2006-1644: INSTRUMENTATION FOR VIBRATION AND MODAL TESTING – A SENIOR DESIGN PROJECT

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Instrumentation for Vibration and Modal Testing -
A Senior Design Project

Abstract

This project was designed for senior students to enhance their hands-on experience with technical instruments and computer based simulations.
Throughout this project, senior students constructed an instrumental set-up to experimentally identify modal characteristics of a bell-shaped structure. Impact excitation method was used to identify the first five resonance frequencies and a commercial FEA package was used to verify the validity of the set up for further applications.

Introduction

At Virginia State University, senior project is a three credit elective course that engineering students can take in their senior level. This project based course allows the students to apply their engineering knowledge and skills and gain hands-on experience in the area of their interest. This project establishes an open ended undergraduate research lab in the area of structural dynamics for both Computer Engineering (CE) and Manufacturing Engineering (MANE) students at Virginia State University.

Instrumentation for vibration and modal testing of a bell-shaped structure was a project done recently. However, lack of generalized mathematical representation of bell vibrations necessitates numerical and/or experimental methods to determine the vibration characteristics of this type of structure.

The purpose of this project was to set up a virtual instrumentation and data acquisition technology to be used for obtaining vibration characteristic of a bell shaped-structure.

Experiment Setup and Procedure

The system consisted of a Data Acquisition (DAQ) board installed on a PC, an accelerometer, an impulse hammer, and connection cables.
LabVIEW 7.1 [1] was used for experimental measurements of the first five natural frequencies and corresponding mode shapes of a bell. The experimental modal parameters obtained by impact testing are compared with corresponding results obtained by a finite-element analysis to verify the accuracy of the experimental results.

The experiment setup of impulse excitation for this study is illustrated in Figure 1. National Instruments' LabVIEW 7.1 software and National Instruments' PCI-4474 data aquisition board are used for data collection. A bell cast from brass is used for vibration testing and modal analysis. The system collects signals from the impulse hammer (Omega's IH-101) and the accelerometer (Omega's ACC104A) attached to the outer surface of the bell rim.

