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Vibration Analysis of Hollow Sectioned Curved Beam using Finite Element Method

Sampath S S, Sawan Shetty and Chithirai Pon Selvan M

School of Engineering & Information Technology, Manipal University, Dubai, UAE
mcpselvan@yahoo.com

ABSTRACT

This paper investigates the vibration characteristic of a curved beam. A beam of known dimensions is modeled and analyzed using computational analysis software ANSYS CFX and the results obtained are compared with the straight beam undergoing vibrations. A study is conducted by considering various materials to obtain optimum material selection. Different degrees of vibration are considered and the corresponding changes in the dimensions are determined.

Key words ANSYS CFX, curved beams, degrees of freedom, modal analysis

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INTRODUCTION

Curved beams are more efficient in transfer of loads than straight beams because the transfer is affected by bending, shear, and membrane action. Some of the structures such as arches and arch bridges are modelled using curved beam elements. Curved beams are the parts of machine members found in C clamps, crane hooks, frames machines, planers etc. Uniform curved beam with varying curvature and taper thickness can also be considered [11]. In straight beams the neutral axis of the section coincides with its centroidal axis and the stress distribution in the beam is linear. But in the case of curved beams the neutral axis of is shifted towards the centre of curvature of the beam causing a non linear [hyperbolic] distribution of stress. The neutral axis lies between the centroidal axis and the centre of curvature and will always be present within the curved beams. Majority of structures can be made to resonate, i.e. to vibrate with excessive oscillatory motion. Resonant vibration is mainly caused by an interaction between the inertial and elastic properties of the materials within a structure [4]. Resonance is often the contributing factor to many of the vibration and noise related problems that occur in structures and operating machinery. Modal analysis is very important to determine the frequency of vibration of the material.

Modal analysis has become a major option to provide a contribution in understanding control of many vibration phenomena which encountered in practice [2]. Determining the nature and extent of vibration response levels and verifying theoretical models and prediction are both major objectives. Vibration in the system is some time desired and most of the time its undesired. The modal analysis helps to reduce the noise emitted from the system to the environment. It helps to point out the reasons of vibrations that cause damage of the integrity of system components [3]. If the resultant force in the system is equal to zero, it represents equilibrium condition and when there is unbalanced force exists it leads to vibration. If the motion is described fully by only one time-dependent coordinate, such a system is termed a 1-degree-of-freedom (DOF) vibration model. When more than one coordinate becomes necessary, the discrete system is said to have multiple degrees-of-freedom. In a single degree of freedom system there exists a single mode and the one natural frequency. But, in multi degree freedom system there exists more than one natural frequency which will make the system to vibrate in various modes. Problems often occur in mechanical structure due to vibration, it is vital to prevent such problem because it can lead to structural fatigue and damage [5]. The structure itself has a certain internal properties and it is important to understand its characteristics. In order to do it, the first important thing to do is modal analysis for data acquisition [9].

Fig. 1(a) Curved Hollow Member

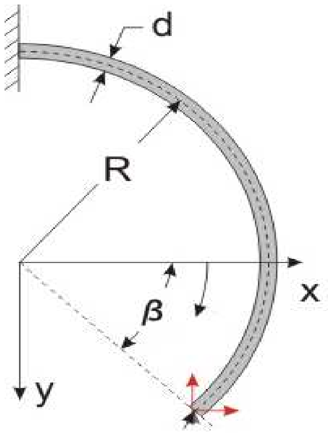


Fig. 1(b) Curved beam fixed at end

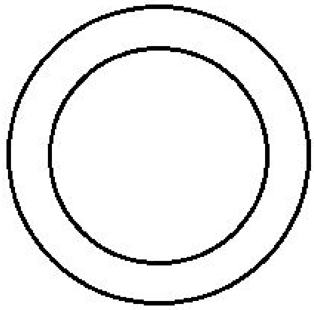


Fig. 1(c) Cross section area of beam

From the above Fig.s, 1(a) represents the simple hollow sectioned curved beam. Fig. 1(b) represents the curved beam attached to one end, like a cantilever phenomenon. Fig. 1(c) represents the cross section of the beam. Keeping the inner diameter of the beam equal to 1 m and outer diameter 1.5 m, and the angle of curve is considered to be 90°. The material which is assumed is titanium with the density 4500 kg/m3. A hollow member undergoes vibration and the corresponding frequency which leads to the change in nodes is noted down.

