrical insulation, low price and easily bonding nature to surface, piezo-ceramics become more popular and extensively used in the field of smart structures. Consequently, a large number of researchers have been involved in modeling the behaviors of laminated composite beams. Due to their anisotropic nature, the analyses of composite beams are much more complicated than the isotropic beams. For any laminated composite beams that may be subjected to dynamic loads, it is quite essential to know and understand their free vibration characteristics including the natural frequencies and mode shapes. In order to obtain the dynamic characteristics of laminated beams accurately, it is important to adopt a satisfactory mathematical model together with a proper solution method. Up to now, there have been developed a number of beam models that are used to evaluate the free vibration characteristics of the laminated composite beams.

From the vibration engineering point of view, modal parameters contain some essential information in design and have a significant influence on the forced response characteristics of a structure. Previously, methods used for studying vibration of plates are essentially based on either theoretical solutions or experimental works. However, due to the inherent difficulties, mathematical complication and high requirements in modeling of practical problems in reality, those conventional methods are often not applicable in general cases. Hence, numerical methods are widely preferable to be developed and applied to provide approximate solutions

II. LITERATURE REVIEW

i) D. Ngo-Cong, N. Mai-Duya, W. Karunasena, T. Tran-Cong [1] presented a new effective Radial Basis Function (RBF) collocation technique for the free vibration analysis of laminated composite plates using the First order Shear Deformation Theory (FSDT). The plates, which can be rectangular or non-rectangular, are simply discretised by means of Cartesian grids. Instead of using conventional differentiated RBF networks, one dimensional integrated RBF networks (1D-IRBFN) are employed on grid lines to approximate the field variables. A number of examples concerning various thickness-to-span ratios, material properties and boundary conditions are considered. Results obtained are compared with the exact solutions and numerical results by other techniques in the literature to investigate the performance of the proposed method.

Free vibration analysis of laminated composite plates using FSDT and 1D-IRBFN method is presented. Unlike DRBFNs, IRBFNs are constructed through integration rather than differentiation, which help to stabilise a numerical solution and provide an effective way to implement derivative boundary conditions. Cartesian grids are used to discretise both rectangular and non-rectangular plates. The laminated composite plates with various boundary conditions, length-to-width ratios, thickness-to-length ratios and material properties are considered. The obtained numerical results are in good agreement with the available published results and exact solutions. The effects of boundary conditions on the natural frequencies are also numerically investigated, which indicates that higher constraints at the edges yield higher natural frequencies. It is also found that the present method is not only highly accurate but also very stable for a wide range of modulus ratio.

ii) Sharayu U. Ratnaparkhi, 1 S.S. Sarnobat [2] presented extensive experimental works to investigate the free vibration of woven fiber Glass/Epoxy composite plates in free-free boundary conditions. The specimens of woven glass fiber and epoxy matrix composite plates are manufactured by the hand-layup technique. Elastic parameters of the plate are also determined experimentally by tensile testing of specimens. An experimental investigation is carried out using modal analysis technique, to obtain the Natural frequencies. Also, this experiment is used to validate the results obtained from the FEA using Ansys. The effects of different parameters including aspect ratio, and fiber orientation of woven fiber composite plates are studied in free-free boundary conditions in details.

Natural frequencies of woven fiber Glass/Epoxy composite plates are measured by data acquisition system for free- free boundary condition. The program developed by FEA is used to measure the natural frequencies of those plates. Experimental values and simulation study are compared with each other. In experimental result, natural mode of frequency sometimes varies within a range. It shows that an approximate agreement with the FEA based program. As the mode no. increases, the percentage error between experimental value and programming value decreases. But the differences between compared results are reasonable. There may be variation of elastic properties of the plate, as the sample cut from the plate was different from the plate used in the case vibration testing. Tensile properties may vary with specimen preparation and with speed and environment of testing. Present specimens couldn't align in the centre of the jaw, because there is a diamond shaped hole where slippage was occurred. Frequency Response Functions are obtained by FFT. Quantitative results are presented to show the effects of different parameters like aspect ratio and fibre orientation. The Percentage of error between experimental value and ANSYS package is within 15%. The difference is probably due to uncertainty in elastic properties and other described reasons. For Free-free boundary condition it is found that the natural frequency of plate increases with the increasing of aspect ratio. Natural frequency decreases as the ply orientation increases up to [45/-45] and again increases up to [30/-60].

iii) A.S.Adkine, V.S.Kathavate, G.P.Overikar, S.N.Doijode [3]:- In their work an attempt was made to analyse the engine mounting bracket. Design includes the modeling of the engine mounting brackets by taking into account all packaging constraints. Analysis includes Static Analysis of engine mounting bracket. The main purpose of this study is to examine the natural frequency by analytically and through developing the model and self excitation frequency of engine bracket. An attempt was made to check whether the natural frequency of engine mounting bracket is less than self excitation frequency of engine bracket. Hence this work is carried by using ERW-1, ERW-2, aluminum and magnesium alloys for the engine mount bracket. The results are analysed for stresses and deformations.