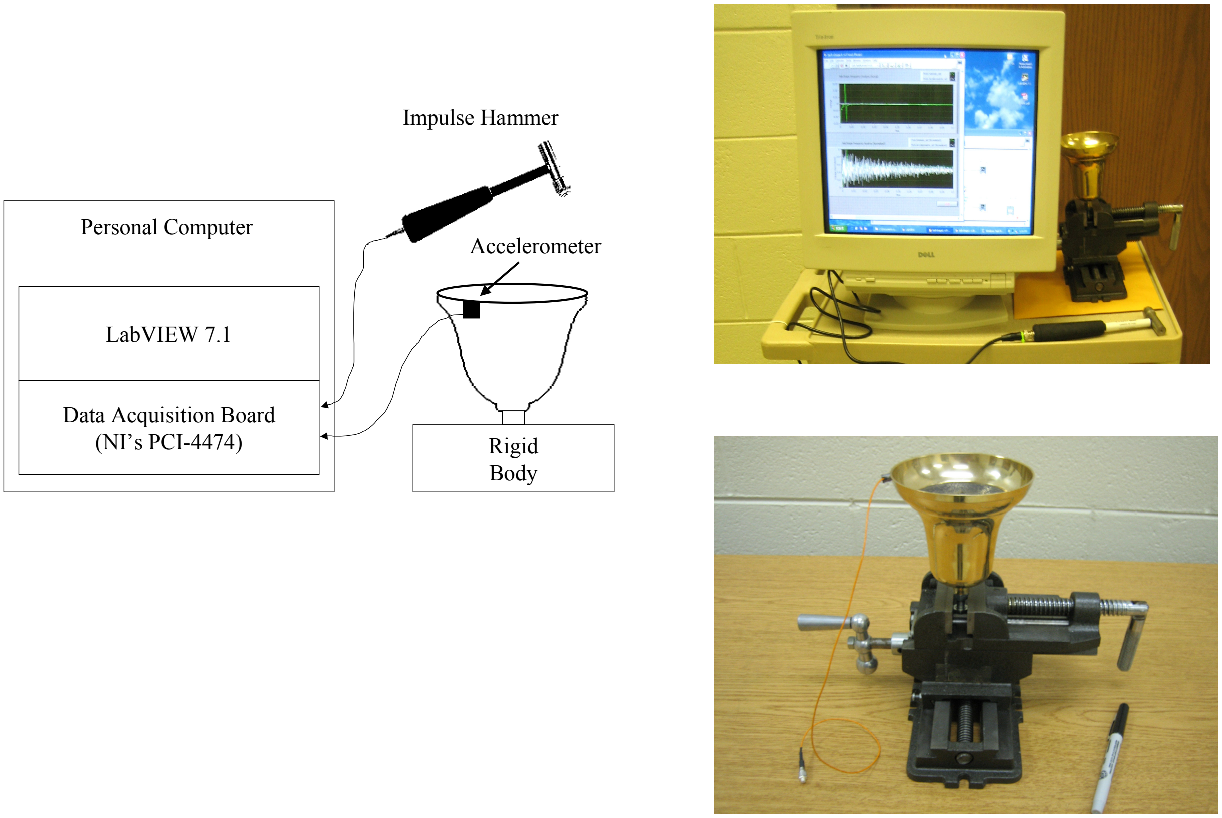


Figure 1: Experiment Setup for Impulse Excitaion

By striking the specimen at any point on its surface and displaying the response signals from accelerometer in frequency domain, the fundamental natural frequencies can be measured at resonant peaks. To illustrate the normal mode shapes corresponding to natural frequencies, the Fast Fourier Transform of signals from both impulse hammer and accelerometer should be analyzed to find the transfer function of the system. In general, such a transfer function describes the complex ratio of a resultant motion signal from accelerometer devided by an exciting force signal from impulse hammer. By using the amplitude (gain) and the phase difference of a transfer function at peak points, the damping factors can accurately be measured. The gain is usually expressed in dBs (decibels) with level of zero corresponding to an output level equal to input signal. Phase difference is expressed in degrees and represents the lead or lag of the output signal with respect to the input signal of the system.

Striking the specimen at several points on a circumferece and collecting the gain values and corresponding phase difference signs for a resonance frequency will provide data for graphing lateral mode shape for that frequency [2]. It should be noted that since the gain values are in dBs, it is necessary to calculate the linear units by applying the following formula:

$$Y = (10)^{dB/20}$$

The block diagram of LabVIEW's Virtual Instrument is illustrated in Figure 2. The analog signals (voltage) from the impulse hammer and accelerometer are digitized by the data acquisition board. The data is then saved in a file and retrieved to analyze its frequency components. The sampling rate and the recording time are 10KHz and 0.1 sec. respectively.

