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Study of Free Vibration Characteristics of Cantilever Beams through Modal Testing and Analysis

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Abstract - *An Most of the structural components are generally subjected to dynamic loadings in their Working life. Very often these components may have to perform in severe dynamic environment where in the maximum damage results from the resonant vibrations. Susceptibility to fracture of materials due to vibration is determined from single degree of freedom stress and frequency. Maximum amplitude of the vibration must be in the limited for the safety of the structure. Hence vibration analysis has become very important in designing a structure to know in advance its response and to take necessary steps to control the structural vibrations and its amplitudes. The present study involves study of free vibration characteristics of cantilever beams through modal testing and analysis. Natural frequencies is found out theoretically by using Euler-Bernoulli's equation, numerically using ANSYS software and experimental investigation is carried out using modal analysis technique (impact hammer method). This study may provide valuable information for researchers and engineers in design applications.*

Key Words: Euler-Bernoulli's equation, single degree of freedom, ANSYS, accelerometer.

1. INTRODUCTION

Vibrations are time dependent displacements of system of particles with respect to an equilibrium position. If these displacements are repetitive and their repetitions repeat at equal interval of time with respect to equilibrium position the resulting motion is said to be periodic. One of the most important parameters associated with engineering vibration is finding out the natural frequency.

Each structure has its own natural frequency for a series of different modes that controls its dynamic behavior. Whenever the natural frequency of a mode of vibration of a structure coincides with the frequency of the external dynamic loading conditions this leads to potential catastrophic failures and excessive deflections. This is the phenomenon of resonance. An example of a structural failure under dynamic loading was the failure of well known Tacoma Narrows Bridge U.S state of Washington during wind induced vibration. Present work deals with the study of free vibration characteristics of cantilever beams through modal testing and analysis.

2. LITERATURE SURVEY

Vaibhav Ghodge, A P Bhattu, S B Patil (2018) [1] on 2nd January 2018 they carried out modal analysis of the cantilever and the simply supported beams in unloaded and with loaded conditions in ANSYS for 4 different materials i.e. structural steel, Aluminium alloy, Copper alloy and Gray Cast iron, with dimensions of the beam as 550*50*5 mm. It was seen that for unloaded cantilever and simply supported condition of the rectangular beam, the structural steel and aluminium alloy constantly gave higher natural frequencies than copper alloy and gray cast iron.

Mr.P Kumar, Dr.S.Bhaduri,Dr.A.Kumar (2016) [2] took a study on behaviour of beams with end mass on them. ANSYS and MATLAB used for Finite Element analysis. For theoretical calculation single degree of freedom(SDOF) model analysis was used. FFT analyzer was used to note the vibration characteristic in experimental analysis was used. A Beam of Iron and Aluminium were taken for the analysis with dimensions of 240*30*1.16mm of length, breadth and thickness respectively for Iron. 250*24*2.04mm of length, breadth and thickness respectively for Aluminium. It was noted that as End mass on the beam increases the natural frequencies of the Beams were decreased for same mode shape.

Rahul.E.Dhoble, Dr B. R.Bharjibhe (2016) [3] On April 2016 published an article about study on vibration analysis of sandwich cantilever beam using finite element ANSYS software. They placed a viscoelastic material in between two similar materials. In this they have taken rubber and neoprene as viscoelastic material. The specimen were made as follows Aluminum, steel rubber, ERP-Rubber-FRP, Aluminum-neoprene-Aluminum, steel-Neoprene-steel, FRP - Neoprene-FRP where FRP stands fibre reinforced polymer. The length is of 500mm, width was 50mm and thickness is of 4.5mm (each layer 1.5mm). The dimensions were remaining same for all the combinations with application of finite element method, the visco elastic sandwich beam has been successfully modeled and testing is carried out. In this entire sandwich beam models face and core layer materials are different. The sandwich beams modeled are carried out for modal analysis. It was seen that damping characteristics of neoprene visco elastic material has best result when compared to rubber visco elastic material. For controlling the vibration of structure like beams, plates the visco elastic constrained layer damping treatment plays a vital role.

The literature on the present context reveal that, there are number of experiments conducted to study the free vibration characteristics of cantilever beam through modal testing and analysis. However there is a limited amount of published experimental results providing detailed source measurements. Also detail study of modes at different points are not provided in the majority of the previous research reviewed. Based on cantilever beams there is abundant availability of literature. But still there is no experimental proofs for some of the available literatures. Rishi Raj, Prabhat Kumar Sinha and Vinay Prakash worked on study of the cantilever beam structure using finite element package ANSYS and MATLAB but no work is carried out using experimental method. Since numerical calculations involves with the ideal conditions of beams no conclusions can be drawn for the application purpose which includes several physically affecting factors like damping.

