Validation of Heterodyning Method Using Comsol Software

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ABSTRACT

Heterodyning effect has been used for many wireless communication, electronics and ultrasound applications. When two different frequencies are applied to proper nonlinear systems, new frequency components develop at the predictable frequencies. In the experimental studies, the perfect plates without any defects behaved like linear systems. Only the applied frequencies existed when the surface vibrations were monitored. However, once a defect like a crack or debonding started to develop the structure behaved like a nonlinear system. New frequencies and their harmonics developed at the difference and addition of the applied frequencies. In this study, COMSOL Multiphysics software was used to simulate the heterodyning effect. The response of two aluminum plates were studied when the upper face of one plate was excited at two different frequencies and the response of the bottom face of the second plate at the opposite side was simulated. Similar to the experimental studies, the monitored signal had only the excited frequencies when two plates were in contact. When the distance between the plates was increased to 0.012 µm, new frequencies were developed at the difference and addition of the excitation frequencies, and at their harmonics. The numerical results agreed with our expectations based on the experimental studies.

Keywords

Structural health monitoring, heterodyning effect, COMSOL Multiphysics software, Debonding, Delamination, crack

I. INTRODUCTION

Many structural health monitoring (SHM) techniques were introduced in the last few decades. Many of them needed a baseline or reference data which was collected when the structure was at the excellent condition. The defects were detected by monitoring the difference between the monitored signal and the baseline. Recently, nonlinear methods where developed to eliminate the need for the baseline data and the false alerts related to the change of the characteristics of the structure with time without any critical defects. Nonlinear methods relied on the change of the characteristics of the structure from linear to nonlinear. Experimental studies proved that, cracks, lose bolts, debonding and delaminations make the structure behave like a nonlinear structure. These defects could be detected with the methods which can identify the change of the response characteristics from linear to nonlinear. Heterodyne method is one of these nonlinear methods. It was developed based on the detection of nonlinearity from the developing new frequencies without any restriction on the range of two or more excitation frequencies. The objective of this study was to validate the heterodyne method by using numerical methods. The study also investigated if the nonlinear characteristics of the structure could be simulated with the finite element analysis methods.

In the SHM studies, numerical methods need to calculate the response of the structure by considering that the experimental methods use piezoelectric (PZT) materials as sensors and actuators [1-6]. Since the thickness and complexity of the structures increase the computational cost, most of the works in this area used the finite element methods developed for thin plates and shells structures [7-11].

In this study, COMSOL Multi-physics software was used to represent a structure with two aluminum plate. Perfect contact of the plates and creating of an extremely small opening between them were considered.

II. MODELING PERFECT CONTACT AND MICRO SEPARATION WITH COMSOL

In this study, piezoelectric device module of COMSOL was used to simulate our piezoelectric transducers which were used as both sensor and actuator. Figure 1 shows the schematic of the simulated structure. The structure had two aluminum plates which have perfect contact. The structure had three cylindrical piezoelectric (PZT) transducers. In Figure 1 the top view of the plates is presented on the left. The plates were turned upside down, and their new view is presented on the right. Two PZTs were bonded on the top surface of the upper aluminum plate. These PZT transducers were excited at two different frequencies. Single PZT transducer was attached to the bottom surface of the second plate. This transducer was used as sensor. The simulations were repeated when the contact between the plates were perfect. Later, the distance between the plates were increased to 0.12 µm. This micro separation simulated the debonding.

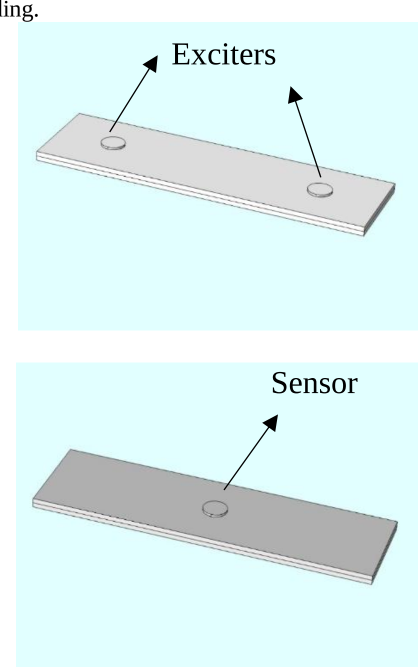

Fig. 1. Experimental setup. Two aluminum plates facing each other with 2 PZT exciters on the left and the view when the plates are turned upside down on the right.