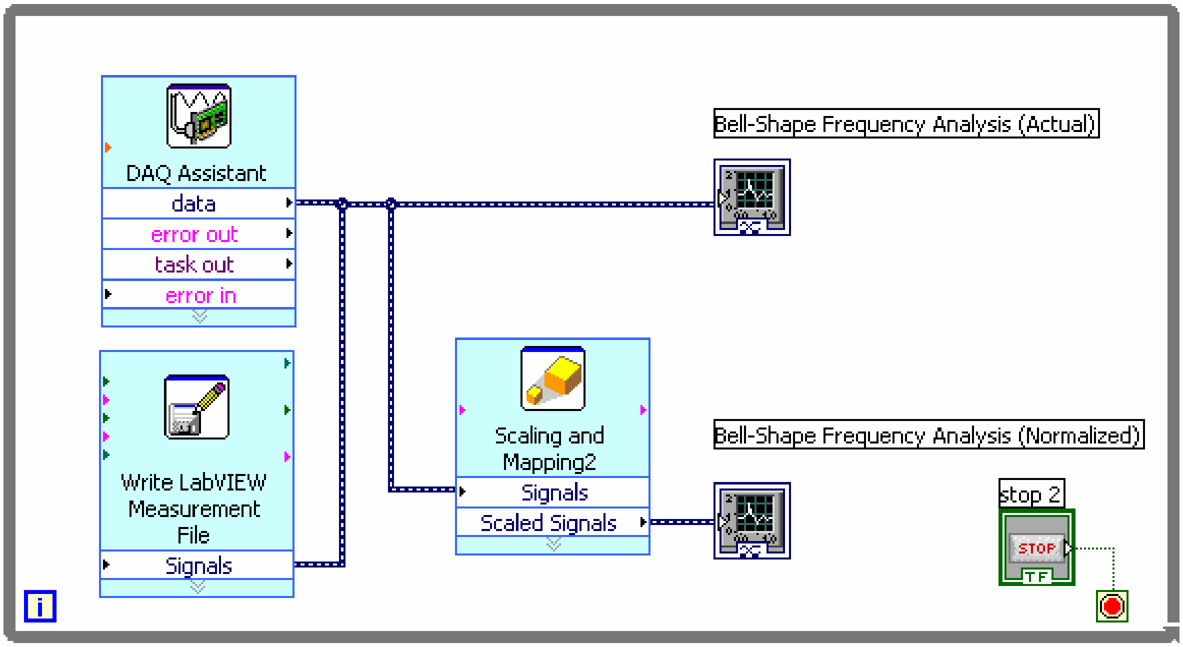


Figure 2: Block Diagram of Virtual Instrumentation

Frequency Analysis

The stored data in time domain is transformed to frequency domain using the MATLAB's fft ( ) function [3]. It is needed to measure the noise level to compute Signal-to-Noise Ratio. Figure 3 shows the noise level of both the accelerometer and impulse hammer when there is no exitation applied. Noise levels are about 0.1mV peak-to-peak and the offset voltage is –0.13 mV for the accelerometer. The sampling rate and the recording time are 10KHz and 0.1 second respectively.

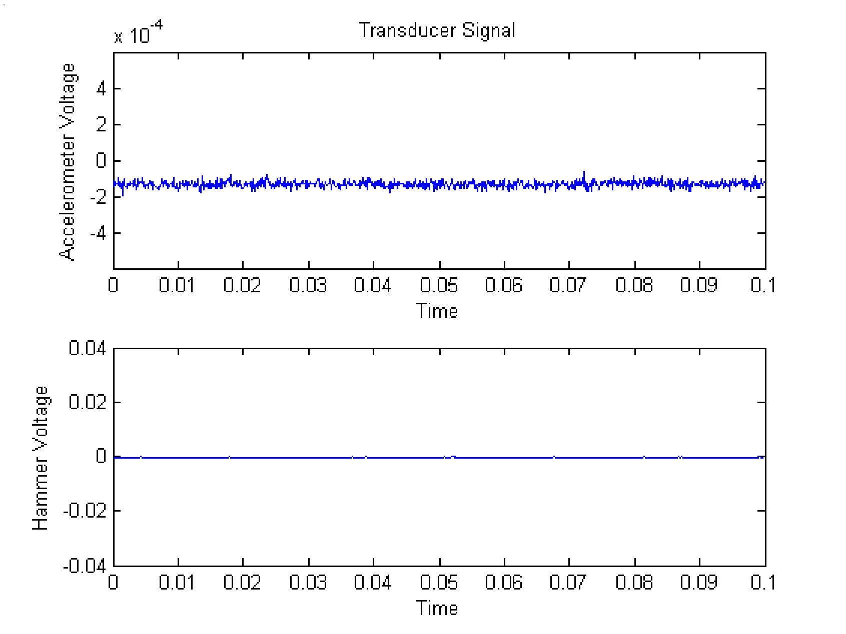


Figure 3: Noise Level signals of accelerometer and impulse

Time domain voltage signals of the accelerometer and impulse hammer for a sample test are shown in Figure 4. The duration of the impulse signal is less than 10 ms. The accelerometer signal has 1mV peak-to-peak and decreases gradually. This figure illustrates that the recording time of 0.1 sec is enough to store the meaningful data.

