Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 5 (2017) 131–138

Structural Integrity Procedia

www.elsevier.com/locate/procedia

2nd International Conference on Structural Integrity, ICSI 2017, 4-7 September 2017, Funchal, Madeira, Portugal

Anomaly detection in composite elements using Lamb waves and soft computing methods

Piotr Nazarko*, Leonard Ziemiański

Rzeszow University of Technology, Powstancow Warszawy 12, 35-959 Rzeszow, Poland

Abstract

Composite materials are widely used in many important structures, which in turn entails the need to develop sensitive and reliable structural health monitoring (SHM) systems. The aim of this study was to investigate the use of guided waves and artificial neural networks as essential components of a two-stage diagnostics system. This system was designed to detect anomalies and to assess their parameters. This paper presents the first result of the application of this system for evaluation of samples made from composite materials. Defects of various origin were artificially introduced. Grids of 8 and 12 piezoelectric transducers were used. Principal components analysis was used for dimensionality reduction of measured signals. Examples of preliminary fault detection results showed that any signal anomalies are detected perfectly whereas the prediction of damage level allowed to distinguishing the defects. Successful experiments carried out on the studied specimens have already proved that this system was able to perform automatic analysis of the elastic waves and accelerate the process of structures diagnosis.

Peer-review under responsibility of the Scientific Committee of ICSI 2017

Keywords: Novelty detection; neural networks; structural health monitoring; composite materials; PCA

1. Introduction

Composite materials, due to their durability, strength and relatively low weight by volume, for many years have been used in the transport industry (aviation, road vehicles, railway). Recently they have become popular also in the construction of buildings, especially as structural components of bridges (e.g. box girders). However, the manufacturing process of these materials and their subsequent use carry the risk of latent defects such as voids,

* * Corresponding author. Tel.: +48-17-865-1621; fax: +48-17-865-1723.
E-mail address: pnazarko@prz.edu.pl

2452-3216
Peer-review under responsibility of the Scientific Committee of ICSI 2017
10.1016/j.prostr.2017.07.080

inclusions, delamination, cracks, chemical corrosion, etc. This of course may endanger the safety and reliability of structures, because this type of defect is usually difficult to detect during scheduled visual inspections. Therefore, many research centers make an effort to develop measurement methods sensitive to such defects. At the same time, continuous health monitoring systems require the diagnostic process which is able to operate automatically in real time. In this situation, solutions based on the phenomenon of propagation of elastic waves with inference based on soft computing methods successfully find their application - Liu et al. (2013), Su and Ye (2005).

The phenomenon of elastic wave propagation is widely used in both non-destructive evaluation (NDE) and structural health monitoring (SHM), see Michaels et al. (2014). This approach assumes that the anomaly appearing in the structure (fault condition) can be detected and identified on the basis of measured signals analysis. In order to actuate and to sense the elastic wave signals a surface-mounted piezoelectric transducers are used. It enables easy integration of the sensing and actuating devices into the monitored structure and setting up the control points in areas that are hidden or inaccessible for most of NDE techniques (i.e. visual inspections, penetration, current edge, thermography, ultrasounds).

Structure reliability also depends on the precision of the diagnosis systems employed hence a signal processing plays major role in damage detection. Since the reflections and dispersion effects may produce quite complex signals, the determination of parameters suitable for such a purpose more and more often requires the application of advanced signal processing techniques (Yu and Giurgiutiu 2005). In this case data filtering, their different transformations (Fourier – Liu et al. 2013, Hilbert - Yu and Giurgiutiu 2005, wavelet - Taha et al. 2006) and statistical analysis (PCA/ICA) (Hernandez-Garcia et al. 2007) are commonly used. Signal processing of the diagnostic system discussed in this paper, utilizes a low-pass filtering, signal decimation and the PCA.

The main advantage of current development of SHM systems is their ability to perform automatic signal analysis and damage identification, significantly reducing the human factor. For this purpose an approach of novelty detection and damage evaluation is proposed in this paper. The main idea is to use a data set of signal parameters obtained from a reference structure (e.g. undamaged, numerical model, laboratory tests) and to use soft computing methods (Waszczyszyn and Ziemiański 2001) in order to warn about the damage appearance and to predict its type, location and extent. In this manner Neural Networks (NNs) can perform automatic analysis of the elastic waves and accelerate the process of structures diagnosis. Martin et al. (2005) have used NNs for 3-by-3 strain sensor array. They reduced the number of channels of data acquisition from N^2 in a conventional system to 2N in the artificial neural receptor system. Similar conclusion was reported by Kirikera et al. (2006) who proposed structural neural system (SNS) that can perform passive acoustic emission sensing or active wave propagation monitoring.

This paper presents an efficient diagnostics system for processing Lamb wave signals in SHM. It is based upon Nazarko and Ziemiański (2015), where two examples of GFRP composite specimens (strip and plate) were studied. The current paper includes the following additional research: prediction of a damage type in the GFRP plate and preliminary results of tests carried out on a CFRP plate equipped with 12 piezoelectric transducers. Anomalies considered (i.e. thermal, chemical corrosion, impact, stress field concentration) were artificially modelled and introduced to the specimens investigated. So far, the results of the study proved that signal anomalies are detected perfectly whereas the prediction of the damage level was allowed to distinguish the defects introduced.

2. Two-stage diagnostic system

The diagnostic system proposed by Nazarko (2013) has been firstly designed for one-dimensional specimens, but recent studies reported (Nazarko and Ziemiański 2015) that this system can also be used to structural health monitoring of 2D models. The system consists of two stages which are intended to provide qualitative and quantitative evaluation of the studied specimen integrity. The main task of these modules is to signal the presence of damage and to predict its parameters. A simple scheme of the functioning of the system is shown in Fig. 1.

The recorded structure responses were then subjected to a procedure of signal processing (decimation, filtering, etc.) and features extraction (PCA). A defined pattern database was then used to train the certain elements of the