Development of Test Setup to Obtain Mode Shapes of Beams

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Abstract: Obtaining the mode shapes in the experimental modal analysis is crucial task. It involves obtaining frequency response function (FRF), converting it into single degrees of freedom (DOF) and fitting a curve. The structure of the system whose mode shapes to be plotted is excited either by impacting a hammer or by a vibration exciter or shaker. The impact hammer test is suitable for lightly damped structure while shaker test is suitable for heavy damped structures. This is because; the impact hammer may not provide sufficient energy to excite the heavy structures. The paper consists of design and development of laboratory setup to excite the beams and plotting mode shapes of beams using commercial modal analysis software. The setup can be used for both roving impact and fixed response method and roving response and fixed excitation method. The setup is designed to excite the beams up to 50 Hz. The first two mode shapes of fixed-free beam are plotted using this test setup. Also, mode shapes of beams with different boundary conditions can also be plotted using this test setup.

***Keywords* – experimental modal analysis; simple harmonic motion (SHM); frequency response function (FRF); nodes and antinodes.**

1. Introduction

An experimental modal analysis or experimental modal testing is the process to obtain the dynamic characteristics of the system viz. natural frequencies, damping factor, mode shapes. It is the process which is widely used in the industries for variety of applications like optimization, defects identifications, etc. Few years ago, the experimental modal analysis was difficult. But, in recent years, development in signal conditioning has led to the development of modal analysis techniques. Experimental modal analysis starts with obtaining the modal FRFs of the systems which show the responses of systems at different frequencies. The FRF is mathematically ratio of response of system to excitation force in frequency domain [1]. Thus, for a same force, response is same because of which FRFs are used to plot the mode shapes. To explain, this consider frequency response curve (Figure 1) at free end of a structural steel fixed-free beam of 920mm×50mm×5mm with load of 100 N at 250 mm from fixed end. The curve is obtained in ANSYS for 5 percent structural damping.

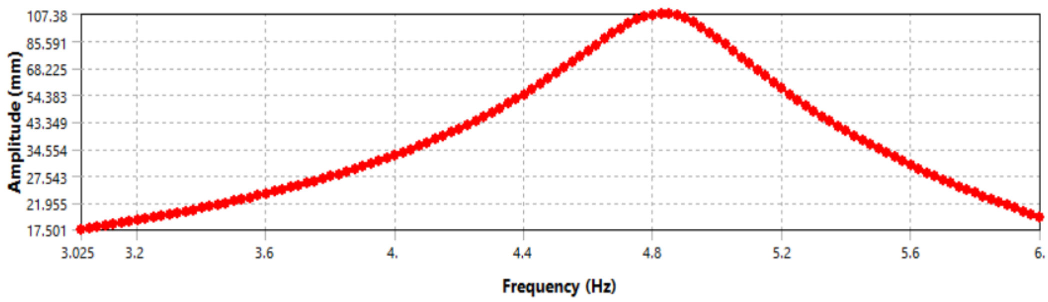


Figure 1. 1 Frequency response curve for fixed-free beam.

For a 100 N force at mentioned point and same amount of damping, response at every point will be same. The experimental modal analysis uses same principle to obtain the mode shapes. Obtaining mode shapes, is basically obtaining responses (FRFs) at different points at natural frequencies and fitting curve of obtained responses against the location of measurement points [2]. The main advantage of experimental modal analysis over numerical methods is that experimental modal analysis considers effect of material and structural damping. Also, the modeling of joints in the numerical methods is very difficult.

2. Experimental Test Setup

As mentioned in Section 1, it is necessary to obtain the modal FRF of structure to plot the mode shapes. The test setup is developed to excite the systems to the natural frequency and frequency response is obtained. The excitation force is known. Thus, mode shapes are plotted using this. The test setup is shown in the figure1. It consists of the cam and follower mechanism to excite the structure. Both roving accelerometer and fixed excitation and roving excitation and fixed accelerometer can be used to obtain mode shapes. The test setup is as shown in the figure 2. It consists of number of parts (as shown in figure 2). The main feature of this setup is that, it has cams to excite the structure and position of the same cams can be changed. Thus, setup can be used for roving excitation-fixed response method.