The following element is modelled, meshed and analysed in software ANSYS CFX and the results are compared. Finite element approach provides the solution at every node of consideration [1, 4]. The present problem was structured as a sequence of fundamental problems built on simple models that determine structural property of the element under study. The models proceed from the simple toward the complex. The objective is to uncover the most fundamental optimization principles (or design trade-offs) that can be put to practical use in real applications. The method of analysis and optimization is the combination of vibration analysis & structures which is used subsequently in many engineering applications [2, 5].

RELATED WORK

Ching and Widodo [5] performed Modal testing and modal analysis is done in using MEscopeVES modal analysis software. The analysis results obtained from experiment are then compared with the results obtained by finite element method (FEM) software ANSYS. Pavol Lengvarský et al [1] considered cantilever beam which is fixed on one end and all degrees of freedom on this end were taken. Mode shapes and natural frequencies are computed in programs ANSYS and compared with numerical formulation of the direct solver including the block Lanczos method by Mohammad Vaziri et al [4].

In this paper in lateral vibration is investigated. This model could be of use in building a controller for reducing vibrations in the mentioned cantilever beam Analysis has been done in two categories which are called as Static and Dynamic analysis. Due to the analysis, displacement in the free end, critical points, stress concentricity, nodal solution, and shape functions is shown. A modal analysis is carried out using analysis software.

METHODOLOGY

Beam is a supporting member which generally supports the transverse loads. Curved beam is much efficient than the straight beams and provides greater flexibility. When the beam is subjected to vibration it generally does not vibrate in a single mode. When there is a rise in fundamental frequency, the modes of vibration also tend to change. The general equation of vibration shown in equation (1) is given in the matrix form, in which all the forces are equated. If the overall sum of the forces is equal to zero then the system is said to be in equilibrium condition. A beam is fixed at one end and the other end is simply supported the fundamental frequency is given by an equation (2).
The general equation of vibration is

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{f\} \tag{1}$$

Fundamental frequency of vibration for a cantilever beam

$$f=\frac{K}{2\pi L^2}\sqrt{E.I/m} \tag{2}$$

M= Mass of the element (kg), C= Damping coefficient (Ns/m), $\dot{x}$= Velocity (m/s), $\ddot{x}$ =Acceleration (m/s^2),
x= Displacement or deflection (m), f= Fundamental frequency (Hz), E= Young's Modulus of the material (N/m^2)
k= Stiffness (N/m), K= Radius of gyration (m), L= Length of the element (m) and I= Moment of inertia (m^4)

MODELLING AND ANALYSIS

A curved beam which is having a hollow cross section is modelled using finite element software ANSYS [2]. The model is split into numerous elements in order to improve the preciseness of the solution therefore the beam is meshed. Fig. 2 shows the meshing of a curved beam, which is fixed at one end and is similar to the cantilever beam. Meshing is a process of splitting into many numbers of elements [1]. As the number of element increase s complexity also tend to increase. Titanium material with a known density is used as a material for the curved beam.

