Damage Detection in Metal Structures Using Acoustic Emission

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Abstract. The structural components of many machines remain in service far beyond their designed lifetimes. This is especially true in the field of aerospace structures, where aircraft, wind turbines, satellites, and other components are expected to be in service for decades. Therefore, a good maintenance system is desired, allowing these structures further service use, while maintaining efficiency and reliability from failures. The focus of this research paper is on developing an improved maintenance system, called structural health monitoring, using acoustic emission sensors and artificial neural networks to detect and analyze any damage well before any component failure occurs. To replicate a damaged component for this study, an experiment was performed, involving thin, flat panels of aluminum with a designed, initial crack. These panels were subjected to static loads that were increased until crack propagation occurred. Acoustic emission sensors, which detect energy released by growing cracks in the form of strain waves, were used to detect this propagation and transform the characteristics of the propagation into electrical signals. These complex signals were then analyzed through an artificial neural network system, which allowed for fast post-processing. A structural health monitoring system was found to be plausible, using real-time analysis of the aluminum panel, detecting and reporting any growing crack from a size larger than 0.05 inches, well before any failure occurred. This study proved that acoustic emission could make structural health monitoring a reality.

1. Introduction

This paper summarizes the results of an investigation of the abilities of a passive ultrasonic scanning system, called an acoustic emission (AE) system to detect structure damage. This system is under development, so the objective of the research was to determine a quick, accurate, and precise method of optimizing the analysis capabilities of an acoustic emission system to form a structural health monitoring system. Using the AE system, an artificial neural network analysis (ANN) was implemented to mimic the**1.** human nervous system for quick and efficient analysis**2.** of structural components in real-time.

As a crack propagates in a material, molecular bonds are broken, releasing small amounts of energy. The energy released spreads throughout the surrounding material in the form of strain waves, or minute deformations in the material with wave frequencies in the ultrasonic range. Acoustic emission has been observed since the dawn of man, listening to structures crack and break. [1] Not until recently though has the technology been capable of detecting minute sounds. Sensors constructed of piezoelectric ceramic materials, which are unique in that a voltage is produced by the deformation of the material, are sensitive enough to detect these minute sounds that produce. The voltage produced by the sensors is recorded into a computer database for further analysis. The AE system uses piezoelectric sensors to passively "listening to" a structural component, recording the voltage generated by the deformation of the sensor as a function of time. The recorded waves are decomposed into characteristics of the strain waves, such as amplitude and duration, using appropriate software. These are analyzed to determine if cracks are present and growing, and whether the component needs to be replaced.[2]

An ANN is an analysis system, imitating the process of the brain of animals and humans, analyzing a set of inputs to obtain a desired output set. This process allows for quick, but approximate, analysis to complex problems. An ANN is capable of pattern recognition and analysis to approximate varying data sets in order to account for influence of unknown variables to reach a desired output. The ANN system seemed appropriate for analyzing strain waves, due to the complexities of the waves after traveling through a material, and the presence of white noise and other unaccounted variables.[3] Previous research had shown that there was potential in connecting ANN analysis to this form of nondestructive testing [4], allowing promise for an integrated system of AE and ANN's for a structural health monitoring of aerospace systems. The focus of this paper is on the initial stages of the analysis for a health monitoring system.

2. Experiment

A thin, flat aluminum panel (Al 2024-T3 with thickness 0.032") was used for experimentation. The panel was subjected to a uniaxial tensile load to initiate crack propagation. An initial edge crack was cut into the panel in the testing region and then the panel was statically loaded on an MTS Sintech 5/G machine through a pin and clevis setup (

Fig. 3). The loading was gradually increased until crack growth occurred. Two AE sensors continuously monitored for any crack growth during the loading process, allowing for measurements of crack propagation. The AE signals were used for an ANN at the conclusion of loading.

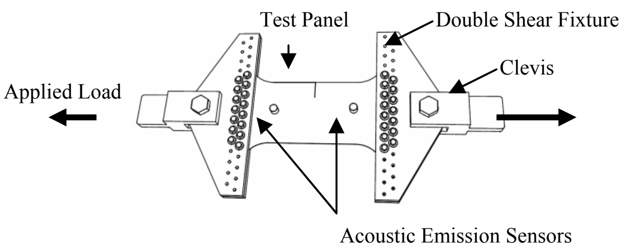

Fig. 3. Setup for test panel and AE sensors

The Physical Acoustics Corporation (PAC) software [5] was used to record the strain waves of the specimen. A typical output for the experiment is shown 3.
in Fig. 4. The results shown in this figure indicate that 4.
crack extension occurred at approximately 465 sec into the loading, when more waves were detected.

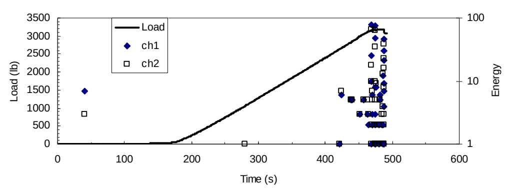

Fig. 4. Energy values of received strain waves over time

For the ANN, a sliding time window of eight seconds was implemented. A histogram of the energy values contained within the time window was created (see Fig. 5) and sorted into groups of crack growth ('yes') or noise ('no'). These were then used as input to an ANN with a self-organizing map architecture to determine groups. Each histogram then formed a data input set of eight points.

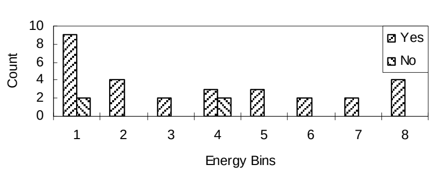

Fig. 5. Example of histograms for 'no' and 'yes' to cracks

The ANN grouped the input data sets using a Euclidean distance method [3]. Each data set was then placed onto a 2D map, which could be interpreted like a topological map, where input sets with similar characteristics were placed into similar regions. Similar to a brain, the ANN was trained with on examples of nine data sets of definite "yes" or "no" traits. After training the system was shown the other time windows, including a "maybe" region around 465 sec, placing new data points into the previous groups (Fig. 6).

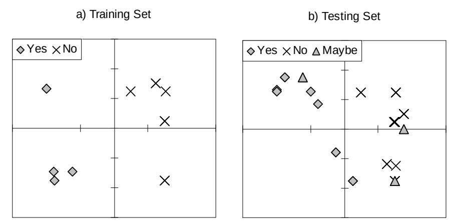

Fig. 6. Resulting maps from ANN

The results presented in Fig. 6 indicate that the combination of AE sensors and ANN can analyze the incoming detections of strain waves and distinguish crack extension from ambient noise.

Conclusion

The focus of this paper was the examination of the ability of an ANN to identify crack growth in flat aluminum panels, using signals from an AE system. Using a sliding time window of the AE sensor output with an ANN, to the system could identify the instant that the crack extended. The self-organizing map architecture of the ANN proved capable of identifying the two categories. This ANN system could be used with a network of AE sensors monitoring a structural component of an aerospace system. Future study is required to isolate problem areas and determine the severity of the crack growth. The size of time window could be reduced, allowing for detection of crack growth to be faster, approaching real time.

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[3] L. Fausett, *Fundamentals of Neural Networks: Architectures, Algorithms, and Applications*, Prentice-Hall Inc, New Jersey (1994)

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