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INFLUENCE OF FREQUENCY AND DAMAGE INDEX ESTIMATION METHOD ON THE PROBABILITY OF DETECTION OF FATIGUE CRACKS BY A SPARSE ARRAY SHM SYSTEM

Lucas Dorneles[1], Henrique Oliveira, Thomas Clarke
LAMEF, UFRGS
RS, Brazil

Fernando Dotta, Leandro Coutinho, André Tamba, Ricardo Rulli
Embraer
São Paulo, Brazil

ABSTRACT

In this paper the probability of detection of fatigue cracks in complex aeronautical aluminum panels by a guided wave structural health monitoring system is evaluated. The effects of operating frequency and sensor positioning relative to the defect were quantified, and showed a marked influence on the results. Different methods of calculation of a damage index and their corresponding thresholds were considered, and their effect on the sensitivity of the system to the defects was also evaluated.

Keywords: Guided Waves, SHM, Probability of Detection

NOMENCLATURE

SHM	Structural Health Monitoring
POD	Probability of Detection
DI	Damage Index
RMS	Root Mean Square
LAD	Length-at-Detection

1. INTRODUCTION

Structural health monitoring methods are those that are able to provide continuous data from a structure in order to evaluate its present condition and estimate its future availability [1]. Industrial application of structural health monitoring (SHM) systems requires detailed knowledge of their reliability and sensitivity to the sort of defect leading to the failure mode of concern. In this sense, probability of detection (POD) curves are often referred to as a way of quantifying the performance of a system; these are usually obtained through measurements on an adequate number of sensors containing a distribution of representative defects of varying severity [2].

Guided wave SHM is attractive due to the possibility of covering large or inaccessible areas from a reduced number of sensor locations, and several groups worldwide focus on the development and application of this method [3]. However, due to the high costs involved and useful information they carry, POD studies are usually considered to be sensitive information and few publications are found on this topic especially for guided wave SHM.

This work aims at showing the influence of operating frequency and sensor positioning on the resulting POD curves of fatigue cracks by a guided wave SHM system on aeronautical aluminum panels. Different signal processing methods were also evaluated in order to extract meaningful damage index values which could be processed to extract POD curves.

2. MATERIALS AND METHODS

2.1 Experimental setup

A dense mesh of piezoelectric sensors was attached to 20 aluminum test panels, always in the same regular arrangement. The density of the mesh allowed for selection of any given number and combinations of pitch-catch pairs. The samples had a machined notch in the central rivet hole, and they were loaded in fatigue on a testing machine.

Initially, the CDP was subjected to 4000 traction cycles for stress relaxation of the samples. Then baselines were acquired, starting with the temperature of 22ºC, with acquisition of signals at each step of temperature of 1 ° C, ending at 26ºC. All data readings and baselines acquisitions were performed with the CDP on the testing machine with the actuator wedge of the machine released. The temperature during data acquisition was kept within the baseline temperature range.

The fatigue test had five stages of crack propagation. At each step of the test the crack size was measured and full data acquisition was performed.

2.1 Data Analysis

Signals and baselines were processed according to well-established baseline stretch and subtraction algorithms [4]. The resulting residual signal was processed in three different ways in

[1] Contact author: lucasdorneles@ufrgs.br

order to extract different so-called damage index values. The first involved simple maximum amplitude of the first arrival which corresponded to the S0 mode (frequency-response and mode purity of the transducers was characterized and will be given). The second processing method involved taking the RMS of an automatically generated window, which had its central time value defined through previously measured S0 group velocity, and its length defined as that of the excitation signal, which was a 5-cycle toneburst centered at 5 different frequencies between 150kHz and 350kHz. The third method involved quantifying the RMS of the power spectrum of the same window described for the second method.

For the analysis of POD, it was considered that the methodology in [3] is not immediately applicable to the specific case of guided wave SHM, since it assumes premises which are not fully valid, such as the independence of all system variabilities, in addition to considering that only one evaluation is done each time for each defect, whereas in this case a crack is monitored (i.e. multiple measurement for each crack size). Hence, for this application the Length-at-Detection method, also known as One-Sided Tolerance Intervals [5] was used, which assumes that each crack has a certain random length at which it will be detected. POD curves were obtained based on the estimation of the confidence interval distribution as in [6], through Eq. (1):

$$L_{(90,95)} = \bar{X} + (K_{n,0.95,0.9})(\sigma) \qquad (1)$$

where, $L_{(90,95)}$ is the crack length for 90% POD and 95% confidence, $\bar{X}$ the mean of lengths at detection, K a probability factor in function of sample size (n) for a confidence level of *0,95* and detection POD of *0.9*, and σ is the standard deviation of detection lengths.

3. RESULTS AND DISCUSSION

The three methods for damage index estimation generated results as a function of crack length and for the 5 different excitation frequencies. Different subsets of the array were also evaluated and their results compared. Selected results were processed at different threshold levels to produce a large number of detection distributions which were then used to generate POD curves for different threshold values and for combinations of sensor subsets, excitation frequencies and DI extraction methods.

Results show a marked influence of sensor subset selection. As expected, the greatest sensitivity (lower $a_{90/95}$ value) was for the combination of pitch-catch pairs which had the crack lying within their propagation path. When other transducer pairs were included, dispersion in the results increased substantially, leading to difficulties in establishing adequate POD curves.

POD curves were also evaluated for different excitation frequencies by normalizing crack-size by the wavelength of their corresponding center frequency. These results show that higher frequencies had higher values of $a_{90/95}$. This is thought to be due to diffraction effects at the crack leading to increases in detectability for given frequencies.

When different DI calculation methodologies were compared only minor differences were seen between POD curves, indicating that the three methodologies were equally efficient as ways of quantifying crack growth.

4. CONCLUSION

A method for calculation of POD curves for guided wave SHM was implemented and tested for different excitation frequencies and DI calculation methodologies. Results show a substantial influence of pitch-catch transducer pair selection and a considerable effect of excitation frequency, especially due to the marked influence of diffraction effects at the crack region. There is a need to improve the method, in addition to further investigation of alternative methods, such as supporting model analysis, ie, applying MAPOD.

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