Experimental Modal Analysis of Non-uniform Mild Steel Beam Using Laser Vibrometer

Prabhat Mahawar[*1], Pankaj Sharma[2], BL Gupta[3]

[*1,2] **Department of Mechanical Engineering, Rajasthan Technical University, Kota (India)**

[3] **Principal, Government Engineering College, Baran**

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ABSTRACT:

This investigation represents an experimental modal analysis of a non-uniform mild steel beam under clamped-free (C-F) boundary conditions. Non-uniform beams are commonly found in engineering applications, and their modal characteristics play a crucial role in design and performance optimization. The experimental modal analysis of a non-uniform clamped-free beam is performed with a laser vibrometer excited with impact hammer excitation. We describe the experimental setup, data acquisition, and signal processing techniques used to extract natural frequencies, mode shapes, and damping ratios. The excited wave signals are converted into the frequency domain and time domain by using FFT (Fast Fourier Transformation). The simulation is performed using COMSOL Multiphysics software 5.6 and ANSYS Workbench 18.1. Thus, the experimental natural frequency and mode shapes of the non-uniform beam are compared with simulation results. A comparison of results obtained experimentally shows a good validation with the results obtained from simulation. The obtained results be used as a reference for future investigation in this domain.

Keywords: Modal analysis, Laser Vibrometer, Impact hammer, Mild Steel

INTRODUCTION

By examining the modal testing parameters, such as natural frequencies, mode shapes, and damping ratios, researchers and scientists in the last few decades have demonstrated an interest in gaining a thorough grasp of the kinematic properties of machine tools structure. It is referred to as modal testing. A linear, time-invariant system's modal testing parameters are assessed using experimental methods in modal testing. Understanding the relationship between a structure's modal parameter and its mechanical components can be useful for a number of tasks, including model update, structural alteration, and health monitoring.

J. Xie et al [1] developed the impact of electrostatic force nonlinearity on a frequency-modulated tapered beam micro-gyroscope's sensitivity performance. An optimal response to the problem of stability is suggested the frequency modulation (FM) approach. The deflection, put off voltage, and usual properties of the mini-gyroscope are gained by using the DQ method. The free and forced vibration of several elastically linked beams was studied by Boping Wang et al [2] using an analytical wave propagation approach. The coupled partial differential equations are established by matrix theory. M. Umapathy et al [3] analyzed the performance of piezoelectric rotational energy harvester for autonomous sensor systems using reversed exponentially tapered multi-mode structure. The primary beam continually generates electrical energy. An energy management system is a wireless autonomous sensor system. M. Sheykhiet al [4] reported the vibration of nano-beam, viscosity and density of fluid by obtaining elasticity theory. Galerkin method was employed to obtain the equations. Lower modes are most affected by the fluid, whereas higher modes are most affected by the nonlocal parameter. Thin-walled beams' free vibration analysis utilising a two-phase local-nonlocal constitutive model computed by M. G. Günay [5] by using Hamilton‘s principle. A two-phase local & nonlocal-constitutive formulation is used to characterize constitutive relations. The solution is obtained by the FEM (finite element method). Y. Cetin et al [6] extended free vibration behaviour of non-uniform/homogeneous helices. Timoshenko’s beam theory was carried out to solve the governing equations. The methods of complementary functions and stiffness matrices are adopted to