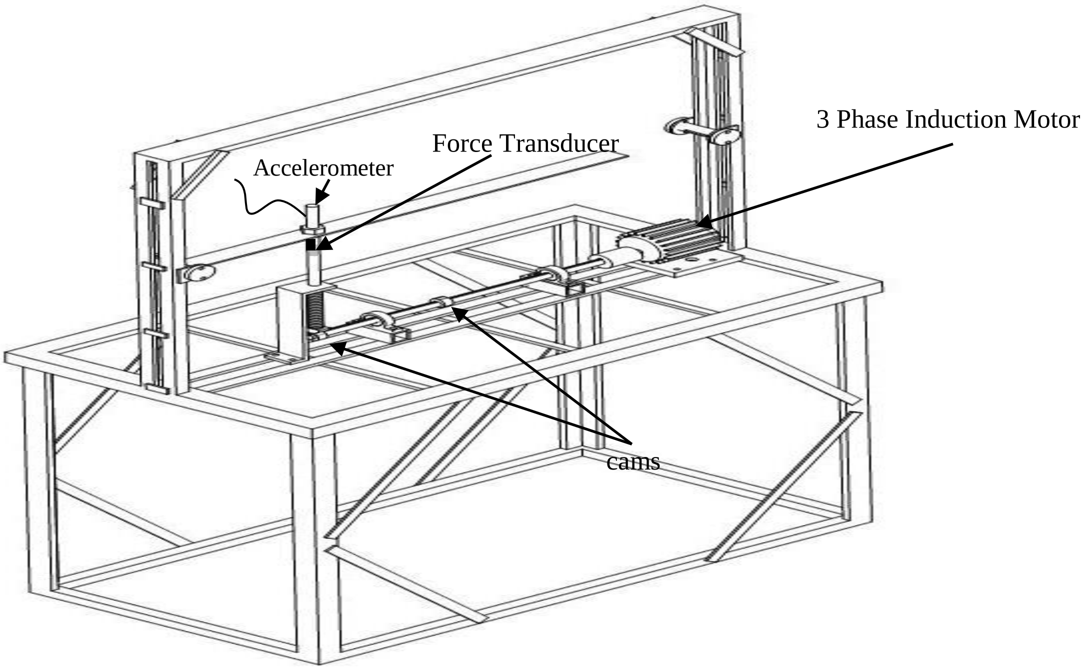


Figure 2. 1 Schematic diagram of Test Setup

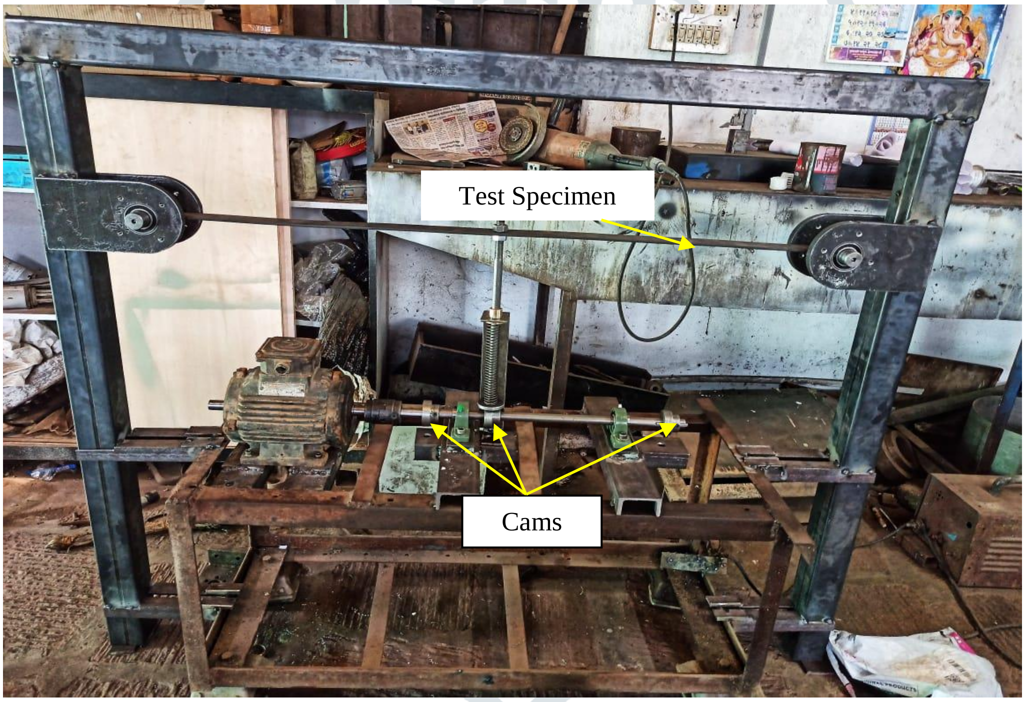


Figure 3. 1 Actual Experimental Setup.

The experimental setup consists of number of components like shaft, keys, bearings, columns, etc. The dimensions of above components are obtained by the standard design procedure. The cam profile is obtained by considering simple harmonic motion of follower as simple harmonic excitation gives true mode representation of structures [5]. The thickness of cam is decided by considering Hertzian contact stresses. The components which do not have standard cross-section are designed by performing simulation in commercial software ABAQUS.

3. Experimental Modal Analysis

The test setup is used to obtain the mode shapes of Fixed-Free beam of 600×50×5mm. The roving response and fixed excitation is method is used to