Our work addresses the modal analysis through theoretical, numerical and experimental analysis which is not found in many of the open accessed journals. It is important to carry out work in these three methods to understand characteristics of beam effectively.

3. PROPOSED SYSTEM

Modal testing is the form of vibration testing of an object whereby the natural (modal) frequencies, modal masses, modal damping ratios and mode shapes of the object under test are determined.

There are several ways to do modal testing but impact hammer testing and shaker (vibration tester) testing are commonplace. In both cases energy is supplied to the system with a known frequency content. Where structural resonances occur there will be an amplification of the response, clearly seen in the response spectra. Using the response spectra and force spectra, a transfer function can be obtained. The transfer function (or frequency response function (FRF)) is often curve fitted to estimate the modal parameters.

Experimental Procedure:

➢ Test specimens were made of Aluminium 6061 and EN 8 with aspect ratio 40,50,60,70 were taken for testing. The specimens were marked at 3 different nodes such that each node is equidistant to each other. Prepared specimens were subjected to experimental model testing with one side fixed.

➢ The cantilever beam is now attached to the fixtures and hence ready for testing. Tri accelerometer is then attached to the free end node with adhesive as paraffin wax.

➢ The connections of the DAQ, accelerometer, impact hammer was properly made. An impact through hammer was given at the free end, the reading is plotted in FRF graph

➢ We get peaks where there is a modal frequency. The acceptance of these peaks are governed by corresponding coherence and phase angle plot. If the coherence value is nearer to 1 at the respective modal peaks then the peaks are acceptable.

➢ If the modal frequency peaks have 1800 phase shift at respective positions then the obtained modal frequencies is agreed.

➢ The response at node 3 due to impact on node 3 is referred as r33and the corresponding frequencies are plotted on FRF plot, in same way response at node 3 due to impact at node 2and 1 is noted r32 and r31.

➢ Similar way frequencies are plotted for different specimen and average is shown.

4. METHODOLOGY

THEORETICAL ANALYSIS

Free vibration takes place when a system oscillates under the action of forces integral in the system itself due to initial deflection, and under the absence of externally applied forces. The system will vibrate at one or more of its natural frequencies, which are properties of the system dynamics, established by its stiffness and mass distribution. In case of continuous system the system properties are functions of spatial coordinates. The system possesses infinite number of degrees of freedom and infinite number of natural frequencies.

In actual practice there exists some damping (e.g., the internal molecular friction, viscous damping, aero dynamical damping, etc.) inherent in the system which causes the gradual dissipation of vibration energy, and it results in decay of amplitude of the free vibration. Damping has very little influence on natural frequency of the system, and hence, the observations for natural frequencies are generally made on the basis of no damping. Damping is of great significance in restraining the amplitude of oscillation at resonance.

The comparative displacement alignment of the vibrating system for a particular natural frequency is known as the Eigen function in continuous system. The mode shape of the lowest natural frequency (i.e. the fundamental natural frequency) is termed as the fundamental (or the first) mode frequency. The displacements at some points may be zero which are called the nodal points. Generally *n*th mode has (*n*-1) nodes excluding the end points. The mode shape varies for different boundary conditions of a beam.

NUMERICAL ANALYSIS

ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineers. So ANSYS, which enables to simulate tests or working conditions, enables to test in virtual environment before manufacturing prototypes of products. Furthermore, determining and improving weak points, computing life and foreseeing probable problems are possible by 3D simulations in virtual environment.

ANSYS software with its modular structure as seen in the table below gives an opportunity for taking only needed features. ANSYS can work integrated with other used engineering software on desktop by adding CAD and FEA connection modules .ANSYS can import CAD data and also enables to build a geometry with its "preprocessing" abilities. Similarly in the same preprocessor, finite element model (a.k.a. mesh) which is required for computation is generated. After defining loadings and carrying out analyses, results can be viewed as numerical and graphical. ANSYS can carry out advanced engineering analyses quickly, safely and practically by its variety of contact algorithms, time based loading features and nonlinear material models.

ANSYS Workbench is a platform which integrate simulation technologies and parametric CAD systems with unique automation and performance. The power of ANSYS Workbench comes from ANSYS solver algorithms with years of experience. Furthermore, the object of ANSYS Workbench is verification and improving of the product in virtual environment. ANSYS Workbench, which is written for high level compatibility with especially PC, is more than an interface and anybody who has an ANSYS license can work with ANSYS Workbench. As same as ANSYS interface, capacities of ANSYS Workbench are limited due to possessed license.

