DYNAMIC CHARACTERSTIC ESTIMATION OF STRUCTURAL MATERIALS BY MODAL ANALYSIS USING ANSYS

Syed Ayesha Yasmeen[1], Anatha Abhijit P [2], Dr.D.Srinivasa Rao[3]

[1, 2] Graduate Students, [3] Professor, Department of Mechanical Engineering,
DMS SVH College of Engineering, Machilipatnam, (India)

ABSTRACT

Dynamic properties of a structural element which are frequency, damping and mode shapes can be described by a process called modal analysis Structural condition can be monitored by analyzing the changes in frequencies and mode shapes. All materials posses certain amount of internal damping, which manifested as dissipation of energy from the system. This energy in a vibratory system is either dissipated into heat or radiated away from the system. Material damping or internal damping contributes to about 10-15% of total system damping. The main objective of this work is to estimate the natural frequency and damping ratio of cantilever beams of Aluminum, Brass, and Steel and Acrylic glass by free vibration analysis and Harmonic analysis using ANSYS. This paper presents results of modal analysis of beams made of assorted materials mentioned by generating models using ANSYS which facilitates to save time and cost. Free vibration analysis was carried out for identifying the natural frequencies and the harmonic analysis was carried out for obtaining frequency response curves from which damping ratios were estimated using Half- power Band Width Method. The results were analyzed.

Keywords: Damping Factor, Free Vibration, Harmonic Analysis, Modal Analysis, Natural Frequency

I INTRODUCTION

Modal analysis is an effective means for identifying, accepting and simulating dynamic behavior and responses of structural elements. Modal analysis using ANSYS is an effective method of determining vibration characteristics. In the present cram the finite element package program was used to model the physical system and to simulate close to its real condition. Simulation enables us to save time and cost. Practical applications of modal analysis cross over assorted fields of science engineering and technology, in particular various explorations connected to automobile engineering, aeronautical engineering and mechanical engineering. The present exploration reports the dynamic characteristics of common structural materials.

Material damping of cantilever beams attracts a lot of work even though extensive literature exists in the area of vibrations of beams. Material damping has not been paid much attention. Vibration characteristics of rotating cantilever beams such as turbine blades or turbo-engine blades or helicopter blades were studied by

H H Yoo and S H Shin[1]. The centrifugal inertia force due to rotation induces stretching and this stretching causes increase of bending stiffness of the structure which generally results in the variation of natural frequencies and mode shapes. A new dynamic modeling method is adopted for deriving the equation of motion of rotating cantilever beams.

Mousa ReZaee and reZa Hassannejad[2] investigated a simply supported beam with a crack by vibration analysis and derived a new analytical method by taking a non-linear model for fatigue crack perturbation method is used for solving the governing equation of motion of the cracked beam. The dynamic response of cracked beam shows super harmonics of fundamental frequency due to non-linear effects in the solution. An explicit expression is also derived for the system damping changes in the crack parameters geometric dimensions, Mechanical properties of the cracked beam. It is observed in the results the system damping increases with crack depth and its approach to the middle of the beam. The frequencies of free vibration of rotating beams have been extensively studied by Chih Ling Huang, Wen Yi Lin, Kuo Mo Hsio[3] generally rotating beams are used for simple models such as propellers, turbine blades and satellite booms. To solve the natural frequency of very slanderous rotating beam at high angular velocity. A method based on the power series solution is used. Each segment governing equations are solved by power series.

JinsuoNie,XingWei[4] concentrated in determining convenient specification of material dependent damping in ANSYS in transient dynamic analysis by mode superposition method. In analysis of complex structures specification of material dependent damping is generally desirable. Since the structural elements can have different energy dissipation capabilities. This paper contains various mode superposition transient dynamic analysis using different ways to specify damping in ANSYS. Shibabrat Naik, Wrik Mallik[5] in their study found substantial importance of dynamic parameters such as modal frequencies and damping constant of structural elements. In their work experimental model testing of cantilever beam has been performed to obtain the mode shapes, modal frequencies and damping parameters. PLUSE lab shop was used to get the frequency response functions and these are checked using finite element software ANSYS.

D. Ravi Prasad [6] in his study explained natural characteristics of a structure like frequency damping and mode shapes. In his work modal analysis of beams was carried out for different beam materials by excitation technique and the response functions were obtain and processed using vibration analysis analyzer to identify natural frequencies, damping and mode shapes. In the present cram the vibration analysis was carries out using ANSYS by model analysis to find natural frequencies and damping factors of various structural materials.