The finite element analysis tool, ANSYS has been used to analyze the engine mounting bracket. The results obtained from the static structural and modal analysis shows that ERW-2 steel is better than ERW-1 steel. It is noted that the modified design i.e. Circular cross section showed less equivalent stress being developed, as well as less deflection but it can be practically implemented as square cross-section gives a better base for engine to rest on its top surface. During this work, study of manufacturing process of engine mounting bracket was also considered and it was found that the ERW tubes are manufactured with the help of through seam weld and after this the tubes are hydro formed to the desired shape where the orientation of seam weld was not taken into consideration. Hence if the hole is drilled on seam weld position it causes initiation of crack. Thus to prevent this it is necessary to mark the seam position and ensure that hole drilled is not on the seam weld position. This work also contributes to the defining alternative material engine mounting bracket, in which magnesium alloy and aluminium alloy were studied along with ERW-2 steel. After analyzing the results, it was found that magnesium can be preferred over Aluminium and ERW-2.The main advantage of the magnesium engine mounting bracket is its light weight. It will help in decreasing the weight of the power train assembly, which can increase fuel efficiency. Magnesium is recyclable; therefore it is an eco friendly material. The magnesium bracket can be manufactured with less amount of time and it posses longer life compared to an aluminium and ERW-2 bracket. The magnesium bracket is less susceptible to corrosion; therefore they are better for the application of bracket. The main problem of using magnesium instead of aluminum is its higher cost; but recent studies have shown that the difference between costs of aluminum and magnesium is decreasing. Also manufacturing cost for magnesium is more as compared to Aluminium and ERW-2. Thus it can be concluded that ERW-2 can be preferred over ERW-1 as a material for an engine mounting bracket.

iv) B. S. Ben, B. A. Ben, Adarsh K , K. A. Vikram and Ch. Ratnam [4] presented the methodology for finding material damping properties at higher frequency and at relatively lower amplitudes. The method employs combined Finite element and frequency response for finding the damping characteristics of composite materials, which are used in high frequency applications. The hybrid method has been implemented on Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) plates. The tests were conducted using ultrasonic pulse generator with scan view plus software as virtual controller. The dynamic mechanical analysis was carried out in high range frequency sweep mode using the hybrid method. The fiber reinforced composites have been characterized for damping parameters at low amplitudes and in a non-destructive mode.

Their work involves frequency sweep since the damping is to eliminate the noise and vibrations resulting from natural frequencies in many industrial applications. In general conventional DMA techniques are used to determine thermo mechanical behavior of polymers by typically employing dynamic shear or tensile loading modes at defined frequencies between 0.1 and 50 Hz. The hybrid method employed for DMA applications depends on type of wave propagated, and viscous damping is determined from the measured acoustic parameters sound velocity and amplitude. In their work they presented work on damping measurements using hybrid method combining finite element and frequency response of the system. The materials properties of the test specimen obtained from experimental setup are reported. The modal analysis was carried out using Block Lancozs method in ANSYS for thirty subsets and shell-190 has been used as meshing element. The continuous digital waveform from the instrument is processed through virtual controlling software scan view plus. The continuous waveform is subjected to fast Fourier transform (FFT) which yield a single peak from the calibrated optimal driving frequency, however for a few finite cycles, the FFT appears as a Gaussian curve. The influence of measurement frequency, dispersion, hysteresis, reflections at material boundaries, and changes in material density on the measured sound velocity and amplitude were taken into account. To support conclusions a wide range of experimental data was evaluated using sensors operating in the frequency ranges 50 Hz to 4 MHz. Combined finite element and frequency response has been explored in their work and tests were carried out on CFRP and GFRP composite plates. The materials have been characterized for damping parameters at their mode frequencies. The main advantage of this method is that the materials can be tested in high frequency range, specifically at its natural frequencies and at relatively low amplitudes and in a non-distractive way.