obtain the mode shapes of beams. For this, beam is divided in to 7 points shown as shown in figure 3. The location of an excitation is set to the point 2 and locations of the responses are changed from point 2 to point 6. For a beam with 7 points, it is necessary to obtain the total 49 modal FRFs [1]. Since, point 1 is fixed, 36 frequency response curves are obtained using ADASH FFT analyzer.

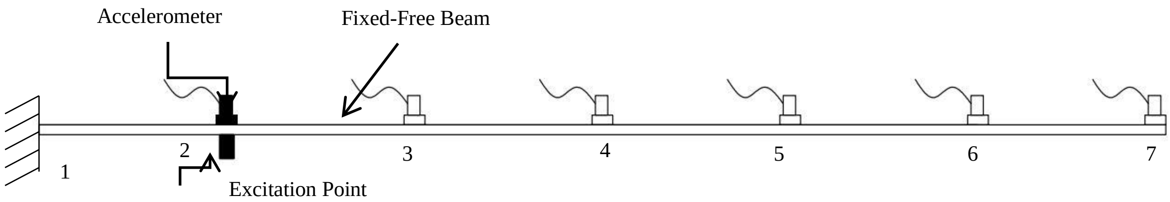


Figure 3. 2 Fixed-free beam.

Out of 36, only 6 frequency response curves are required to plot the mode shapes of the beam. The frequency response curve for excitation at point 2 and response at point 2 is shown in figure 4. The figure 4 shows responses at natural frequencies viz. 11Hz, 66.5 Hz, etc. For that magnitude of force, response at natural frequencies will remain same. This principle is used to obtain the mode shapes of the beam.

