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MODELING OF ULTRASONIC SPECTROSCOPY FOR DAMAGE IN MULTILAYER STRUCTURES

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ABSTRACT

There is a need for improved methods for the inspection of damage in thick composite materials with specialty coatings. This paper explores the development of numerical models on ultrasonic spectroscopy for inspection of thick multi-layer composites with damage. Initial simulated studies were found to be in good agreement with experiments, and provided useful insight on improving sensitivity to damage.

Keywords: coatings, composites, impact damage, ultrasonic spectroscopy.

NOMENCLATURE

FEM	finite element method
NDT	nondestructive testing

1. INTRODUCTION

There is a need for improved methods for the inspection of damage in thick composite materials with specialty coatings. Ultrasonic spectroscopy is a promising technique where the measured broadband frequency response can be used to evaluate the material state [1-2]. A novel swept-frequency ultrasonic spectroscopy (UltraSpec®) technique has been developed [3-4] and has demonstrated sensitivity to poor bond quality [4-9].

While nondestructive inspection technique development has often depended on experimental studies, there is a need for quality measurement models for complex problems such as the inspection of thick composites for damage. Models can be helpful to interpret raw data, to provide guidance on selecting the appropriate features for material and damage classification, and to optimize the transducer test parameters [10]. Prior work on modeling for ultrasonic spectroscopy has focused on analytical models for bonded structure [7-8,11], with limited work to date on the resonance behavior of impact damage in composites [12]. The focus of this paper is on the development of numerical models for improved representation of ultrasonic spectroscopy for thick multi-layer composites with damage.

2. MATERIALS AND METHODS

2.1 Forward Models for Ultrasonic Spectroscopy

To demonstrate the capability to simulate the UltraSpec® technique, a 2D finite element method (FEM) model was constructed in COMSOL. In this work, two test panel sets were considered, shown in Figure 1: a three-layer challenge panel and an example composite panel with a thick coating and a delamination field representing impact damage. In this work, a parametric model was implemented to study varying material properties, layer thicknesses, transducer size and position, swept-frequency range, and delamination field extent and depth.

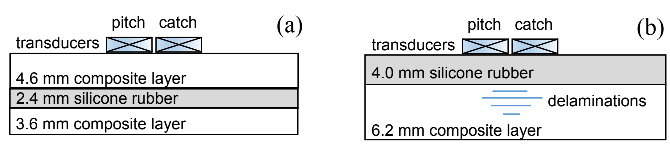


FIGURE 1: DIAGRAMS OF (a) A THREE LAYER TEST PANEL AND (b) AN EXAMPLE COMPOSITE PANEL WITH A THICK COATING AND A DELAMINATION FIELD.

2.2 Signal Processing

A continuous swept-frequency input signal from 0.25 – 5.0 MHz was used in the model, shown in Figure 2. The frequency response of the signal is shown in Figure 3. A high pass filter of 0.125 MHz was applied to reduce artifacts in the numerical simulation and better represent the experimental measurement.

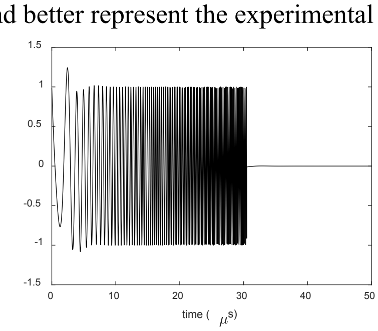
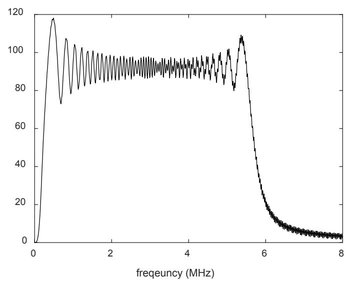


FIGURE 2: INPUT CHIRP WAVEFORM TIME SIGNAL.



(b)

FIGURE 3: INPUT CHIRP WAVEFORM FREQUENCY RESPONSE.

3. RESULTS AND DISCUSSION

Results are presented in this section for the three-layer test problem shown in Figure 1(a) only. The simulated signal for the catch transducer in the time domain is shown in Figure 4. The simulation sample rate was 40 MHz. Using the Fourier transform on the time signal, the frequency response is shown in Figure 5. With repeated reflections between the three different layers, repeated resonances associated with this spacing are observed in the frequency domain. Note, viscous damping was included in the model, resulting in a decrease in magnitude with increasing frequency.

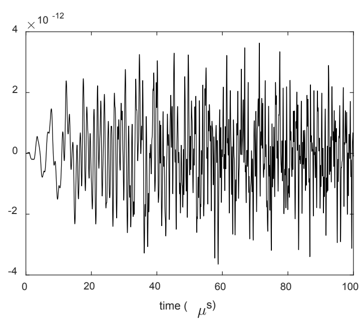


FIGURE 4: PITCH-CATCH SIMULATED RESPONSE FOR THE THREE LAYER TEST PROBLEM.

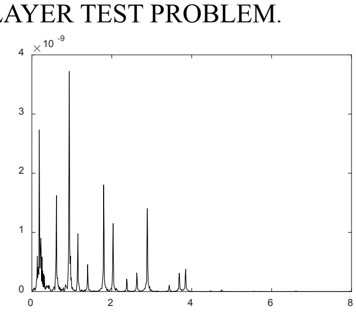


FIGURE 5: FREQUENCY RESPONSE FOR THE THREE LAYER TEST PROBLEM.

At this stage, a second Fourier transform can be applied to the frequency response to evaluate the most dominant sets of frequency spacing due to the multi-layer resonances. Resonance spacing is plotted in Figure 6. Three key layer resonance frequencies are highlighted and were found to be in close agreement with experimental resonance results: top layer = 0.33 MHz; bottom layer = 0.42 MHz; middle layer = 0.64 MHz. Remaining discrepancies are likely due to differences in the chirp signal and the material properties used for the layers. Additional results will be presented addressing the model for Figure 1(b), considering varying coating material properties, top and bottom layer thicknesses and the delamination field extent and depth.

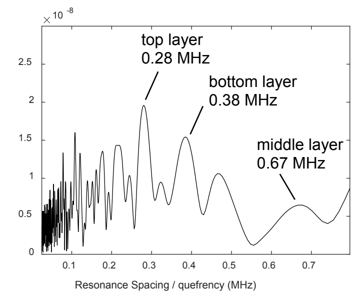


FIGURE 6: SPECTRUM RESONANCE SPACING FOR THE THREE LAYER TEST PROBLEM.

4. CONCLUSION

Introductory work was presented on the development of numerical models on ultrasonic spectroscopy for the inspection of thick multi-layer composites with damage. Initial simulated studies were found to be in good agreement with experiments. Continued work is planned to optimize the technique, in terms of transducer size and position, swept-frequency range, and signal processing, over a wide range of expected varying conditions of material properties, layer thicknesses, and delamination field extent and depth.

ACKNOWLEDGEMENTS

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