v) S. K. Panda • B. N. Singh [5] analysed the nonlinear free vibration behavior of thermally post-buckled laminated composite spherical shallow shell panel. The nonlinearity in geometry of the shell panel is considered in Green–Lagrange sense and the mathematical model is developed based on Higher order Shear Deformation Theory (HSDT). System of governing differential equations is derived using Hamilton's principle. A direct iterative method in conjunction with nonlinear finite element approach is used to solve the system of equations. Effects of various geometries and material properties on the nonlinear free vibration frequencies are examined in detail and discussed. The difference between the results speaks the necessity and the requirement of the present model for the prediction of actual nonlinear characteristics of the laminated structures having severe nonlinearity in thermal environment. They also examined the nonlinear free vibration behavior of laminated composite spherical shell panel for different geometric and material properties and to do so a computer code has been developed in MATLAB 7.0 based on the proposed nonlinear model. A convergence test has been carried out using the present code for laminated composite spherical shell panel.

Nonlinear free vibration behavior of thermally post buckled composite spherical shell panel is analyzed by considering the geometric and nonlinear stiffness matrices in Green–Lagrange sense based on the HSDT. In order to obtain a general type of mathematical model all the nonlinear higher order terms have been incorporated in the formulation. In this study a uniform temperature field is considered through the shell panel surface and the thickness. The nonlinear system equations are derived using Hamilton's principle and are solved using a direct iterative method in conjunction with nonlinear FEM. The nonlinear free vibration behavior of thermally post-buckled composite spherical shell panel for different parameters such as the lamination schemes, the curvature ratios, the aspect ratios, the support conditions and the modular ratios are studied in detail.

III. PROBLEM DEFINITION

The Industry, in general, has had been working on ways to counter the ill-effects of vibrations. While in some applications like radio and utility hardware in the electronic industry like vibrators, this phenomenon of hyper response to a signal i.e. resonance is certainly useful. In most other cases, it is highly undesirable or acts as an irritant for the user. Especially in applications as the Automotive, Aerospace and Machine Tool Industry, the effort of the Design Engineer is to minimize or negate the occurrence of vibrations thereby improving the perception of comfort and/or contributing to reduced levels of noise. The value of natural frequency could, though, be controlled by virtue of physical parameters that influence response to an excitation. The undesirable resonance could be avoided by shifting the natural frequency away from the range of values experienced within the operating range. For the components that fall within their gambit, the physical parameters could be altered for realizing a different Eigen value so as not to cause resonance and bring down the amplitude of vibrations. The challenge is to minimize the effort and cost in doing so. The significant parameter needs to be chosen succinctly for a given case since each case might call for a distinct altercation in the parameter identified. This work shall look at alternatives for composition of the material, either in layers or a homogeneous matrix that would offer favorable response for countering the incidence of vibrations.

Objectives

1. Identifying areas of concern for the case study assigned – Engine mounting Bracket
2. Benchmarking the current performance of the part (sub-assembly) in the domain of vibrations.
3. Evaluating methodologies for finding solution through modifications over the significant parameter - damping.
4. Deploying computational technique to access alternatives for enhancing performance.
5. Conducting experimentation to validate the solution as an alternative methodology
6. Recommended solution to compliment the application.

Expected Outcome:

1. Reduction in vibration to aid enhanced fatigue life for related Components.

2. Perception for comfort during ride to be positive while reducing 'human fatigue' during driving.
3. Industry in all engineering domains to benefit due to this research work that aims for negating the ill-effects of vibration through change in material configuration.

Methodology:

Computational method:

1. Prepare the CAD model of test specimen using the CAD software such as CATIA, UGNX .
2. Pre-processing (meshing):
   - Importing the neutral format of CAD geometry in Pre-processor such HyperMesh.
   - Discretization of geometry and applying material properties and boundary conditions using HyperMesh.
3. Processing (Solver):
   - Meshed model submitted to solver to find out the natural frequencies and Mode shapes of test specimen using Radioss or MSC Nastran , etc.
4. Post-processor:
   - Visualizing the results typically using HyperView as post processor.
5. Comparing the results with benchmark model with variants.
6. Identifying alternative material/s to reduce vibration of existing test piece.
7. Propose the best suitable material.