II THEORTICAL ANALYSIS

2.1. Theory of Free Vibrations of Cantilever Beam

The equation of a motion of a cantilever beam subjected to free vibration, the system of which is considered as continuous one can be written as

$$\frac{d^2}{dx^2}\left\{EI(x)\frac{d^2Y(x)}{dx^2}\right\} = \omega_n^2 m(x)Y(x) \ldots\ldots\ldots\ldots\ldots\ldots..(2.1)$$

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_n is the circular natural frequency, m is the mass per unit length, m=ρA(x), ρ is the material density, x is the distance measured from the fixed end.

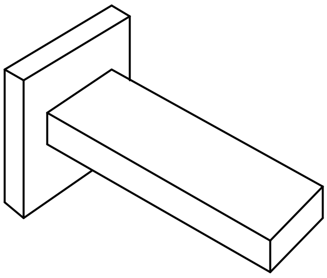


Figure 1.Cantilever Beam

$f_{nf} = \frac{\omega_{nf}}{2\pi}\, Hz$…………………… (.2.13)

Following are the boundary conditions for a cantilever beam.

At $x = 0, Y(x) = 0, \frac{dY(x)}{dx} = 0$ … … … … … …. (2.2)

At $x = l, \frac{d^2Y(x)}{dx^2} = 0, \frac{d^3Y(x)}{dx^3} = 0$ … … … … ….. (2.3)

For a uniform beam under free vibration from (2.1) we get

$\frac{d^4Y(x)}{dx^4} - \beta^4 Y(x) = 0$ … … … … … … … (2.4) With $\beta^4 = \frac{\omega_n^2 m}{EI}$ … … … … … … …. (2.5)

Using the boundary condition from “Equation. (3.4)” & Equation (3.5)”, the frequency equation is obtained as

$cos\beta_n L + cosh\beta_n = -1$ … … … … … … (2.6)

Which must be solved numerically and it yields an infinite of solutions of β_n .

Corresponding to the Eigen values of β_n , the mode shapes for a continuous cantilever beam is given as

$$f_n(x) = A_n\{(\sin\beta_n L - sinh\beta_n)(\sin\beta_n x - sinh\beta_n x) + (\cos\beta_n L - cosh\beta_n L)(\cos\beta_n x - cosh\beta_n x)\} \ldots\ldots (2.7)$$

Where, $n = 1, 2, 3 \ldots\ldots\ldots\ldots \infty \;\&\; \beta_n L = \alpha_n \ldots\ldots\ldots\ldots\ldots (2.7.1)$

A closed form solution of the circular natural frequency ω_{nf}, from above equation of motion and boundary conditions can be written as, $\omega_{nf} = \alpha_n^2 \sqrt{\frac{EI}{mL^4}}$ … … … … . (2.8)

The equation (2.8) is satisfied by a number of values of $\beta_n L$ corresponding to each normal mode of oscillation, which for first three modes are given as

$\alpha_n = 1.875, 4.694, 7.855 \ldots \ldots \ldots \ldots (2.9)$

Where, First natural frequency

$$\omega_{nf} = 1.875^2 \sqrt{\frac{EI}{\rho A L^4}} \ldots\ldots\ldots\ldots\ldots (2.10)$$

Second natural frequency

$$\omega_{nf} = 4.694^2 \sqrt{\frac{EI}{\rho A L^4}} \ldots\ldots\ldots\ldots\ldots (2.11)$$

Third natural frequency

$$\omega_{nf} = 7.855^2 \sqrt{\frac{EI}{\rho A L^4}} \ldots\ldots\ldots\ldots\ldots (2.12)$$

The natural frequency is related with the circular natural frequency as

2.2. Measurement of Damping

2.2.1. Half- power Band Width Method

The half power bandwidth method is used for quantitative measure of damping. In mechanical systems damping is represented in various formats and the most frequent forms are Q and ζ. Here Q is amplification or quality factor and ζ is the viscous damping ratio or fraction of critical damping. With the combination of these two variables the formula obtains i.e.

$$2\zeta = \frac{1}{Q} = \frac{\omega_2 - \omega_1}{\omega_n} \ldots \ldots \ldots \ldots (2.14)$$

The half power bandwidth method is also used to estimate damping ratio from frequency domain on a decibel scale this corresponds to a 3db drop from the peak. For this reason the damping measurement technique is also called as 3db method. The 3db point are also called as "Half power points" when they represent on the transfer magnitude curve. Here Δf i.e. (frequency width) is another damping parameter between the 3 db points in the transfer magnitude curve. This is shown in "Fig 2".