Table 1. Dimensions of plates and PZTs

Name	Value
Length of plates	0.28 m
Width of plates	0.08 m
Height of plates	0.004 m
Radius of PZTs	.01 m
Height of PZTs	0.002 m
Voltage	100 V
First excitation freqency	1.7E5 Hz
Second excitation freqency	1.9E5 Hz
Distance between two plates	0-0.012 µm

The model was created with the COMSOL's piezoelectric device module. Time and frequency domain studies were performed. The simulated PZT transducers were made of Lead Zirconate Titanate (PZT-4) with density of 7500 kg/m3. The boundary condition of all four sides of the plates was defined with fixed constraints. The other sides were defined as free. The lower surfaces of PZTs which were attached to the plates were considered as ground with a zero charge. The upper surfaces of the exciters were charged with harmonic waves. The upper surface of the sensor was connected to the probe to be monitored. The solid model was meshed with free tetrahedral elements (Figure 2). The minimum and maximum mesh sizes were set to 450 µm and 10500 µm respectively.

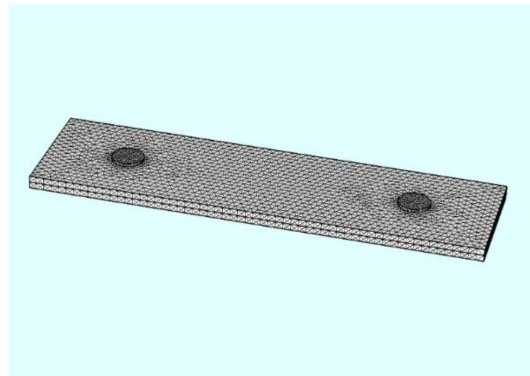

Fig. 2. Mesh structure of the finite element model.

To evaluate if the structure demonstrate the heterodyning effect, the structure was excited with two harmonic signals with different frequencies. Time domain response of the structure with two plates was captured from the PZT transducer at the bottom of the structure. The Fast Fourier Transform (FFT) of the response signal was calculated, plotted and studied. As you can see the propagation of the two harmonic signals with different frequencies was shown in figure 3.

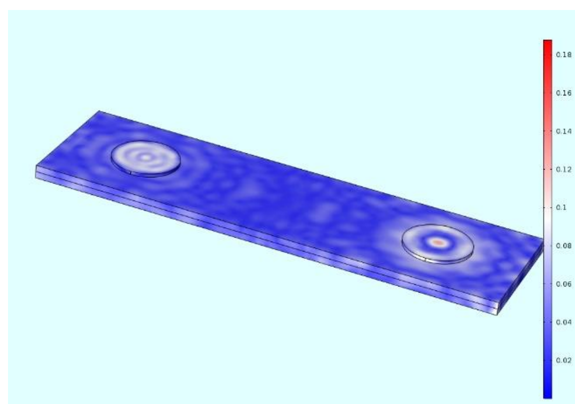

Fig. 3. Wave propagation of the two harmonic signals with different frequencies

I. SIMULATION RESULTS

In the simulations, aluminum plates with the density of 2700 kg/m3, modulus of elasticity of 70GPa, and Poisson's ratio of 0.33 were considered. Two PZT exciters at the top of the plates were excited with harmonic signals with the frequencies of 170 kHz and 190 kHz. The excitation signals had 100V peak to peak voltage. The simulate signal of the PZT attached to the bottom plate was sampled at 1MHz. First, the response of the structure was calculated when the plates had perfect contact with no separation distance between two plates. This corresponded to perfect bonding. The time and frequency domain plots of the simulated signals of the PZT transducer are presented in Fig. 4, 5.