Meshing is discretizing of an element into finite number of parts and each element is considered and solved separately [2]. Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric domain. The term 'grid generation' is oftenly used interchangeably. Typical uses are for rendering to a computer screen or for physical simulation such as finite element analysis or computational fluid dynamics. After this step a one end is made to fix before the application of vibration. Since Titanium is considered as the material for the beam, density of the material is 4500 kg/m^3. Modelling and Meshing is done using FEA and the simulation is performed. Behaviour of the beam is determined by selecting different modes and the frequency corresponding to the mode is noted down [1, 2]. By means of the numerical solution, vibration analysis of the entire element is achieved [1].Validation of the results obtained in the FEA is compared with the classical equation. It can also be compared with the modal analysis obtained for cantilever beam [1, 2 and 5]

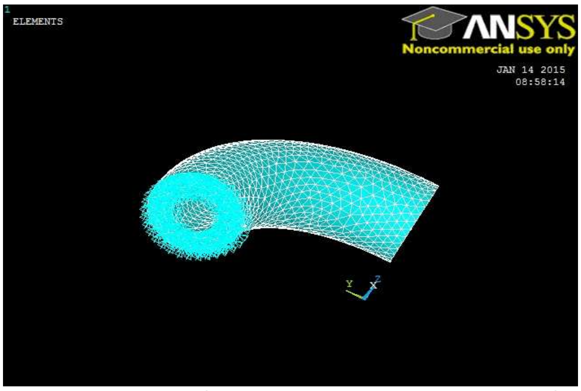


Fig. 2 Meshing of a curved beam with the application of displacement function

Table 1 Fundamental Frequency at Different Modes in ANSYS – Index of Data Set on Result File

Set	Time/Freq	Load step	Sub step	Cumulative
1	109.60	1	1	1
2	111.93	1	2	2
3	330.31	1	3	3
4	386.70	1	4	4
5	545.32	1	5	5

RESULTS AND DISCUSSION

The simulation to determine the vibration characteristic in a curved beam is carried out with the application of appropriate boundary conditions. Analysis is carried out and the mode change with respect to the corresponding frequency is noted down [1]. Fig.s 3 to 7 shows the deformations, minimum and maximum deflections at various frequencies. Table 1 represents the various frequencies at different modes.

Figures 3 (a) - 7(a) represent the maximum deformations in various modes whereas the Fig 3(b) - 7(b) represent the minimum and maximum result value in different modes [2]. Maximum deformation region determines the tension and the minimum deformation region identifies the compression regions in different phase of vibration and the results are validated in comparison with Pavol Lengvarský et al [1].

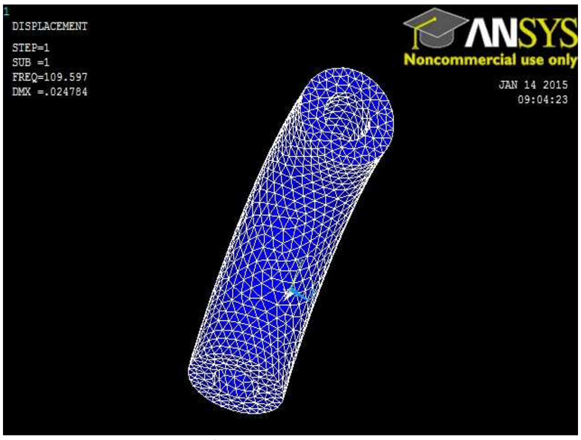


Fig. 3 (a) Maximum deflection in mode 1 (Frequency= 109.60 Hz)

Fig. 3 (b) Minimum and maximum result value in mode 1

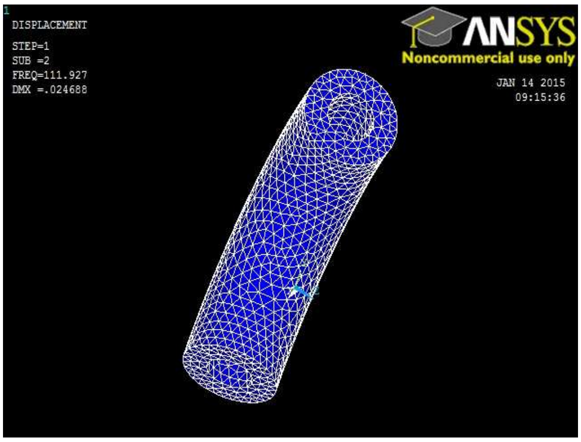


Fig. 4 (a) maximum deflection in mode 2 (Frequency= 111.93 Hz)