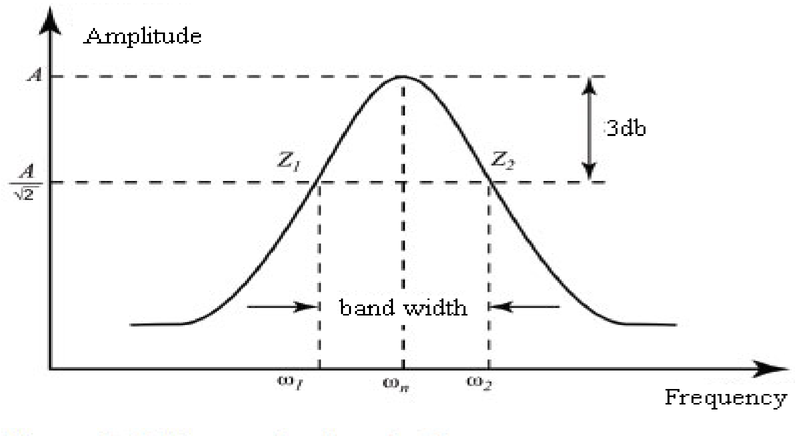


Figure 2. Definition of Half Power Band width Method

III MODAL ANALYSIS

Modal analysis is a universal methodology used which permit fast and reliable recognition of system dynamics in complex structures. In the previous decades numerous methods have been developed in expedition to develop accuracy of modal replicas extracted from test data and to expand the applicability of modal analysis in manufacturing environment.

Structures vibrate in special shapes called mode shapes when excited at their resonant frequencies. A mode shape is the typical deformation contour defined by relative amplitudes of the farthest locations of vibration of a system at a particular natural frequency. The modal parameters are the natural frequencies, damping ratios and modal masses connected with each of the mode shapes. In general working circumstances, the structure will vibrate in a complex combination of all the mode shapes. Modal analysis refers to evaluating and forecasting the mode shapes and frequencies of a structure.

IV ANALYSIS USING ANSYS

The following procedure has been adopted for modeling cantilever beam of a particular material. In the main menu, in preprocessor the structural element type was selected and Brick 8 node 45 solid element was selected. The young Modulus and poison's ratio values were given. By using modeling option the beam was generated in two dimension and next it was extruded along its length to obtain 3D model of the beam. By using meshing tool option the beam was meshed and by applying boundary conditions the beam was fixed at one end and then the modal analysis was performed by using Block Lanczos method. The results were obtained from General Post Processor after solution was done. Harmonic analysis was performed by choosing analysis type i.e. (Harmonic) and by giving frequency range (0-200Hz), number of sub steps 30 and by choosing stepped boundary conditions. Then the boundary conditions were applied by giving Force/ Moment at other end and by choosing solution option in main menu the modal was solved. By choosing time history postprocessor menu and by choosing define variables sub menu the defined time history variables dialog box appears and by choosing Add the Add time – history variable dialog box appears from this the Nodal data was entered. By selecting graph variables and by entering graph parameters a graph appears in the graphic window.

