TEMPORAL INFORMATION EXTRACTION METHODS FROM DEGRADED ULTRASONIC SIGNAL APPLIED TO AIR COUPLED NDE

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Abstract

Several authors are working in the possibility to use air-coupled medium in ultrasonic non-destructive testing. These studies are offering important industrial applications in a near future such as aerospace, naval and automotive. However, at present several experimental prototypes have been developed only at a laboratory level.

The Time-Frequency characteristics of ultrasonic signal present valuable information pertaining to the characterization of materials and detection of defects. In this paper, our first interest is focused on the time characterization of the ultrasonic signal propagating in different materials in order to determine material properties and to identify inside and/or surface defects so as to predict and prevent failure of structural systems. The method is based on extract information of the test sample material from: Maximum value of ultrasonic signal, Energy, Number of times that exceeds a certain amplitude and Time delay. Experimental images results are obtained and compared. The other interest is the study of the effect of noise in these time characteristics of the ultrasonic signal.

It is shown that the Energy of the ultrasonic signal is the parameter which give the best information of the material characteristics and this parameter is not very affected by the inherent noise of the system.

The aim of this process is the establishment of an optimal automated system of materials inspection when the environment is more affected by noise.

Introduction

The ultrasonic non-destructive testing [1-3] is an essential tool for the quality control in the manufacturing of high expensive products, such as the control of welds in the refrigeration systems pipelines of thermal and nuclear head plants. This inspection tool is also very important in the production of aeronautical structures based on resins reinforced by carbon fiber. In the ultrasonic inspection of large structures, it is necessary high speed of inspection and precision while keeping the cost of the tests as low as possible. Conventional methods of non-destructive testing demand a certain coupling medium between the transducers and the material under inspection, generally a thin layer of liquid or gel is used; this makes them ineffective for a rapid inspection, specially when we are trying to evaluate surfaces with irregularities. For this reason, the automation of the inspection turns out to be complicated.

An alternative solution that solves the coupling of the acoustic energy is the utilization of a water jet or the complete immersion of the transducers and the material to be evaluated inside water. Unfortunately, this system can not be used when the specimen under study is composed of honeycomb-shape structures. In this case, is used a manual inspection with gel as a coupling medium. A way of proceeding in conditions similar to that of the water jet is the air coupling [2]. However, the potential advantages and limitations of using air coupling in non-destructive material inspections have been studied to a great extent in the literature. In particular, air coupling was found desirable in applications involving the inspection of materials that could not be immersed in water or that would be damaged by physical contact with an ultrasonic transducer [4]. Such materials include propellants, certain wood and paper products, foams, art objects, and many advanced composite materials used by the aerospace industry. A major difficulty of using air coupling in non-destructive testing is the 140-dB reduction in the available signal [5] when compared with standard water-coupled systems. This arises from air attenuation and impedance mismatch between the transducer/air/test specimen interfaces. Due to these high insertion losses, a solution has to be found in order to provide the signal with a signal-to-noise ratio (SNR) large enough for good quality signal processing and imaging. The solution of this problem involves the improvement of the impedance matching between the transducer and air by means of matching layers [6,7] or the use of efficient capacitive ultrasonic transducers [8,9], the excitation with high voltage spikes of the transmitter transducer [10] and use of extremely low-noise receivers [11].

In this paper, two air-coupled ultrasonic measurement setups are studied: through transmission and Lamb waves inspection in order to extract the information of flaws from ultrasonic signals received by non focused piezoelectric transducers. The main goal in this work lies in the time characterization of ultrasonic signal propagating in different materials and the study of noise effect in these time characteristics of the ultrasonic signal. This characterization will proved us with a dear identification of inside and/or surface defects in order to predict structural failures in systems.