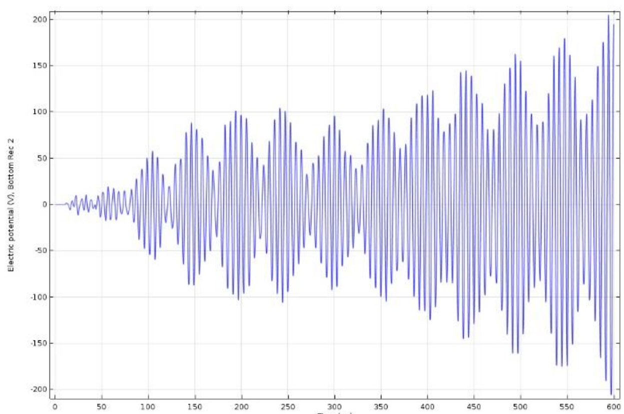

Fig4. Time domain response of the system when there is no debonding

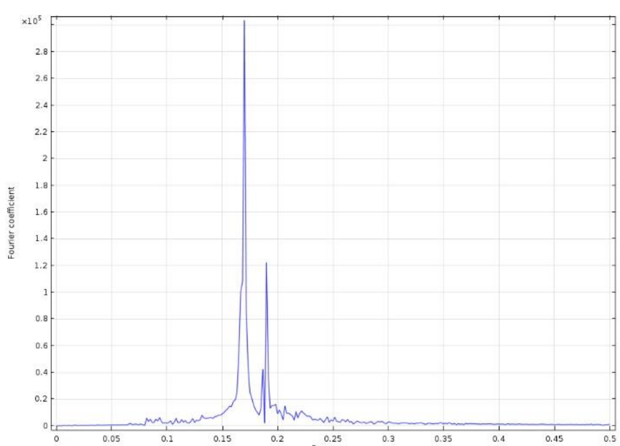

Fig4. Frequency domain response of the system when there is no debonding

The spectrum had two dominant frequencies at the excitation frequencies of 170 kHz and 190 kHz. The simulation was repeated when the distance between the aluminum plates was increased to 0.012 µm. The time domain response and FFT of the simulated sensor output is presented in Fig.6, 7.

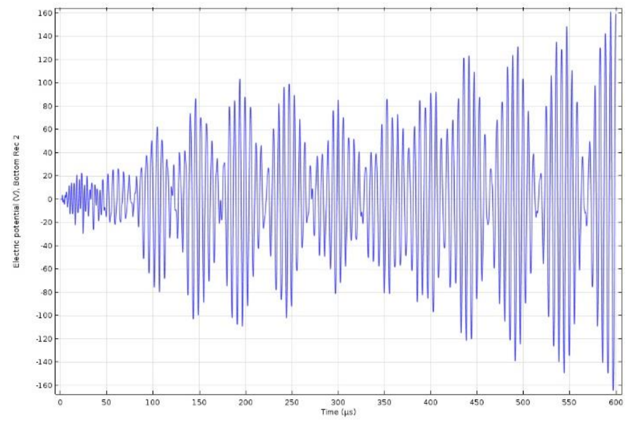

Fig. 6. Time response of the system for 0.012 µm distance between two plates

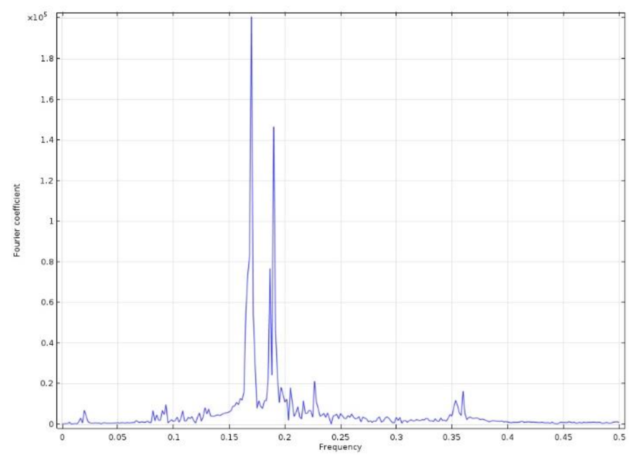

Fig. 7. Frequency response of the system for 0.012 µm distance between two plates

As it was expected, in the presence of micro separation (debonding), a small peak appeared at the difference of two excitation frequencies. The amplitude of the spike at the difference of the excitation frequencies is presented in Table 2.

Table 2. Comparing the amplitude of the peak at the difference of the excitation frequencies

Distance between two plates (µm)	Amplitude of the spike at the frequency of the difference
0	700
0.012	5600

I. CONCLUSION

Nonlinear SHM methods detect the defects from the characteristics of the monitored signal. According to the experimental studies, perfect structures behave as a linear system. Certain types of defects such as debonding, cracks, loose bolts and delaminations change the behavior of the system from linear to nonlinear.

In this study, perfect structure and debonding was simulated by using the COMSOL Multi-physics software. The FFT of the simulated sensor's data was investigated. The study indicated that two aluminum plates which are always in contact with behave like a linear system. When one of the plate is excited with two harmonic signals with two different excitation frequencies, the monitored signal of the simulated sensor which was attached to the other plate has two frequency components with the excitation frequencies.

Spikes showed up at the difference and sum of the excitation frequencies, and their harmonics as soon as the plates were separated. The spike at the difference of the excitation frequencies was very clear when the distance between the plates was 0.012 µm. The structure behaved as a nonlinear system as soon as the micro separation started. These results showed that the heterodyne method can be used for detection of debonding.

The results also confirmed that the COMSOL Multi-physics software is capable to simulate the response of the structures even if they have nonlinear behavior.

I. REFERENCES

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