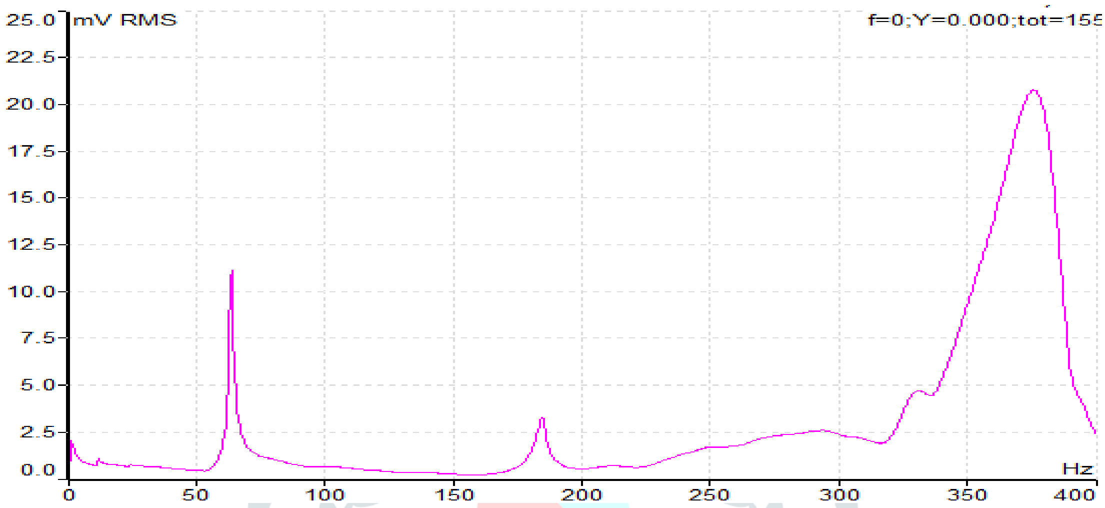


Figure 3. 3 Response at point 2 when excitation is at point 2.

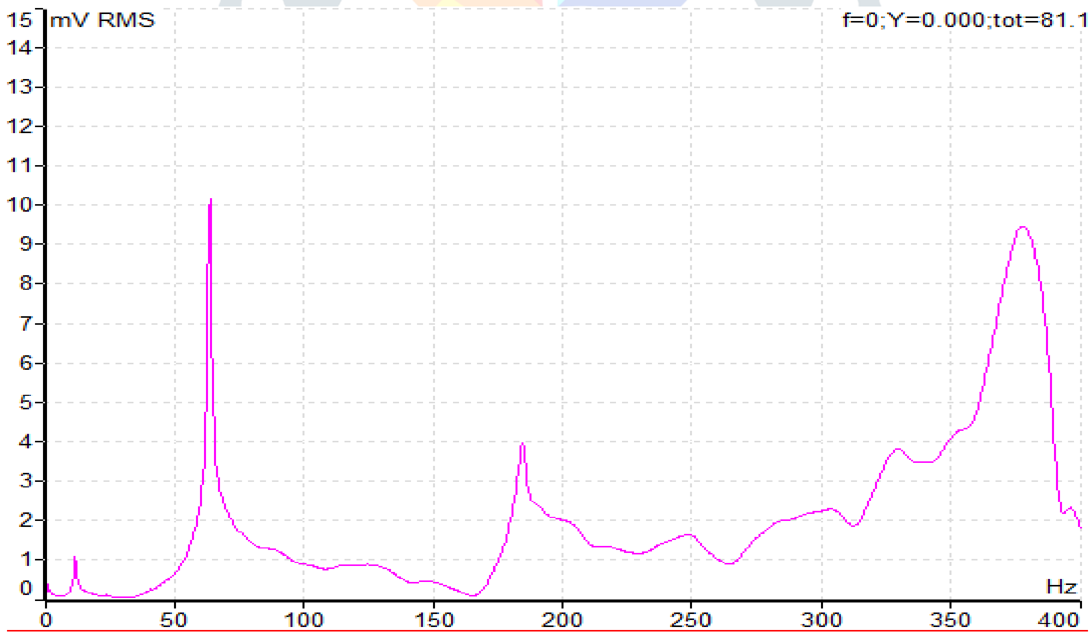


Figure 3. 4 Response at point 3 when excitation is at point 2.