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obtain ODE. With the higher order Haar Wavelet approach, free vibration analysis of the tapered Timoshenko beam was performed by M. Mehrparvar et al [7]. This method reduces the absolute error without increasing computational complexity. A. Rahmouni [8] did vibration analysis of cracked tapered beams resting on Winkler elastic foundations. Mode shapes and respective frequencies for different constraints are obtained through Lagrange's equations. Using the discrete model for the processing of natural vibrations, tapered beams carrying masses at different spots are reported by A.Moukhliss et al [9]. And problem is stated in mathematical form through Lagrange formalization. M. Hossain et al [10] did vibrational analysis of tapered cracked double nano-beams. The impacts of non-local factors, crack strictness and spring constant on the vibration of the double nano-beam are examined using numerical analysis. I. El Hantati et al [11], used Euler-Bernoulli beam theory to study free and forced vibrations of tapered beams. An approximate method was acquired to obtain the nonlinear system equations with the help of Hamilton's principle. The LADM was carried out by Ming Lin et al [12] to examine the free vibration analysis of a non-uniform Bernoulli beam. The characteristic equation of a non-uniform beam is created from the governing equation by using LADM. C. Wu et al [13] studied elastic vibrations and rigid-body motions of a double-tapered beam under free-free condition. The underlying modes and natural frequencies for the unconstrained and constrained beams are reported. A. Zargarani et al [14] computed the double-cantilever structure's vibration behaviour and torsional stability. In order to determine the governing equations of motion, Hamilton's principle is used under several boundary conditions. The fundamental frequency is dependent on the beam's length. Analysis of the vibration of revolving, curved, pre-twisted blades in a heat environment is reported by P.A. Chandran et al [15]. Vibration analysis is performed to obtain the blade pitch angles, and taper ratios at a variable rotational speed. Mei Liu et al [16] examined the static and free vibration analysis for nonlinear beam model. Von Karman's relationship is adopted to develop and analyze the model. The governing equations are discretized using the Galerkin method. Vibration behavior of a non-homogenous un-symmetric beam subjected to temperature surrounding is studied by C.R. Nayak et al [17]. Parabolic variation is obtained by using power law distribution. To get the governing equations for various boundary conditions, Hamilton's principle is applied. Free vibration analysis of an attached cantilever Timoshenko beam under elastic restraint is reported by Y. Pala et al [18]. Obtained non-dimensional parameters like natural frequency and mode shapes affected by attached mass and spring constant. The polynomial expansion method was adopted by Murat Kara et al [19] to investigate the free vibration analysis of non-uniform uncertain beams. Differential equations are solved by the discrete singular convolution method at small discretization points. Y. Du et al [20] computed the behaviour of axial-loaded beams with varied cross-sections and several concentrated elements. The vibration characteristics of the beam were analyzed by using the transfer matrix method. The Frobenius method is adopted to solve the differential equation. Response analysis of a rotating tapered beam is carried out by Dan Wang et al [21] by using Galerkin's method. The cause of frequency ratio, and radius of the beam is also reported.

Beam geometry:

Figure 1 displays the geometry of a rectangular non-uniform beam. Here L and t denote the length & the thickness of the beam, and B and b are larger and smaller end widths.

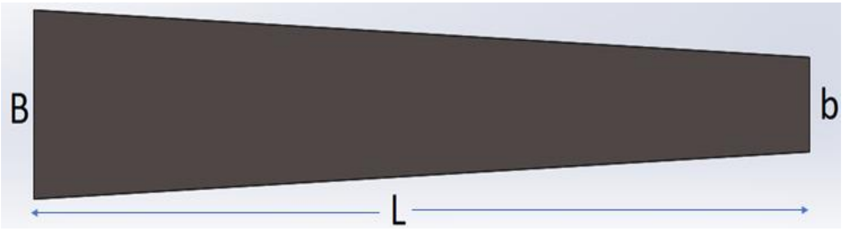

Fig. 1. Beam geometry.

Beam of Mild steel is taken for the analysis whose dimensions and material properties are summarized in Table 1 below. All the dimensions are taken into millimeters (mm). Here Young's modulus is represented by E, & ρ, and ν stand for, density, and Poisson's ratio of the M.S. beam.

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Table 1. Material Properties.

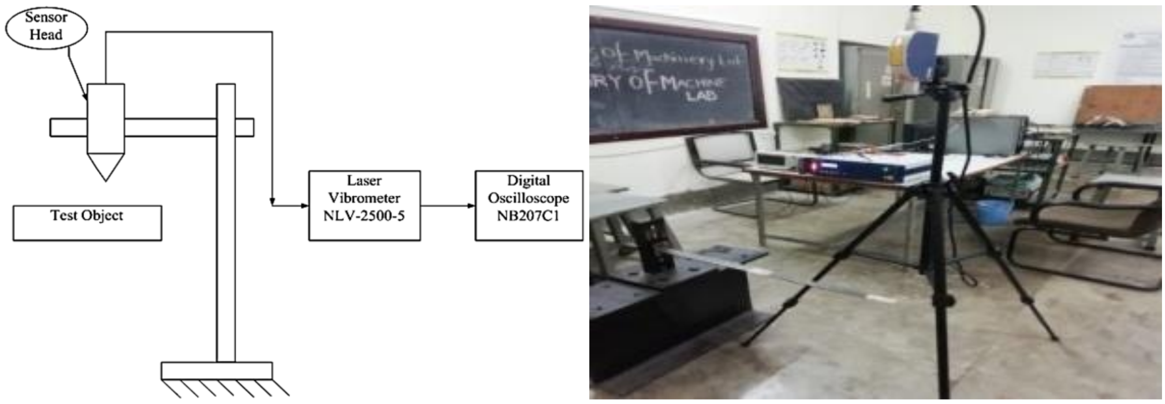
Material properties	Mild Steel
E	200 GPa
ρ	7830 Kg/m^3
ν	0.303

Table 2. Geometrical Parameters.