Analytical Method:

Prepare the analytical model of test specimen to find out the natural frequencies and mode shapes. For a cantilever beam subjected to free vibration, and the system is considered as continuous system in which the beam mass is considered as distributed along with the stiffness of the shaft, the equation of motion can be written as (Meirovitch,1967),

$$\boxed{\frac{d^2}{dx^2}\left\{EI(x)\frac{d^2Y(x)}{dx^2}\right\}=\omega^2 m(x)Y(x)} \qquad (1)$$

Where, E is the modulus of rigidity of beam material, I is the moment of inertia of the beam cross section,

$Y(x)$ is displacement in y direction at distance x from fixed end, ω is the circular natural frequency, m is the mass per unit length,

$m= \rho A\ (x)$, ρ is the material density, x is the distance measured from the fixed end.

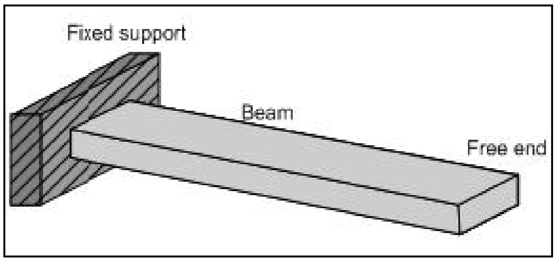


Fig (1) Cantilever beam

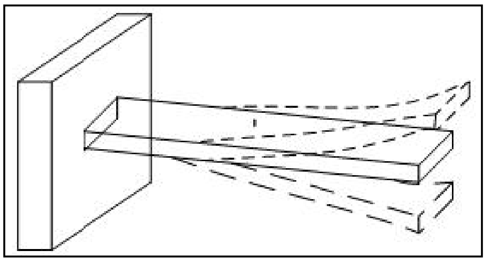


Fig (2) Beam under free vibration

Fig. 1 shows of a cantilever beam with rectangular cross section, which can be subjected to bending vibration by giving a small initial displacement at the free end; and Fig.2. Depicts of cantilever beam under the free vibration.

We have following boundary conditions for a cantilever beam (Fig.1.)

$$\text{at } x = 0, Y(x) = 0, \frac{dY(x)}{dx} = 0$$

$$\text{at } x = l, \frac{d^2Y(x)}{dx^2} = 0, \frac{d^3Y(x)}{dx^3} = 0 \qquad (2\&3)$$

For a uniform beam under free vibration from equation (1), we get

$$\frac{d^4Y(x)}{dx^4} - \beta^4 Y(x) = 0$$

With

$$\beta^4 = \frac{\omega^2 m}{EI} \qquad (4)$$

The mode shapes for a continuous cantilever beam is given as

$$f_n(x) = A_n\{(\sin\beta_n L - \sinh\beta_n L)(\sin\beta_n x - \sinh\beta_n x) + (\cos\beta_n L - \cosh\beta_n L)(\cos\beta_n x - \cosh\beta_n x)\}$$

Where

$$n = 1, 2, 3 \ldots \infty \text{ and } \beta_n L = n\pi \qquad (5)$$

A closed form of the circular natural frequency *ωnf*, from above equation of motion and boundary conditions can be written as,

$$\omega_{nf} = \alpha_n^2 \sqrt{\frac{EI}{mL^4}}$$

Where

$$\alpha_n = 1.875, 4.694, 7.885 \qquad (6)$$

So,
First natural frequency

$$\omega_{nf} = 1.875^2 \sqrt{\frac{EI}{\rho A L^4}} \qquad (7)$$

Second natural frequency

$$\omega_{nf} = 4.694^2 \sqrt{\frac{EI}{\rho A L^4}} \quad (8)$$

Third natural frequency

$$\omega_{nf} = 7.855^2 \sqrt{\frac{EI}{\rho A L^4}} \quad (9)$$

The natural frequency is related with the circular natural frequency as

$$f_{nf} = \frac{\omega_{nf}}{2\pi} \mathrm{Hz} \quad (10)$$

For a rectangular cross section

$$I = \frac{bd^3}{12} \quad (11)$$

Where *b* and *d* are the breadth and width of the beam cross section

Numerical Methodology (Finite Element Modeling

A sandwich structure shall be modeled and its natural frequencies and modes of vibration to be determined using the FEM software, typically – ANSYS, Radioss, Nastran, Optistruct or the like. A detailed explanation of the various steps involved in the analysis is given below:

