Acoustic Damage Localization for Suspension Bridge Main Cables

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Chapter 1

Introduction

1.1 Objectives

1.1.1 Phase one (Fall 2014)

The objective of the first phase of this project was to explore a practice for exciting a scale steel rod with an acoustic signal. A methodology for determining the best frequencies of propagation was developed in order to be applied to large scale system. This was to involve the testing of theoretical calculations to determine whether or not resonant frequencies could be accurately predicted using the method. Experiments were to be carried out on a small scale steel rod for several types of excitations. The results of which were to be compared to the expected theoretical calculation to verify the accuracy of the prediction method. Resonant frequencies were selected to be the best frequencies of propagation due to the fact that they cary the best in a medium. Injection of a signal at the resonant frequency of a medium would require less amplitude than other spectra and might result in a stronger response of returned signal.

Chapter 2

Frequency Predictions

Modal Analysis Modal Analysis is the analytical evaluation of the modal shapes and natural frequencies a vibrating system assumes. This type of analysis is important in this investigation because it can determine fatigue or failure in a structure. Theoretical frequencies are calculated using modal analysis for predetermined modes. These theoretical results are compared with experimental results to determine accuracy. Utilizing vibrational waves through a structure, any anomalies or inconsistencies within the material's natural frequencies can be seen then as fatigue, fracture, or break. Both transverse and axial waves were used as vibration stimuli in this report. A transverse wave is a moving wave where the particle displacement motion oscillates perpendicular to the direction of propagation. Where as an axial wave is a moving wave where is the particle displacement oscillates parallel to the direction of wave propagation.

Wave Speed Any sinusoidally oscillating system governed by Equation 1, which is the second derivative of the progressive wave function Equation 2, with wavelength λ, will travel with speed v.

$$\frac{d^2y}{dx^2} = \frac{1}{v^2}\frac{d^2y}{dt^2} \tag{2.1}$$

$$y = A\sin\frac{2\pi}{\lambda}(x + vt) \tag{2.2}$$

For a solid rod v is a function of Young's Modulus Y and the density ρ of the material, displayed in Equation 3.

$$v = \sqrt{\frac{Y}{\rho}} \tag{2.3}$$

Chapter 3

Experiments

3.1 Free Hanging Resonance Tests with a PMNT Piezoelectric Sensor

Several experiments were carried out on a 20 foot long, 1/4th inch 114R steel rod. These tests were performed in order to determine the methodology for finding resonant frequencies of the rod when excited with both longitudinal (axial) and transverse (shear) waves. The purpose of these tests was to experimentally validate the described method for determining resonant frequencies in a free hanging metal rod. Tests were performed using multiple types of piezoelectric sensors as contact microphones for observing and analyzing the response of exciting vibrations along the rod.

3.1.1 Experimental Procedure

A steel rod was suspended from 4 equally spaced laboratory stools using elastic bands in order to isolate the vibrations from the rod to the stools. This method was used in order to attempt to represent an ideal free hanging rod with no support on either end. A PMNT piezoelectric sheet was attached around the rod at one of the free hanging ends and connected to a computers sound card using a 3.5mm patch cable. The attached piezoelectric sensor and rod can be seen below in Figure 3.1 as well as the elastic suspension of the rod in Figure 3.2.

Figure 3.1: Suspension of steel test bar

Figure 3.2: PMNT Sensor placement on end of bar

The rod was excited mechanically using the strike of a hammer and a rubber mallet. With the piezoelectric sensor secured around the end of the rod as seen above, the rod was struck at the opposing endpoint using both the mallet and the hammer. This was done in order to produce an axial (or longitudinal) wave propagation down the length of the rod. The produced sound data was recorded in to individual files. The rod was then struck on its midpoint in the same manor in order to generate a transverse wave. The data was recorded for each striking surface. This procedure yielded 4 sets of sound data. The sets corresponded to metal and rubber strikes for both longitudinal and transverse excitations along the rod with the sensor recording near the endpoint.

The sensor was then repositioned to the midpoint of the metal rod. Sound data was collected once again for transverse and longitudinal excitations. Once again the endpoint of the rod was struck longitudinally using both a hammer and rubber mallet to axially excite the rod. In order to excite the rod transversely, the rod was struck on its *side* very close to the end point. These strikes were recorded individually to produce 4 more sets of data. This data corresponded to metal and rubber strikes for both longitudinal and transverse excitations along the rod with the sensor recording at the midpoint.

3.1.2 Results and Analysis

The 8 data sets from the experiment were interpolated with MATLAB and cropped to the beginning of each strike. The cropped waveform for the axial rubber mallet strike, with the sensor recording from the opposite endpoint, can be seen below in Figure 3.3.