Experimental Setup

Several through transmission experiments were performed with the set-up shown in Figure 1. A pair of ultrasonic transducers are aligned on opposite side of a test sample which is mounted to a computer controlled three-axis scanning system (NSK Ltd, Tokyo, Japan). The system consists of two non-focused 1MHz PZ27 piezoelectric transducers with a λ/4 matching layer and 20 mm of diameter [6,7]. A panametrics 5800 pulser-receiver (Panametrics, Waltham, MA) is used to generate the pulse excitation of the transmitting transducer with an energy of 100 μJ and a damping value of 500 Ω. The output waveform from the receiving transducers is first amplified by the ultra-low noise amplifier whose gain is 50 dB and an input-spectral noise density of 1nV $Hz^{-1/2}$[11]. Finally, The received signal was filtered and digitized by a Lecroy LT 344 digital oscilloscope (Lecroy, Chesnut Ridge, NY), the output of which is fed to the same computer that controls the scanning system.

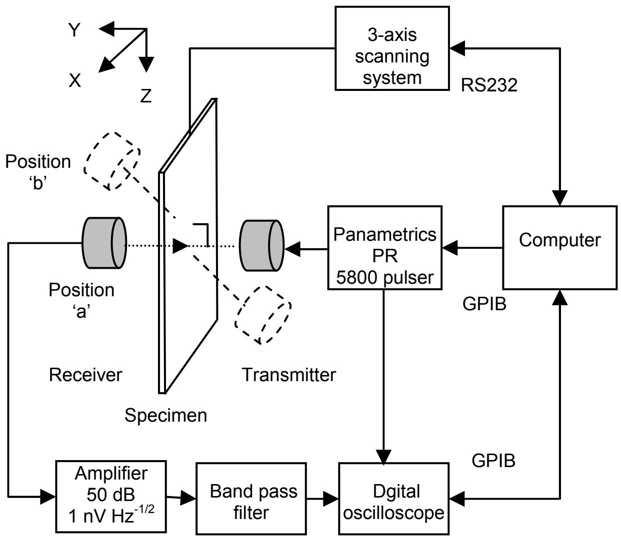


Figure 1 : Diagram of the experimental setup, position 'a' for through transmission and 'b' for Lamb wave inspection.

For Lamb wave inspection, the same experimental setup was used but with the transducers placed in position 'b', show Fig. 1, in this case transducers are placed at the correct angles for generating and detecting a particular Lamb wave mode.

Time characterization and study of noise effect

When transmitting the ultrasonic signal through a defected material, the time characteristics of ultrasonic signal are changed, from Fig. 2, we can see that, in time domain the ultrasonic signal is attenuated and displaced. The time characterization method is based on a comparative study of the received ultrasonic signals in every point of the test sample material. The object of this characterization is searching the parameter which is more affected by the change in the material characteristics, which allows us to detect the presence of a defect respect to the position in the material under study, we are interested in the amplitude of the ultrasonic signal, its energy, time delay and number of times that it exceeds certain amplitude (number of peaks).

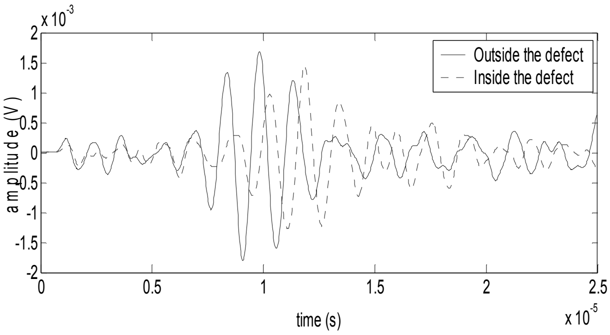


Figure 2 : Typical ultrasonic waveform

An other interest is study of noise effect in these characteristics of ultrasonic signal. The noise comes from the inspection system can be characterized as the additive white gaussian noise (WGN). Then the degraded ultrasonic signal can be modeled as

$$x(t) = s(t) + n(t)$$

where s(t) denotes the ultrasonic signal and n(t) denotes the additive WGN.

The study consist in comparing the variances of these time characteristics of the ultrasonic signal: Amplitude, Energy, Time delay and number of peaks. Variance of each parameter is calculated and plotted for different values of SNR in the range 10- 30 dB.

Images are obtained and compared. for both through transmission and Lamb wave inspections of different materials.