5. RESULTS

In our study the theoretical and analytical work was carried by using Euler's beam theory and FEM software package but this is to be verified by doing experimentally, hence impact hammer method was used for experimental test. It was seen that both theoretical and analytical values are in agree with the experimental values.

AL 40	Numerical frequency(H_z)	Experimental frequency (H_z)	PERCENTAGE ERROR(%)
MODE 1	101.60	76.73	24.4
MODE 2	634.71	536.80	15.4
MODE 3	1770.6	1661.45	6.1

Table 5.1: Comparison of modal frequency of AL 40

AL 50	Numerical frequency(H_z)	Experimental frequency (H_z)	PERCENTAGE ERROR(%)
MODE 1	64.92	51.00	21.4
MODE 2	406.09	365.66	9.9
MODE 3	1134.40	978.33	13.7

Table 5.2 Comparison of modal frequency of AL 50

AL 60	Numerical frequency(H_z)	Experimental frequency (H_z)	PERCENTAGE ERROR(%)
MODE 1	45.04	37.00	17.8
MODE 2	281.89	248.66	11.7

Table 5.3 Comparison of modal frequency of AL 60

AL 70	Numerical frequency(H_z)	Experimental frequency (H_z)	PERCENTAGE ERROR(%)
MODE 1	33.06	27.66	16.3
MODE 2	207.03	185.00	10.6
MODE 3	579.00	550.66	4.8

Table 5.4 Comparison of modal frequency of AL 70

EN 40	Numerical frequency(H_z)	Experimental frequency (H_z)	PERCENTAGE ERROR(%)
MODE 1	105.13	83.33	20.7
MODE 2	656.81	537.84	18.1
MODE 3	1832.1	1629.16	11.0

Table 5.5 Comparison of modal frequency of EN 40

EN 50	Numerical frequency(H_z)	Experimental frequency (H_z)	PERCENTAGE ERROR(%)
MODE 1	67.20	56.00	16.6
MODE 2	420.34	370.66	11.7
MODE 3	1174.1	1172.00	0.17

Table 5.6 Comparison of modal frequency of EN 50

EN 60	NUMERICAL(H_z)	EXPERIMENTAL(H_z)	PERCENTAGE ERROR(%)
MODE 1	46.63	38.66	17.0
MODE 2	291.84	288.66	1.08

Table 5.7 Comparison of modal frequency of EN 60

EN 70	Numerical frequency(H_z)	Experimental frequency (H_z)	PERCENTAGE ERROR(%)
MODE 1	34.23	30.66	10.4
MODE 2	214.36	191.33	10.7
MODE 3	599.49	543.66	9.3

Table 5.8 Comparison of modal frequency EN 70

The Comparison of theoretical, experimental and numerical frequencies is as shown below-