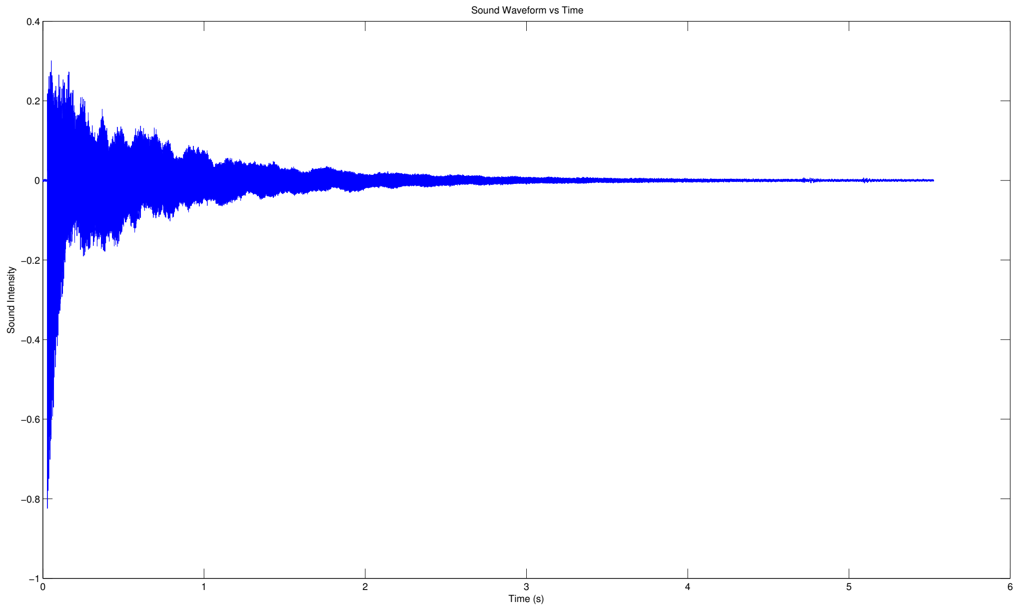

Figure 3.3: Waveform for cropped rubber mallet axial strike (sensor at opposing endpoint)

This is an example of the sound data produced for each strike during the experimental trials. Each one of these datasets was then analyzed for frequency content using the two methods of Fourier Analysis and Prony's Method. The Fast Fourier Transform was taken for each dataset and the FFT of the above axial rubber strike can be seen below in Figure 3.4.

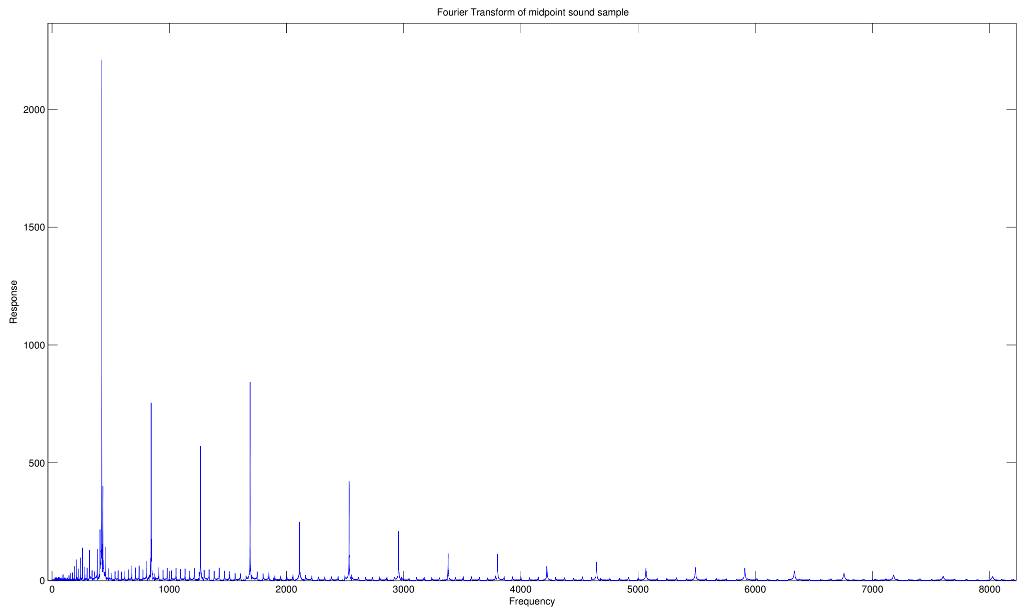

Figure 3.4: FFT for cropped rubber mallet axial strike (sensor at opposing endpoint)

Several definitive peaks can be seen steadily decreasing along the spectrum as frequency increases. These peaks correspond to the first several resonant modal frequencies of the free hanging rod in excitation. The first and strongest frequency response is seen to be at 424.8 Hz. This was repeated for each trial and the results were tabulated.