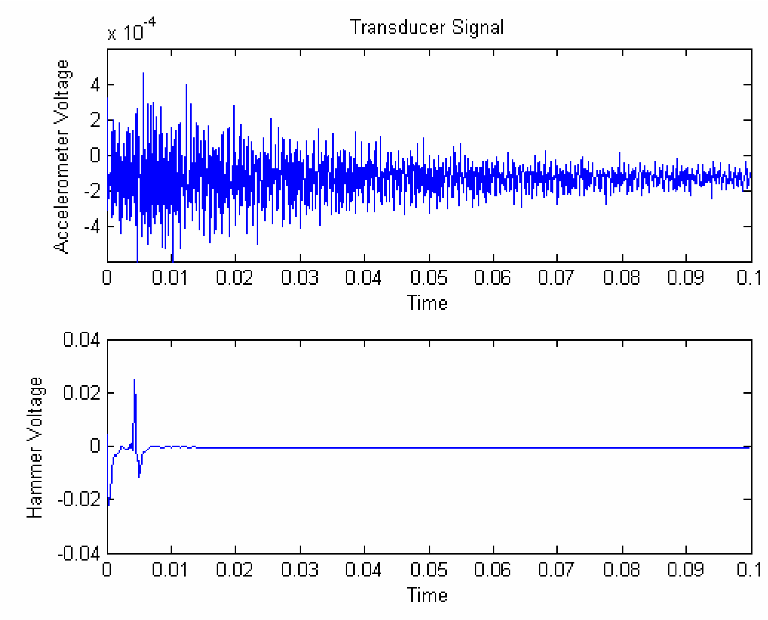


Figure 4: Voltage Signals in Time Domain

The fundamental natural frequencies of the model can be predicted from the frequency domain of the accelerometer response. The bell was exited from different position and the predicted frequencies were almost the same in all cases. Figure 5 illustrates accelerometer responses in frequency domain for two different excitations.

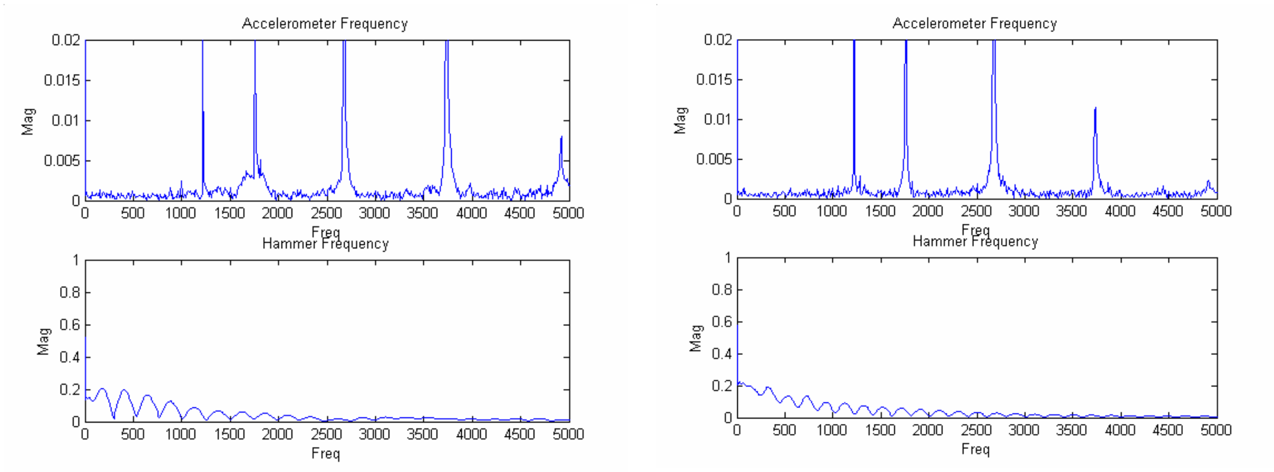


Figure 5: Frequency Responses of Accelerometer

To determine the circumferential mode shape corresponding to a natural frequency of the model, a large number of repeated tests are required. Fixing the accelerometer on the bell rim, striking the model at different points on the same circumference, and using transfer functions will show how the stroked points will be deflected relative to the accelerometer's position. Figure 6 illustrates the transfer functions of the amplitude and phase for a sample test.