1. Preferences to be set for Modal/ FRA/ Structural Analysis
2. The input data to be specified using the preprocessor
3. The HEX8 element type is selected as a suitable element
4. Three layers are created using 3D mesh having thickness 2mm-1mm-2mm
5. Material properties to be assigned for the respective layers
6. Boundary conditions are applied as per the Test Standard (Cantilever type)
7. Respective cards to be assigned considering the type of Analysis
8. Specify the `type of analysis' while creating the load step
9. Select the desired output using the dialogue box
10. Submit the output file to the Solver
11. View results using Post-processor

Experimental Method and Validation:

The common methods used to measure damping are the free vibration decay method , the resonant dwell method, the hysteresis method and the frequency response technique. The most suitable techniques for characterizing the material properties of CLD configuration in the medium frequency range (from 1 Hz up to several KHz) is the `frequency response' technique. This technique offers potential for rapid non-destructive evaluation of material and structures. In this technique the specimen is excited impulsively with a controlled impact hammer with a force transducer attached to its head. The specimen response is sensed by an accelerometer. The signals from the force transducer and the accelerometer are sent to a fast Fourier transform (FFT) analyzer which displays the frequency response spectrum.

In this work, experimental tests based on ASTM standard test method for measuring Vibration-Damping properties of materials were developed in order to determine damping factor. The experimental program shall consider several beams of different viscoelastic materials. The types of specimen to be used in the vibrating beam test are illustrated in fig.3 (a) & (b)

The simple symmetrical sandwich beam is composed as per ASTM standard E756-05. It consists of two layers of aluminum & the viscoelastic material in the core composed of a high strength acrylic double face adhesive. The storage shear modulus G & `loss factor' η of viscoelastic material are also temperature dependent. However that is not going to be considered here since in the most dynamic analysis, constant temperature could be assumed. The prototype for this research work may resemble the above based on the relevant standard and/or application.

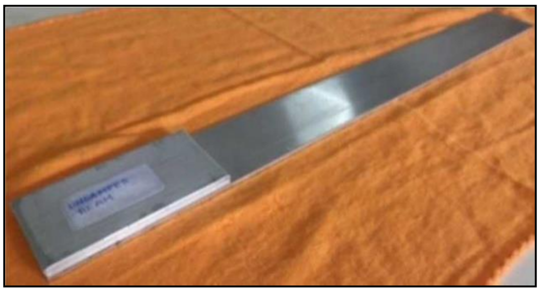
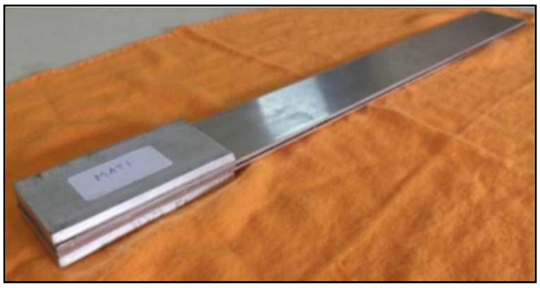


Fig.3(a) Oberst Undamped Beam



3(b) Symmetric sandwich CLD beam

Experimental setup:

The experimental set up used for the vibration of cantilever sandwich beam is shown in fig.4. The beam test scheme consists of CLD beam clamped rigidly in a fixture to simulate cantilever beam condition. The test CLD beam consists of a layer of the soft VEM layer whose properties are of interest.

The experimentation will be performed on sandwich test CLD beam of different viscoelastic materials by using passive damping technique. The dynamic responses of the beams shall be obtained by means of accelerometer measurements during a free vibration test performed by employing instantaneous hammer impact as excitation. A typically test setup consists of the following equipment for data acquisition - accelerometer model uniaxial type 4515, Impact hammers 8206-002 and FFT analyzer - 4 channel. Typical results of the FRF response are shown in fig.5.

By analyzing the resonant peak for a particular mode, the loss factor, a measure of damping, is obtained from the real part of the response spectrum as shown in fig.5. These curves could be presented using suitable software like MatLab.