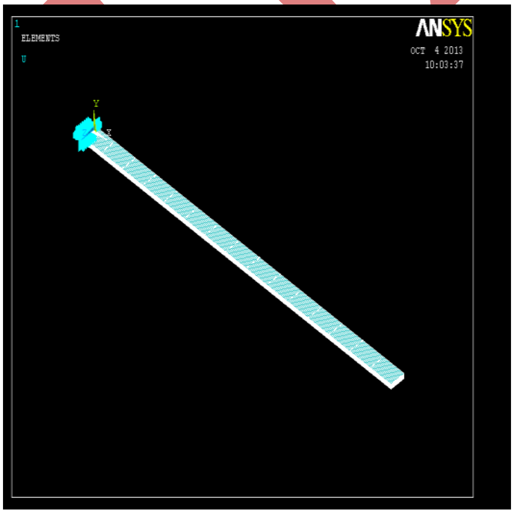


Figure 1. Cantilever Beam for Modal Analysis

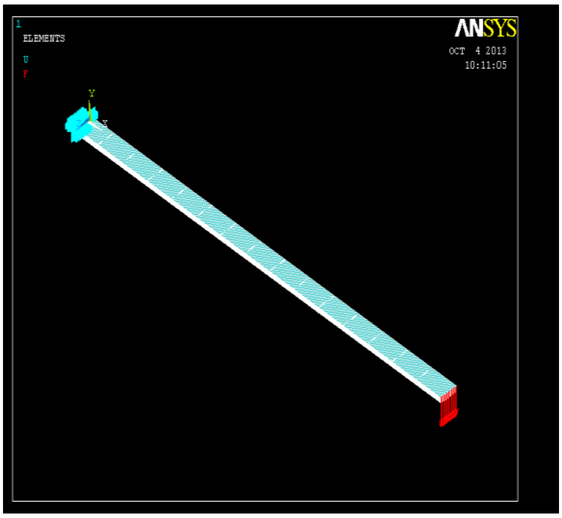
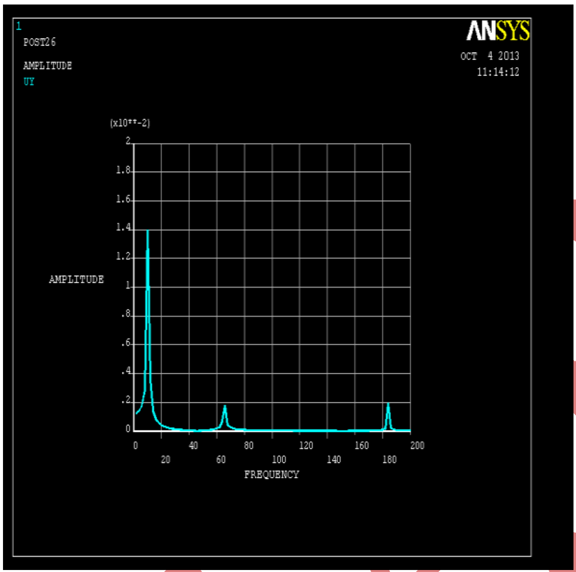


Figure 2. Cantilever Beam for Harmonic Analysis

V RESULTS AND DISCUSSION

The objective of the present work is to compare the natural frequencies and damping of different structural materials like Brass, Aluminum, Mild Steel and Acrylic glass materials. The observations have been taken to calculate damping factor for various materials mentioned above by taking common dimensions of the Cantilever Beam in the frequency range of (0 to 200 Hz).

The first five natural frequencies were calculated by Modal Analysis using ANSYS by generating the modal of the beam. The harmonic analysis was done on the beams of different materials using ANSYS and frequency response curves were obtained. From these curves at the fundamental frequency the damping factor was estimated using "Half- power Bandwidth method" for each harmonic response and results were tabulated. These results are shown in "Table 1" and "Table 2".