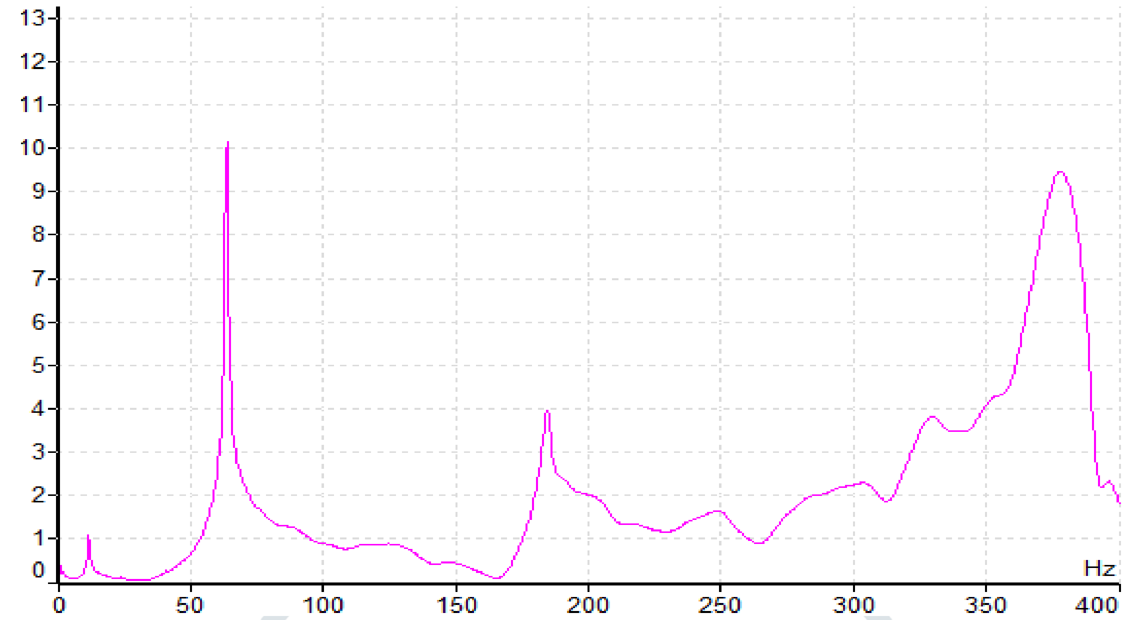


Figure 3. 5 Response at point 4when excitation is at point 2.