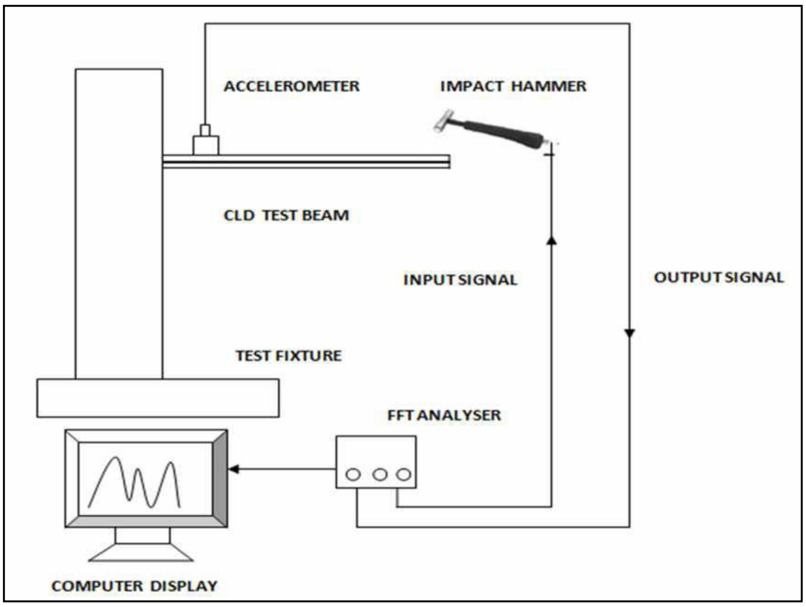


Fig.4. Experimental set up

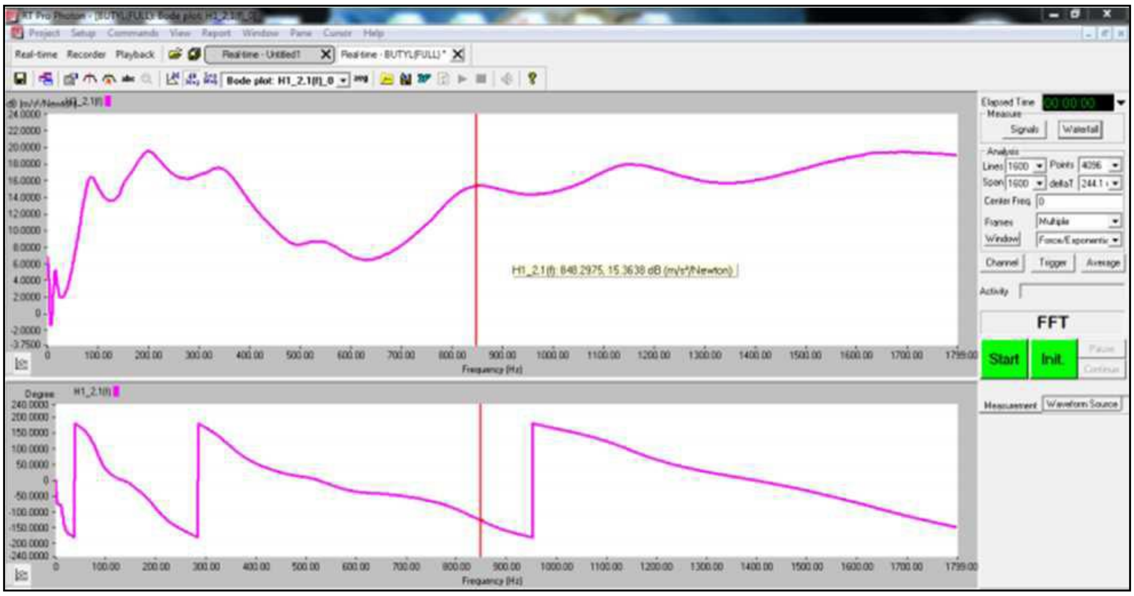


Fig.5. Frequency response function (FRF) Output by FFT analyzer

Fig.6. Graph - FFT analyzer

Fig.7. Vibrometer

Natural frequencies and mode shapes of test specimen obtained from the computational method can be validated through the results of Analytical and/or Experimental method.

IV. CONCLUSION

1. From the Literature Review, it is concluded that Finite Element Method is identified as the prospective methodology to find mode shapes and natural frequency.
2. FFT analyzer or Vibrometer could be used to measure natural frequencies and mode shapes
3. Virtual analysis reduces the time and cost required for extensive experimentation with number of iterations using prototypes. The experimentation could be performed for only the optimal configuration of the sandwich beam (for validation)

V. FUTURE SCOPE (FOR ANOTHER RESEARCH WORK)

1. Structural analysis of engine mounting bracket for effect of forces acting on it
2. Identifying scope for weight optimization using tools like Topology Optimization for a given application.
3. Deploying computational techniques to explore performance in the domain of Noise Vibration and Harshness analysis (NVH)
4. Identifying potential applications in the Automotive or Consumer Product industry for utilizing the findings of this research work.

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