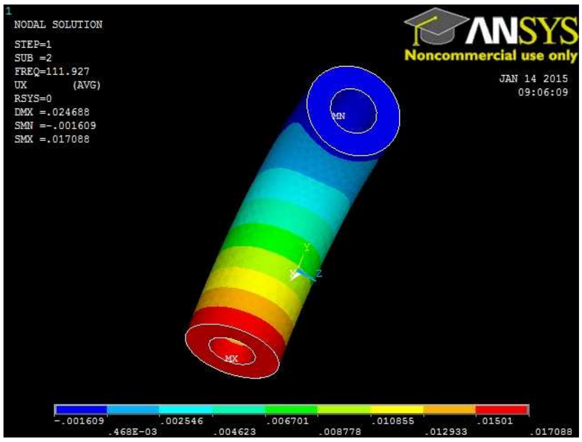


Fig. 4 (b) Minimum and maximum result value in mode 2

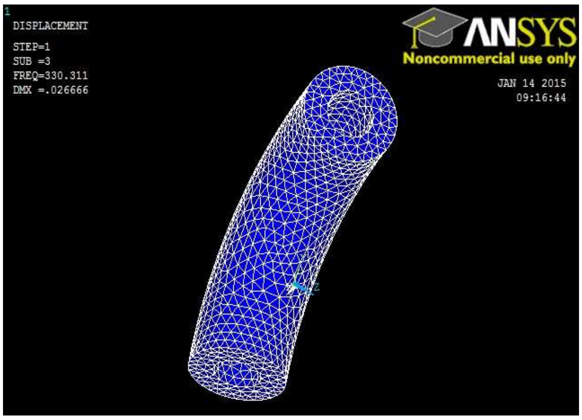


Fig. 5 (a) maximum deflection in mode 3 (Frequency= 330.31 Hz)

Fig. 5 (b) Minimum and maximum result value in mode 3

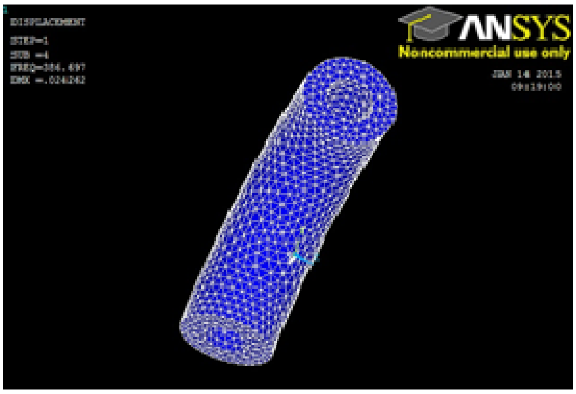
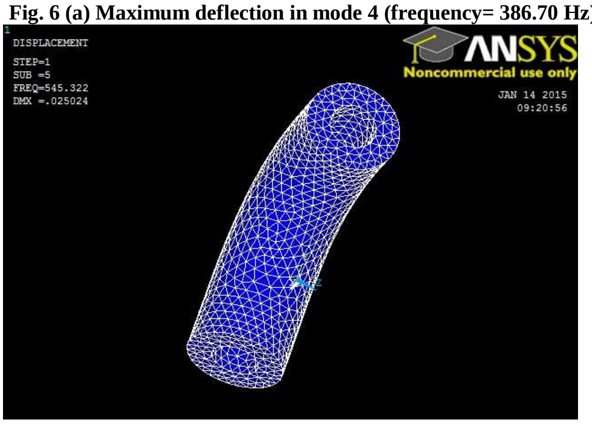


Fig. 6 (a) Maximum deflection in mode 4 (frequency= 386.70 Hz)