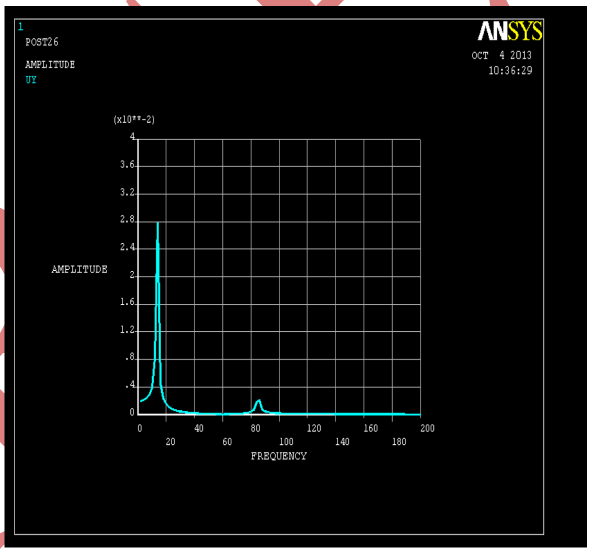


Figure 3. Frequency response curve of Brass Beam

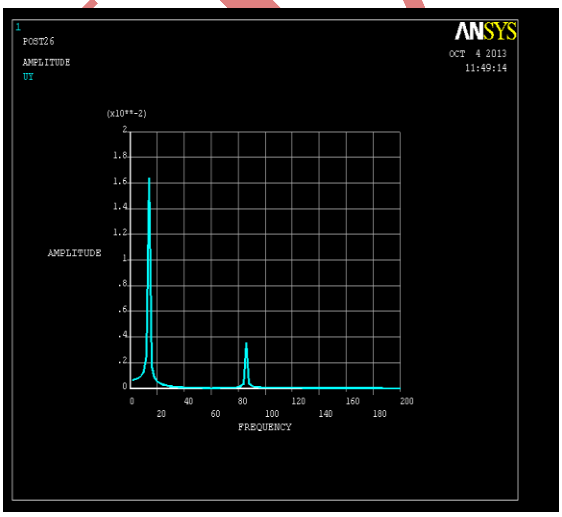


Figure 5. Frequency response curve of Mild Steel

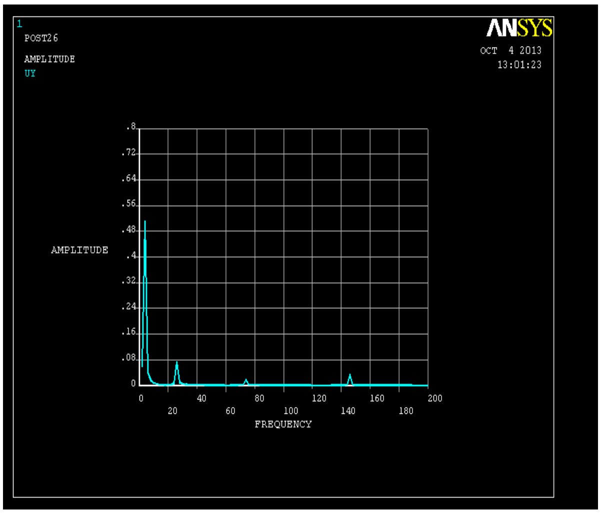


Figure 6. Frequency response curve of Acrylic Beam

Table 1. Comparison of Theoretical and ANSYS Natural Frequencies

Material	Frequency by Theoretical method	Frequency using ANSYS	% error
Brass	10.323	10.461	1.33
Aluminum	13.607	13.797	1.39
Mild Steel	13.588	13.776	1.38
Acrylic	4.129	4.186	1.38

Table 2. Indication of damping Factors of Materials Considered

S.No	Material	Beam dimensions(mm)	Damping Factor (ζ)
01	Brass	600x25.4x6	0.163
02	Aluminum	600x25.4x6	0.288
03	Mild Steel	600x25.4x6	0.344
04	Acrylic	600x25.4x6	0.464

It is found that the Natural Frequency of Aluminum and Mild Steel are more than Brass and that of Acrylic beam is very low. This implies that the stiffness in turn the Young's Modulus of Aluminum and Mild Steel are more compared to Brass and the stiffness of Acrylic glass material are very low.

It is evident that the material damping is higher for Acrylic material and mild steel beams when compared to Aluminum and Brass for the adopted dimensions of the beam. It was observed during iterations that the damping ratio depends on the dimensions of the beam. Hence the modal analysis is plays a major role in evaluating the vibration parameters like natural frequencies and structural damping factors. The results obtained are well corroborated with theoretical values.

VI CONCLUSION

The main objective of the present work is to study the vibration damping characteristics of four structural Materials i.e. Acrylic, Steel, Aluminum and Brass. The cantilever beams have been subjected to free vibration and Harmonic Analysis using ANSYS and damping ratio has been computed using 'Half power Band Width Method'.

On the basis of present study the following conclusions are drawn. It is a nondestructive testing strategy based on model generation. From the Analysis it is evident that material damping is higher for Acrylic and steel in comparison with Brass and Aluminum beams of same dimensions.

- The increase in material damping could be correlated to the stiffness of materials.
- The damping of specimen made up of Brass was found to be lowest than Acrylic, Steel and Aluminum.

- The theoretical result obtained by the method proposed in this work and ANSYS results of vibration are in fair matching in terms of natural frequency.

The model testing using ANSYS has been proven to be an efficient and non-destructive method for estimation of dynamic characteristics like damping factors and natural frequencies.

REFERENCES

[1] H H Yoo and S H Shin, Vibration analysis of rotating cantilever beams, Journal of Sound & Vibration, Pages 807-828, 12 Dec.1997.

[2] Mousa ReZaee and reZa Hassannejad Damped free vibration analysis of a beam with a fatigue crack using energy balance methods, International Journal of the Physical Sciences, Pages 793-803, Volume 5(6), June, 2010.

[3] Chih Ling Huang, Wen Yi Lin, Kuo Mo Hsio Free vibration analysis of rotating euler beams and high angular velocity, Deptt. Of Mechanical Engineering; National Chiao Tung University, Hsinchu Tiawan 14 Nov. 2005.

[4] JinsuoNie,XingWei On the use of material-dependent damping in ANSYS for made superposition of transient analysis, Proceedings of the ASME-2011 pressure vessels and piping division; Broakhaven National Laboratory, July,2011.

[5] Shibabrat Naik, Wrik Mallik Experimental modal testing for estimating the dynamic properties of a cantilever beam, Structural Dynamics.

[6] D. Ravi Prasad A study on dynamic characteristics of structural materials using modal analysis , Asian Journal of Civil Engineering, Volume 9, Number 2, Pages 141-152, 2008.

7] ANSYS Release 10.0, ANSYS Inc.2010

[8] MATLAB 7.0.1 The Mathworks.Inc.