Parameters	Dimension
L	700 mm
B	37 mm
b	25 mm
t	3 mm

Experimental Modal Analysis

Fig. 2 shows a basic experimental setup used in this work. This experimental set-up comprises a digital oscilloscope (NB207C1), an impact hammer, and laser vibrometer (Polytec, NLV-2500-5). The laser vibrometer is a non-contacting apparatus for obtaining vibrations. The laser vibrometer provides a wide range of measurements for vibration amplitude and frequency in all technical applications. The non-uniform M.S. beam's natural frequencies can be found by the experimental setup.



(a) (b)

Fig. 2. (a) Basic and (b) actual experimental set-up.

The beam was fixed at one end displayed in Fig. 2(b). Validation of FE model is done against the results obtained through experimental analysis. The sensor head is attached to a tripod stand so as to keep away the beam from the sensor. The connections among all the components were ensured before the excitation

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Simulation of non-uniform beam

The 3-D geometrical model of the beam is constructed in solid works and then computational modal analysis has been performed to attain the mode shapes. The geometric parameter and material properties have been taken from Tables 1 and 2. Relevant b.c. is applied at both end of the beam and obtained results were compared with experimental results.

RESULT

Modes and their respective frequencies obtained under fixed-free condition of beam are summarized in Table 3. Figures 3 shows frequency domain signal while figure 4 displays the time domain for given fixed-free condition. The Ist peak occurs at the Ist natural frequency (5.229 *Hz*) of the beam, and the IInd peak occurs at the IInd natural frequency (33.46 *Hz*), according to the frequency domain signals graphs produced by the MATLAB program using FFT. Using an impact hammer excitation, we can quickly identify the natural frequencies up to the second mode under fixed-free boundary conditions. It is challenging to use the impact hammer to excite the model to higher modes because of its high rigidity. It should be highlighted that, when operating with fixed-free boundary conditions, the tests could only produce fundamental natural frequencies.

Table 3. The natural frequencies of C-F M.S. non-uniform beam.

Mode	COMSOL (Hz)	ANSYS (Hz)	Experimental (Hz)
Mode 1	5.64	5.66	5.229
Mode 2	32.58	32.722	33.46

The experimentally obtained frequency-domain signal and time-domain signals are displayed in figure 3-4.

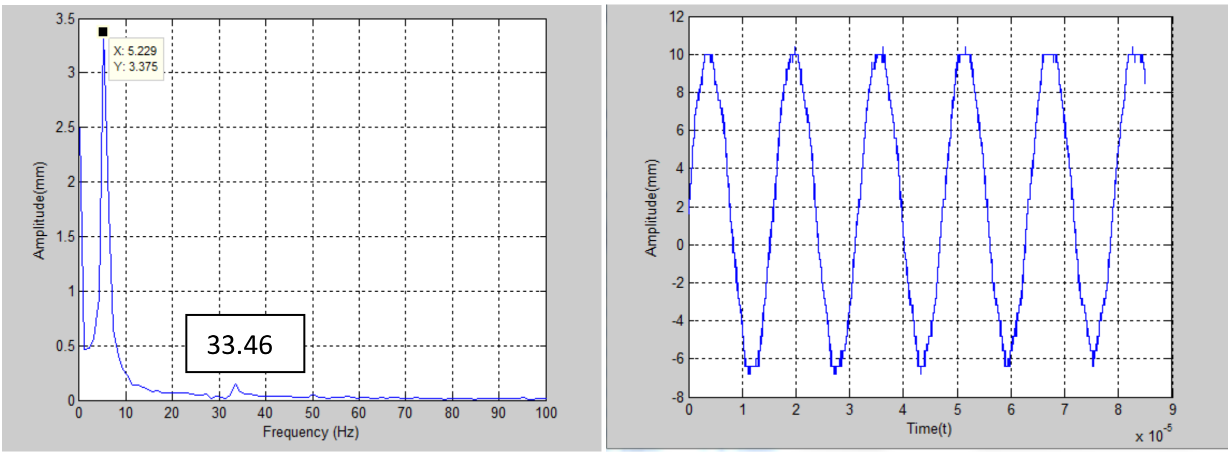
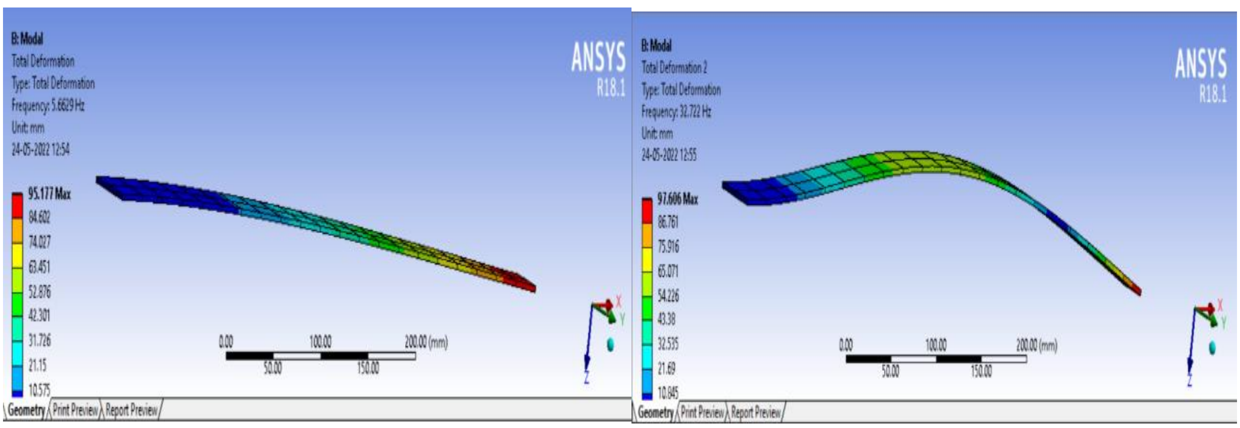