It was discovered during this analysis that several of the data sets were very noisy and it was nearly impossible to extract a pattern of frequencies. The trials which produced these results were both the transverse excitations with the sensor near the endpoint and the transverse excitation using the rubber mallet with the sensor at the midpoint. An FFT from one of these noisy data sets can be seen below in Figure 3.5.

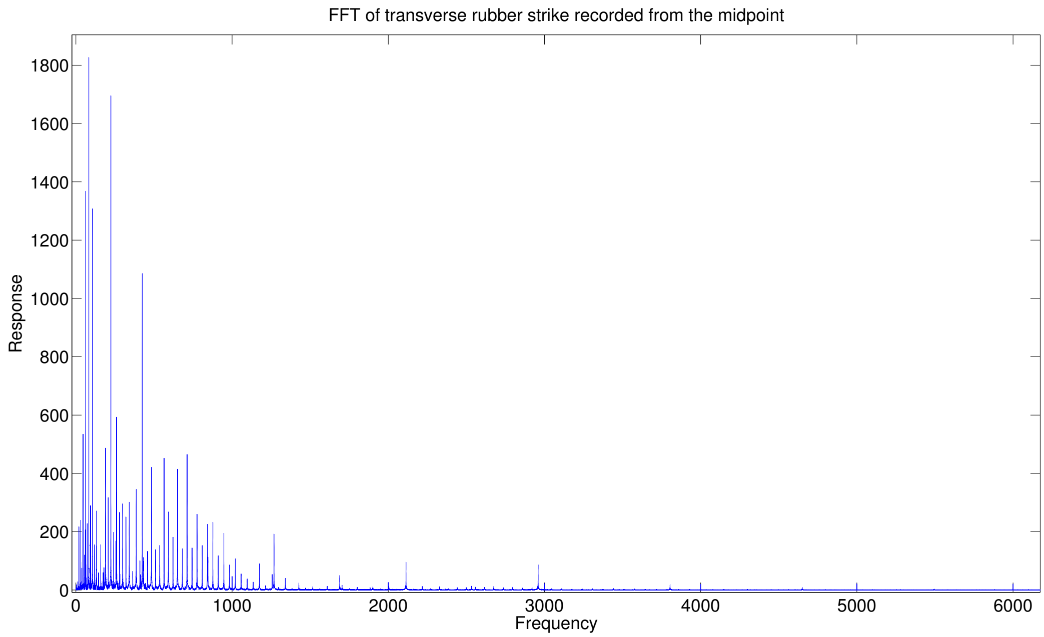

Figure 3.5: Noisy FFT data from transverse rubber mallet strike recorded at midpoint

This may have been as a result of attempting to measure transverse vibrations from an axial excitation, and a weak strike using the rubber mallet.

Prony analysis was also completed in order to determine the first and strongest 8 frequencies present in the data for each trial. In the following tables, the first 8 discovered frequencies for both the Prony and Fourier Analysis can be seen alongside the expected theoretical frequencies calculated in the previous section.

Dominant frequency	1	2	3	4	5	6	7	8
Axial midpoint Metal	424.8 Hz	845.9 Hz	1269 Hz	1691 Hz	2113 Hz	2535 Hz	2959 Hz	3379 Hz
Axial midpoint rubber	424.8 Hz	845.2 Hz	1269 Hz	1690 Hz	2114 Hz	2534 Hz	2960 Hz	3379 Hz
Axial endpoint metal	424.8 Hz	845.7 Hz	1269 Hz	1690 Hz	2114 Hz	2534 Hz	2960 Hz	3379 Hz
Axial endpoint rubber	424.8 Hz	845.5 Hz	1268 Hz	1690 Hz	2114 Hz	2534 Hz	2960 Hz	3379 Hz
Theoretically Expected	415.3 Hz	830.7 Hz	1245.98 Hz	1661.4 Hz	2076.7 Hz	2493 Hz	2907.3 Hz	3322.6 Hz

Table 3.1: FFT extracted frequencies for each trial compared to theoretically expected frequencies

3.2 Free Hanging Resonance Tests with a PZT Piezoelectric Sensor

Another series of experiments were carried out on the same steel rod as before. For these tests, a small circular (0.5cm) PZT sensor was used in place of the PNMT film. The PZT sensor was placed on the endpoint of the rod for these experiments. Attempting to place the PZT sensor on the side of the bar caused them to shatter as they are very fragile.

Several experiments were carried out on a 20 foot long, 1/4th inch 114R steel rod. These tests were performed in order to determine the methodology for finding resonant frequencies of the rod when excited with both longitudinal (axial) and transverse (shear) waves. The purpose of these tests was also to experimentally validate the described method for determining resonant frequencies in a free hanging metal rod. Tests were performed using multiple types of piezoelectric sensors as contact microphones for observing and analyzing the response of exciting vibrations along the rod.

Appendices

Appendix A

MATLAB Calculations