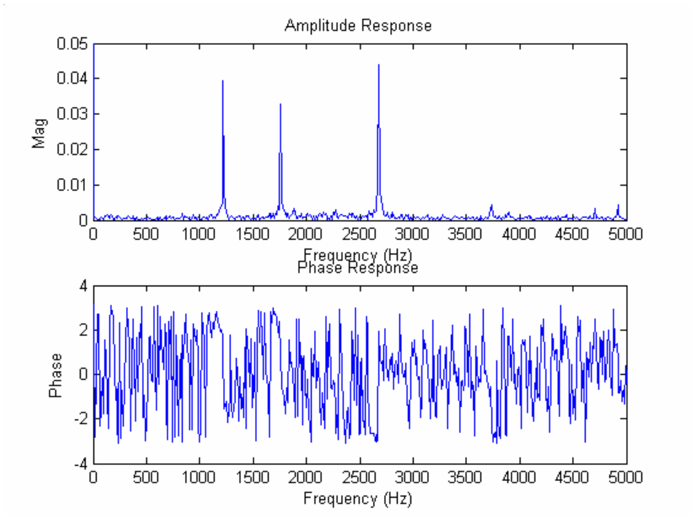


Figure 6: Transfer Functions of Amplitude and Phase

The analysis of captured signals from accelerometer responses and transfer functions gives the same five natural frequencies of the model as shown in Table 1.

Table 1: Natural frequencies of the model (Experiment)

Frequencies Hz	1220	1760	2680	3745	4935
Ratio to the First mode	1.00	1.44	2.20	3.07	4.05

Numerical Analysis

A commercial FEA package (COMSOL Multiphysics 3.2) [4] was used to find the natural frequencies and corresponding mode shapes of the model. The thickness of the model varied from 0.06 in. at open side (sound bow) region, to 0.15in. at the close side (hanger) region. The material properties of the specimen used for analysis are shown in Table 2.

Table 2: Material Properties of the Specimen

Young's modulus (E)	16.7 E6	lb/in^2
Density	0.32	lb/in^3
Poisson's ratio	0.3	

In this study, the model was meshed into 1700 elastic shell elements with 3360 degrees of freedom. The profile geometry and generated finite elements of the model is shown in Figure 7.