Experimental results

To test de validity of the air-coupled NDE inspection system, several experiments and images have been performed. The system has been tested in the through-transmission and Lamb wave mode with a 1mm thick aluminium plate containing a cross-milled on the surface. The cross-dimensions are 30 mm × 30 mm, the width is 5 mm and the defect depth is 0.5 mm. the photograph of the sample appears in Fig. 3.

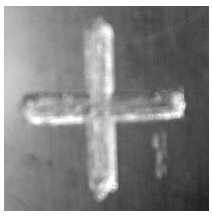


Figure 3 : Photograph of the sample to be inspected.

A). Through transmission results

In this through-transmission inspection, the distance between transducers is 5 mm. Fig. 4 shows time ultrasonic signal and its variances parameters. From Fig. 4(a), we can see that, exists great difference between measured ultrasonic signal inside and outside the defect for this test sample, therefore, all the time parameters can give information about defect. From Fig. 4(b), we see that, with a SNR of 10 dB, the variances of energy and amplitude parameters are less than that of the others parameters of the ultrasonic signal. With a SNR higher than 30 dB, all signal

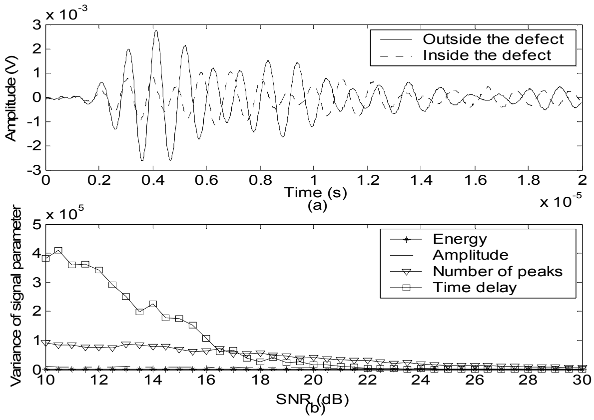
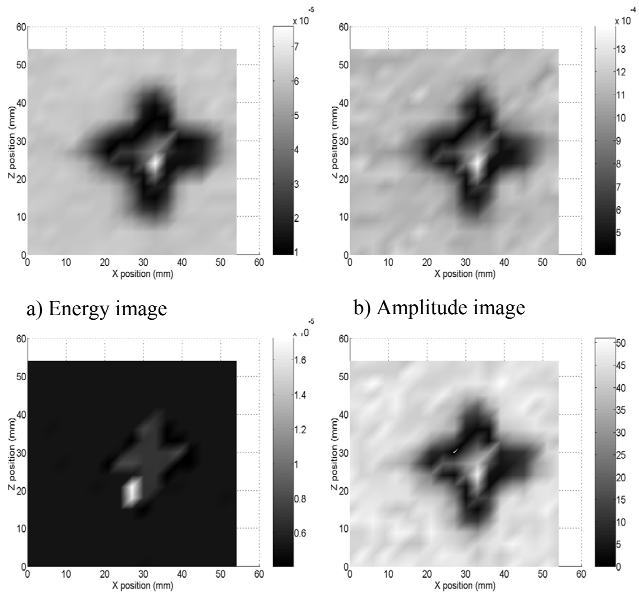


Figure 4 : Through transmission results: a) The measured ultrasonic signals, b) variance of signal parameters.

parameters have minimum variances. From these results, it can be seen the behavior of each signal parameter in function of SNR level and it can be know which parameter offer major information about test to be inspected when the ultrasonic signal is degraded.

A typical 2D scan images of this test sample shown in Fig. 3 are obtained with steep size of 3 mm. Energy, Amplitude, Time delay and peaks images are obtained and compared for an averaging of 63 and 15,