Fig. 6 (b) Minimum and maximum result value in mode 4



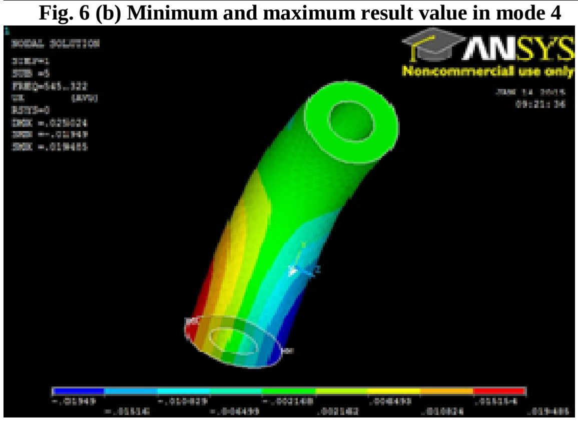


Fig. 7 (a) Maximum deflection in mode 5 (frequency= 545.322 Hz) **Fig. 7 (b) Minimum and maximum result value in mode 5**

Fig. 8 shows vibration change in the behaviour of the structure with the rise in vibration levels and Fig. 9 shows the increase and decrease of the maximum deformation which takes place in the structure. From the graph it shown that maximum deformation will be at the frequency of 330.31 Hz. Overall nature of the curve is a sinusoidal which may again rise to a particular point of frequency and again drop.

Table - 2 Fundamental Frequency Variations with the Number of Modes

Modes of vibrations	Frequency (Hz)
1	109.60
2	111.93
3	330.31
4	386.70
5	545.32

Table - 3 Maximum Deformations Due to the Rise in Fundamental Frequency

Fundamental Frequency (Hz)	Maximum deformation (m)
109.60	0.024784
111.93	0.024688
330.31	0.026666
386.70	0.024262
545.32	0.025024

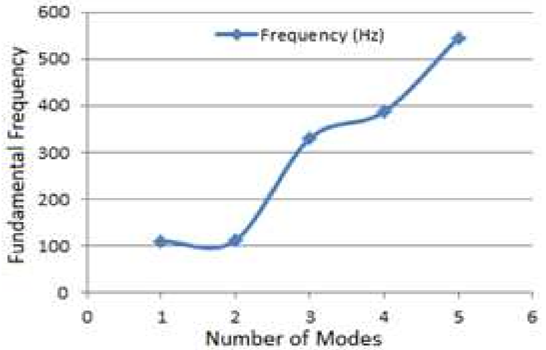


Fig. 8 Variation of modes with the change in fundamental frequency

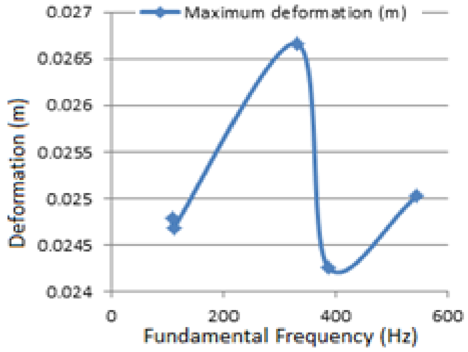


Fig. 9 Maximum deformation variation with the fundamental frequency (No of Modes)

CONCLUSION

Present work determines the vibration characteristics of a curved beam which is attached to an end. Modes of vibration at various frequencies are determined using finite element analysis technique. It provides the understanding of the behaviour of the beam when it is subjected to multiple degree of vibration. Nature of the graph infers that, there is a rise and fall in the maximum deflection values with the increase in the fundamental frequency which means that material is continuously under tension and compression. When the deformation is minimum and in the elastic limit, it can return to its original position, but if it exceeds the limit of elasticity there will be a permanent deformation. On recurrence of this nature of vibration leads to a failure in curved beams. Therefore material selection is important to keep the elongations within the limit. It is possible to obtain an optimum solution by selecting a material which has better structural performances. Further analysis can be carried out by changing the dimensions or selecting beams of different sections. Appropriate design of the curved beam can only be completed with the consideration of vibration. Analysis can be further carried for more than 5 modes and the behaviour of the beam can be determined.

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