Doctoral Dissertation
Doctoral Program in Mechanical Engineering (33rd Cycle)

Structural Health Monitoring based on Piezoelectric transducers: a Carbon Fiber Automotive Component Application case

by

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Abstract

In the recent years, the materials composing the structure of Aircraft, such as steel and aluminum, are being progressively replaced with lower density materials, as the Reinforced Plastics. The same trend is found in the Automotive field to achieve the reduction of fuel consumption and CO_2 emission. It is known that polymer composites have outstanding properties of specific modulus and strength respect to their low density but suffer more than metals from damage generation and propagation. Furthermore, defects can be included in the material during manufacturing and work as crack initiators for catastrophic delamination.

The maintenance on composite structure is therefore based on finding the defects or damages, thanks to several Non-Destructive Techniques (NDT). To optimize the maintenance on aircrafts, a variety of on-board systems has been applied for on-line Structural Health Monitoring (SHM). SHM systems based on piezoelectric transducers earned a particularly high interest for continuous monitoring on metallic and composite structures. The application of this system in the automotive sector could enhance passenger safety, through the monitoring of the vehicle structure health status.

The principle behind the system is the propagation of ultrasonic Lamb waves inside the material between a couple of piezoelectric patches that act as actuator and sensor. A difference in the vibrational behavior in time is an indicative of damage or a defect in the structure. The validation of the SHM system - composed of sensors, electronic devices and algorithms - is commonly conducted using sections of the structure or specimens with same materials and simple geometry.

In this Thesis, six mathematical models for evaluating the electrical response of piezoelectric sensors were implemented, with the aim of selecting the most effective model for damage identification. Two specific programs have been created for Off-line and On-line monitoring of the composite structures.

The preliminary tests for the system validation were carried out on three types of simple specimens of different geometries made of different materials (steel, aluminum and carbon fiber). The “beam” and “plate” specimens allowed the study the phenomenon of free propagation of the guided Lamb waves in the frequency range 1-100 kHz both in unidirectional and on the plane, evaluating their

interference with superficial and volume damages. The "simulacrum" specimen was subjected to vibrational test at different loading steps, using 4-point bending test equipment.

The specimens' configurations were necessary for the evaluation of the overall behavior of ultrasonic waves on the structures. The developed methodology was created to identify any damage generated in the bending loading on an innovative Automotive component, a carbon fiber leaf spring suspension. The types of damage and the geometries studied in the Thesis are depicted in Figure 0.1.

Figure 0.1 – Damage types and geometries studied in the Thesis

A correlation study has been carried on the virtual simulation of the vibrations generated by the piezoelectric transducers for the evaluated geometries, in order to support the positioning of sensors on the component to be monitored.

The proposed numerical-experimental methodology is an essential foundation for the monitoring systems based on piezoelectric transducers in the Automotive sector.