Fig. 3. Frequency domain and Time domain signals for non-uniform M.S. beam



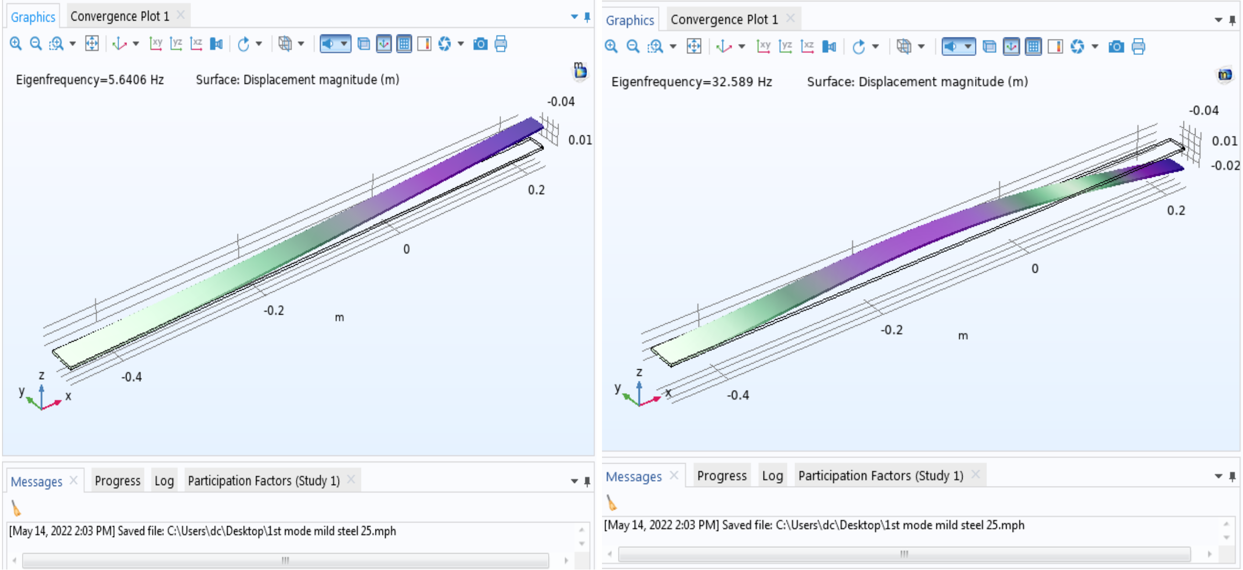


Fig. 4. Natural frequency of C-F M.S. non-uniform beam and corresponding mode shapes by simulation

CONCLUSION

In this study, finite element & experimental modal analysis is carried out over a non-uniform beam. The impact hammer excitation method and a laser vibrometer were used to test the non-uniform beam's modulation. In the modal testing, the impact hammer excitation approach was not practical for exciting the third mode of the non-uniform beam in clamped-free boundary conditions. The simulation-based results are gained using the COMSOL Multiphysics software 5.6 and ANSYS Workbench 18.1. Better correlations are found between experimental and simulation results. Variation in results is obtained because of slight differences in the dimensions of the non-uniform beam and variations in material properties. This work's presentation of the modal technique perhaps useful in creating and perfecting the design of engineering structures for improved outcomes.

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