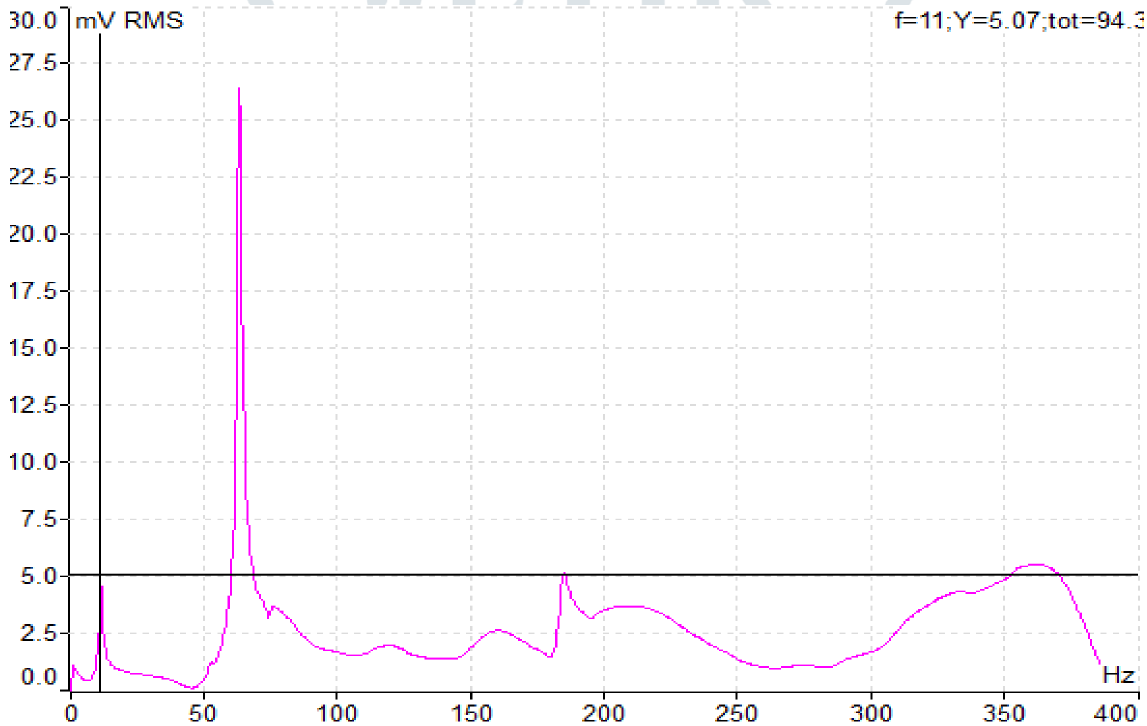


Figure 3. 6 Response at point 5 when excitation is at point 2.

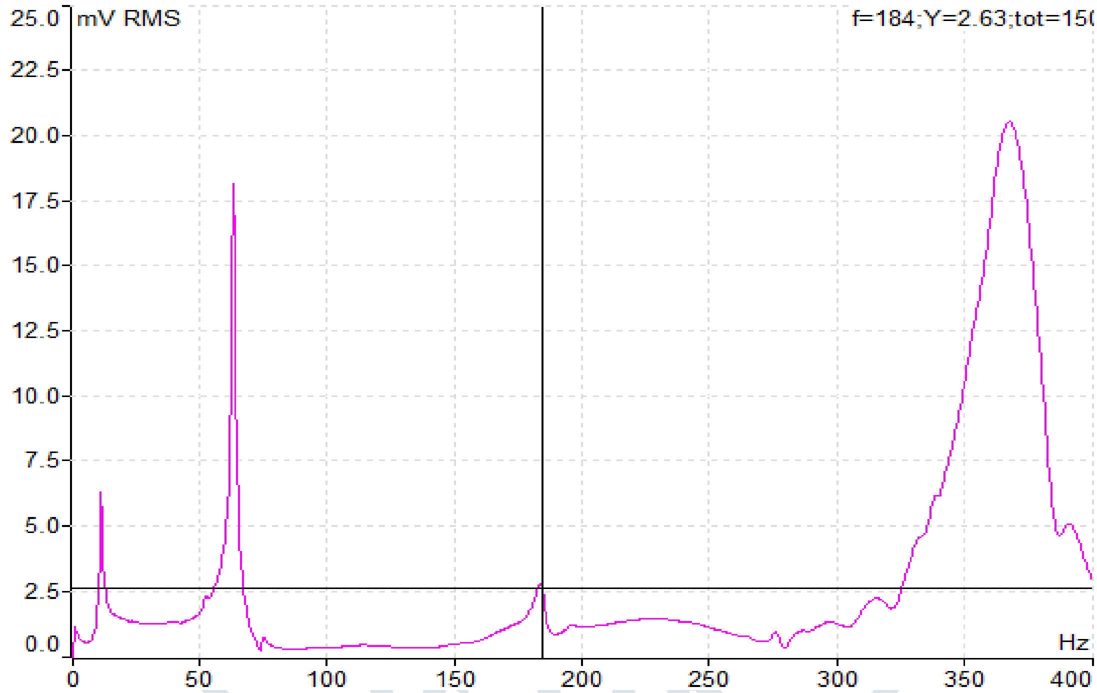


Figure 3. 7 Response at point 6 when excitation is at point 2.