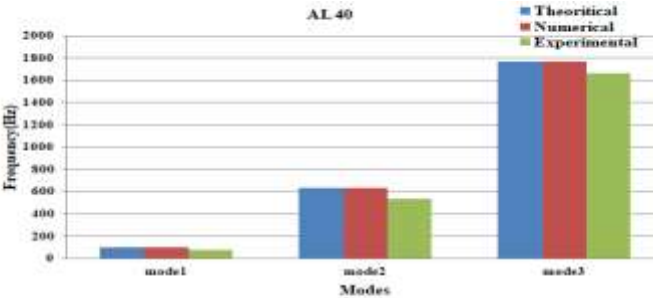

Fig 5.1: Plot between frequency versus modes

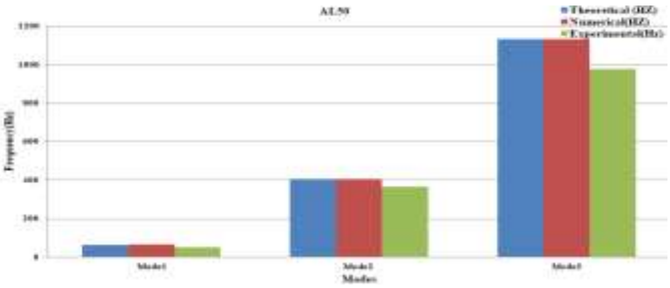

Fig 5.2: Plot between frequencies versus modes

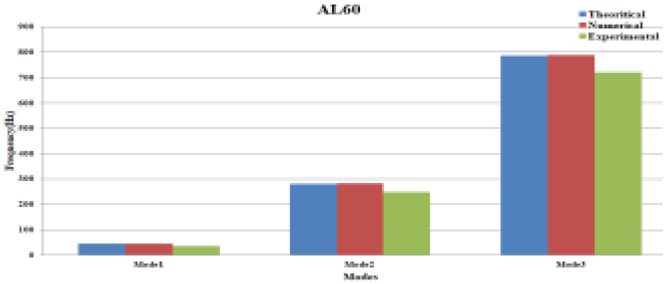

Fig 5.3: Plot between frequency versus modes

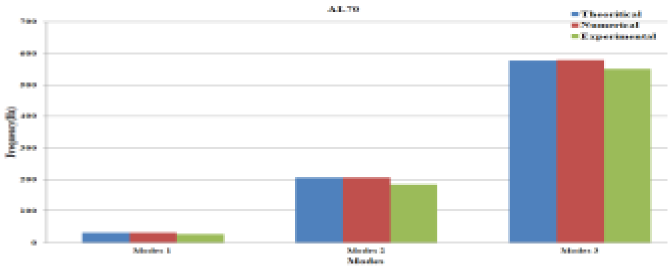

Fig.5.4: Plot between frequency versus modes

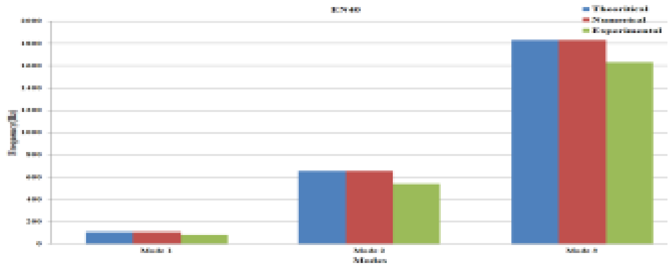

Fig.5.5: Plot between frequency versus modes

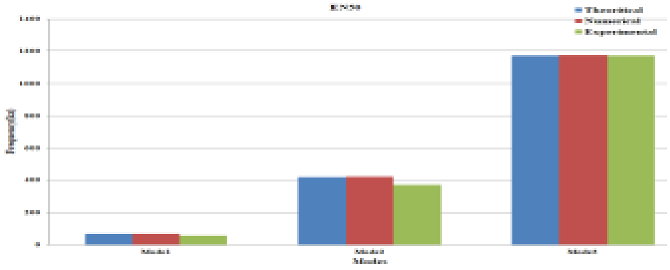

Fig.5.6: Plot between frequency versus modes

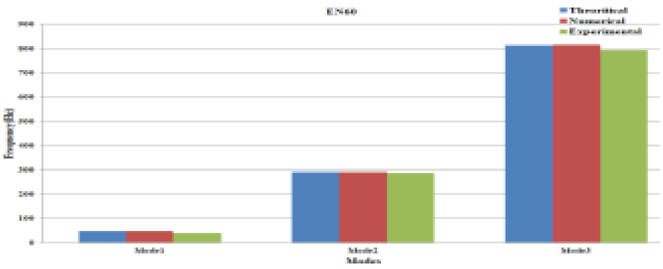

Fig.5.7: Plot between frequency versus modes

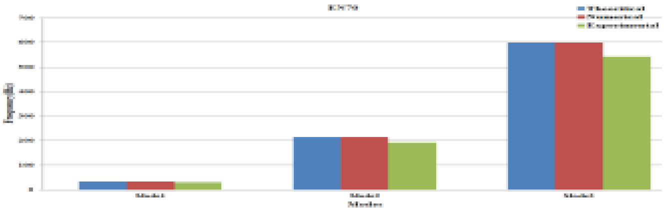

Fig.5.8: Plot between frequency versus modes

6. CONCLUSIONS

The main objective of our project was to make a study on free vibration characteristics of cantilever beams of different aspect ratio through model testing and analysis. The result obtained by three different methods i.e. theoretical, numerical and experimental are compared and we found out that the value of frequency obtained in numerical is greater than other two. Natural frequency of the EN8 is slightly larger than the Aluminum 6061 of the same aspect ratio. Frequency is inversely proportional to the aspect ratio. By carrying out the above processes our objective has been achieved.

➢ Free vibration characteristics are studied for different nodes for materials Aluminum 6061 and EN 8.

➢ It was seen that as the aspect ratio increases frequency decreases.

➢ Modal analysis of beam using commercial FEM package ANSYS was done.

➢ Modal analysis is done theoretical experimental and then compared with numerical values. It was seen that obtained values are in agree with each other.

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BIOGRAPHIES

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