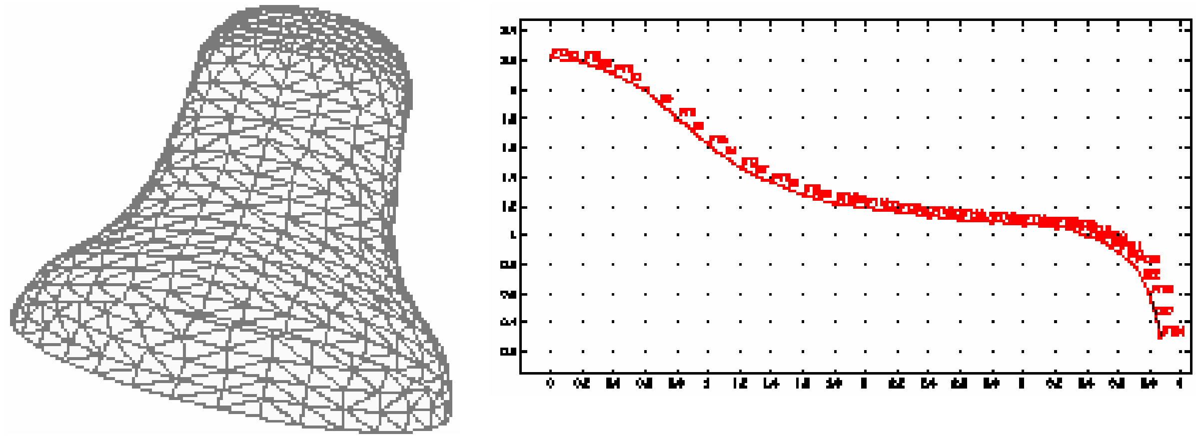
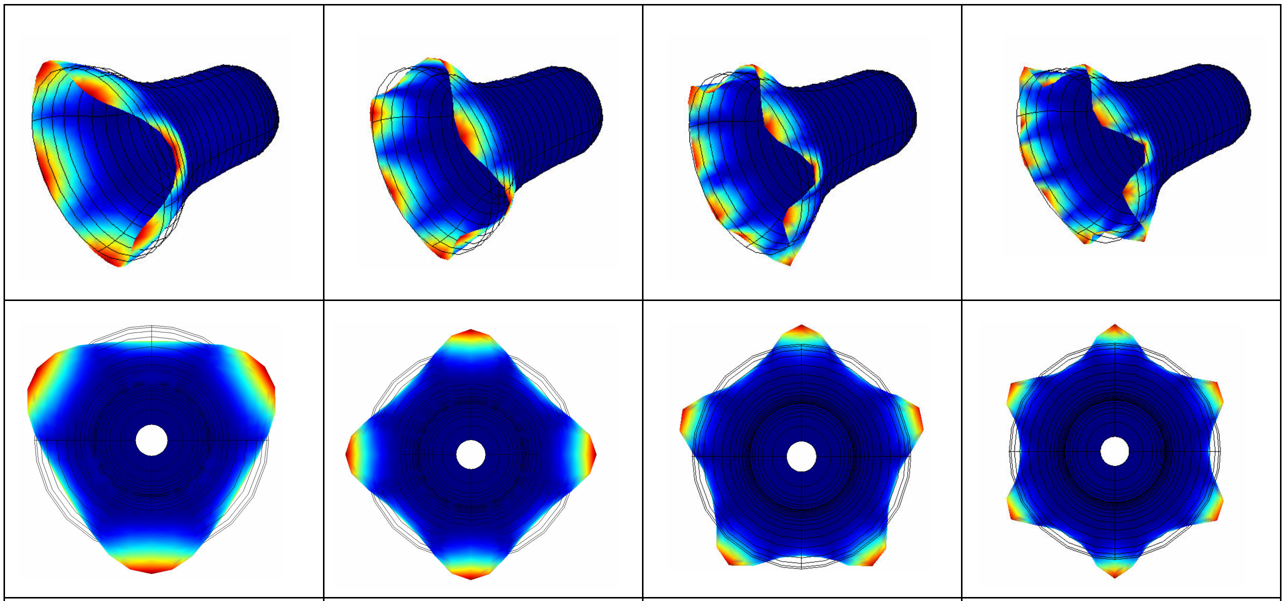


Figure 7: The profile geometry and generated finite elements of the model

The FE analysis was done to find the targeted eigen frequencies and corresponding eigen modes. The graphical results for the first four predicted lateral resonance frequencies and corresponding mode shapes are illustrated in Figure 8.



2287 Hz | 3061 Hz | 4635 Hz | 9028 Hz

Figure 8: Fundamental Frequencies and Corresponding Mode Shapes by FEA

Results and discussion

Figure 8 shows the harmonics mode shapes for the first four lateral vibration modes. These are 3rd, 4th, 5th, and 6th harmonics mode shapes. The ratio relationships of these frequencies lead to the estimated 2nd harmonic frequency to be 1530.5 Hz. This is shown in table 3.

Table 3: Natural frequencies of the first mode vibration (FEM)

First Mode Vibration (one circumference node)	Harmonic number				
	2	3	4	5	6
Frequencies Hz	***1530.5****	2287	3061	4635	9028
Frequency Ratio	1.00	1.49	2.00	3.03	5.90
* This frequency was estimated					

Even though comparisons of Tables 1 and 3 show close agreements between the two results, still additional experiments are needed for comparing the individual vibration modes. The study may continue to include the prediction of the mode shapes for each natural frequency.

Conclusion

This project confirms that rapid advances in Virtual Instrumentation programs on the one hand and precise data acquisition technology on the other hand, enable the analysis of complex vibration problems to be feasible in a normal research laboratory.
Students through this project were able to build a measurement set up for a solid structure and be confident about their results by verifying their data using computer simulation. This project has also established an open-ended undergraduate research lab in the area of structural dynamics.

Acknowledgments

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