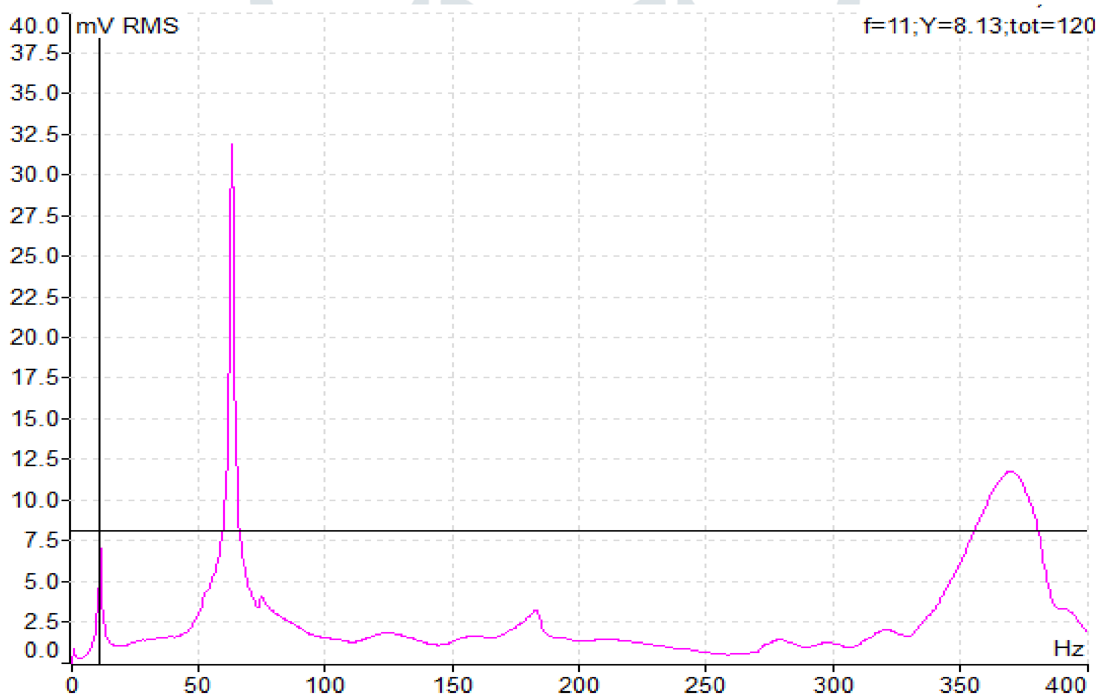
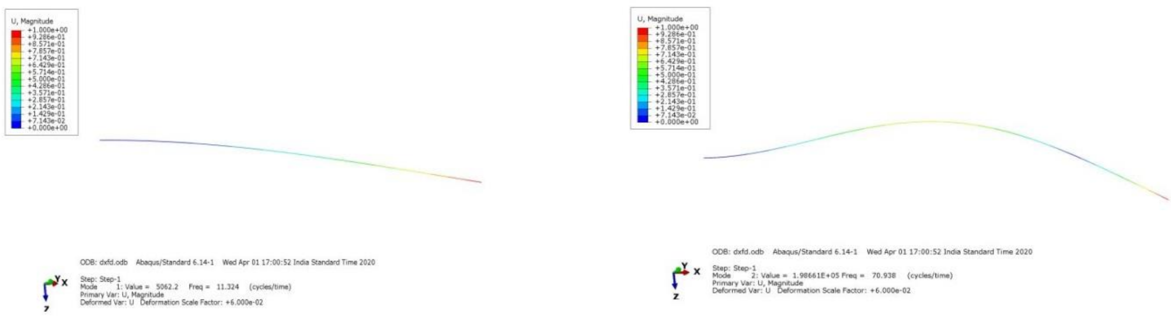


Figure 3. 8 Response at point 7 when excitation is at point 2.

The figures 3.3 to 3.8 shows the frequency responses when excitation is at point 2. This is an example of fixed excitation and roving response method. The graphs show that the response at higher natural frequency is large, this is due to the tip of excitation is harder. The obtained responses at natural frequencies are plotted against the locations of measurement to plot the mode shapes of fixed-free beam. The phase identification is difficult for the responses at higher natural frequencies using this method. Thus, only first two mode shapes can be plotted using this method. Phase measurement is necessary for the responses at higher natural. The mode shapes can be plotted using this test setup. But, for this, we need force transducer and modal analysis software like DEWESOFT FRF, Lab View, etc.

4. Results and Discussion

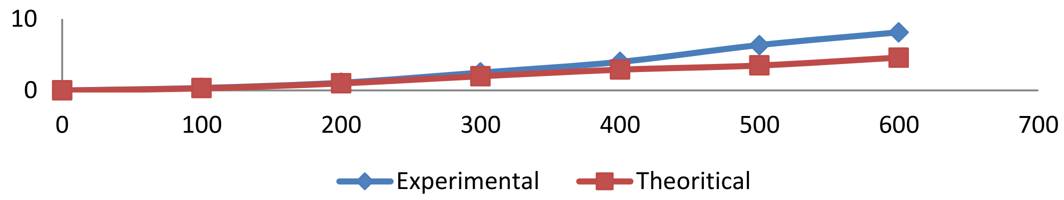
The results obtained using this test setup is compared with the analytical and finite element base software. The ABAQUS is used to obtain the mode shapes of Fixed-Free beam. The beam is modeled using 1D-beam element. First two mode shapes of the beams are obtained using ABAQUS software. Figure 5 shows mode shapes of fixed-free beam plotted in ABAQUS.



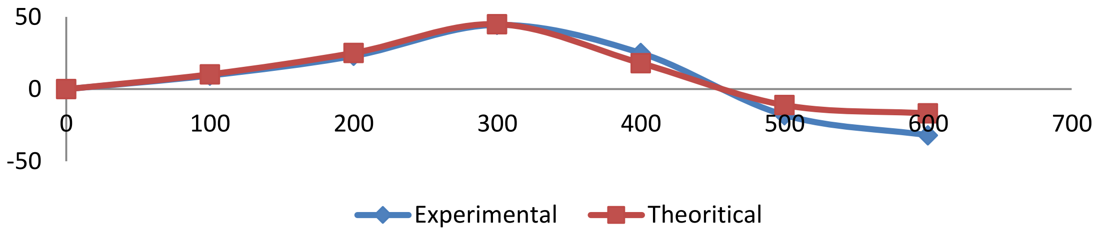
(a) Mode 1 (b) Mode 2

Figure 4.1 Mode Shapes of Fixed-Free Beam in ABAQUS.

The analytical mode shapes and mode shapes plotted experimentally with this setup are shown in the figure 6. The horizontal axes in Figure 6 are the distance of measurement points from the fixed end in millimeters and vertical axes indicates the relative amplitude.



a) Mode1



b) Mode 2

Figure 4.2 Mode Shapes of Fixed-Free Beams using Experimental and Analytical Method.

The main purpose of plotting mode shapes is to find the location of nodes and antinodes. The optimization of structure depends on the position of antinodes. The location of nodes for the mode shapes is also obtained in using this experimental setup. The results obtained using above analytical, numerical and experimental method is shown in the Table1.

Table 4. 1 Comparison between analytical, numerical and experimental methods.

		Analytical Method	Numerical Method (FEM)	Experimental Method
Natural Frequency (Hz)	1	11.33	11.32	11.5
	2	70.69	70.94	66.5
Location of Second Nodes from Fixed-Free for Mode 2 (mm)		469.56	-	476

5. Conclusion

The experimental results show that the test setup is able to excite the fixed-free beams at maximum frequency of 50 Hz. This indicates, the harmonic response of fixed-free beams whose one or more natural frequencies are less than 50 Hz can be obtained using this setup. The values of natural frequencies obtained by analytical, numerical and experimental are equal which indicated the method we followed for the modal analysis is correct. The results table shows the location of nodes and antinodes are almost same. The figures 5 and 6 shows the setup has become successful in the plotting of the mode shapes of fixed-free beam. The future work will be to extend the method for obtaining mode shapes of any arbitrary object.

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