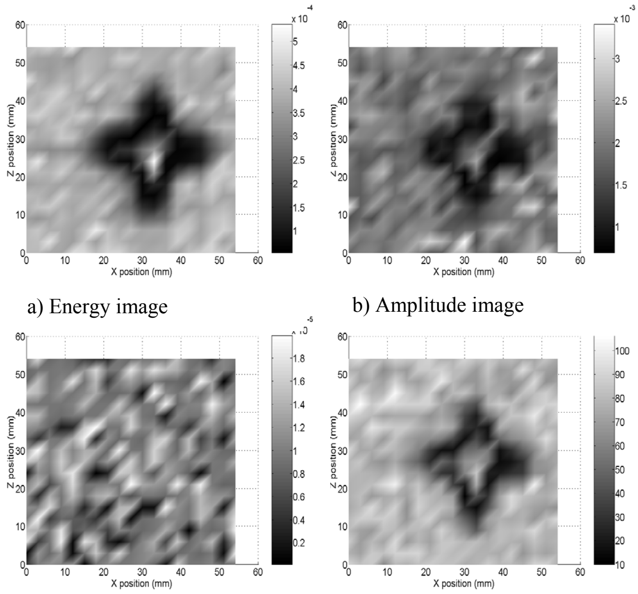


a) Energy image b) Amplitude image

c) Time Delay image d) Number of peaks image

Figure 5 : Through transmission images with SNR = 16.80 dB.

these images results are represented respectively in Fig. 5 and 6. From Fig. 5 (63 of averaging, SNR of 16.80 dB), best images are obtained and the artificial defective area is clearly identified. In the case of



a) Energy image b) Amplitude image

c) Time Delay image d) Number of peaks image

Figure 6 : Through transmission images with SNR = 11.12 dB.

Fig.6 (15 of averaging, SNR of 11.12 dB) the best images are obtained from energy and number of peaks parameters.

B). Lamb waves results

The system has been arranged to perform the Lamb wave inspection of the sample show in Fig. separation between the pair of transducers is 10 mm and the angle of incidence to generate the fundamental anti-symmetric Lamb mode a0 is 9.5°. Fig. 7 shows time

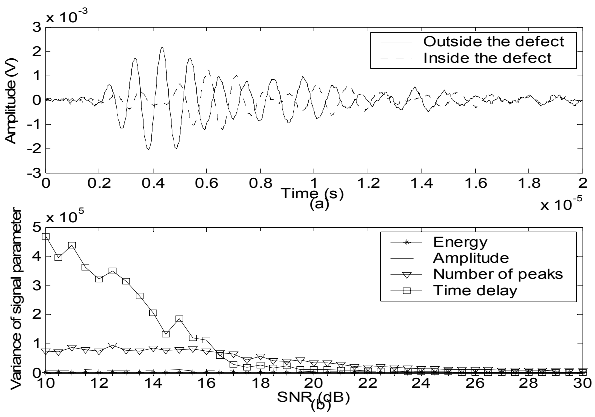
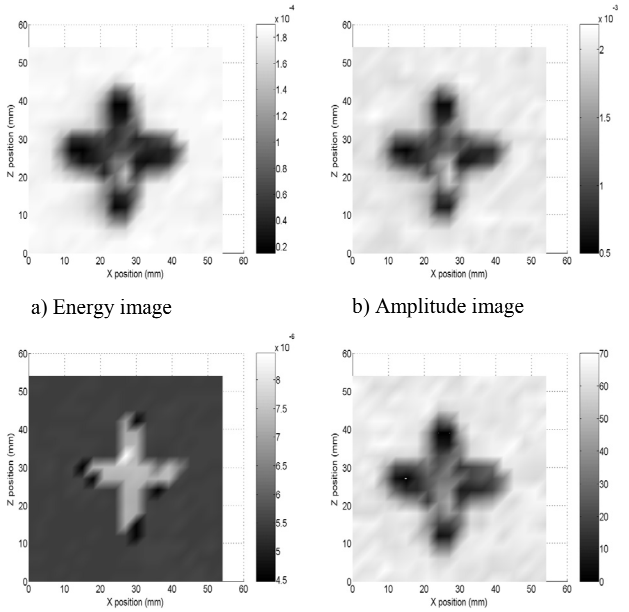


Figure 7 : Lamb wave results: a) The measured ultrasonic signals, b) variance of signal parameters.

ultrasonic signal and its variances parameters. The same remarks obtained in through transmission results are valid for Lamb wave results. 2D scan images using Lamb waves are obtained and compared for an averaging of 63 and 15. these images results are represented respectively in Fig. 8 and 9. From Fig. 8

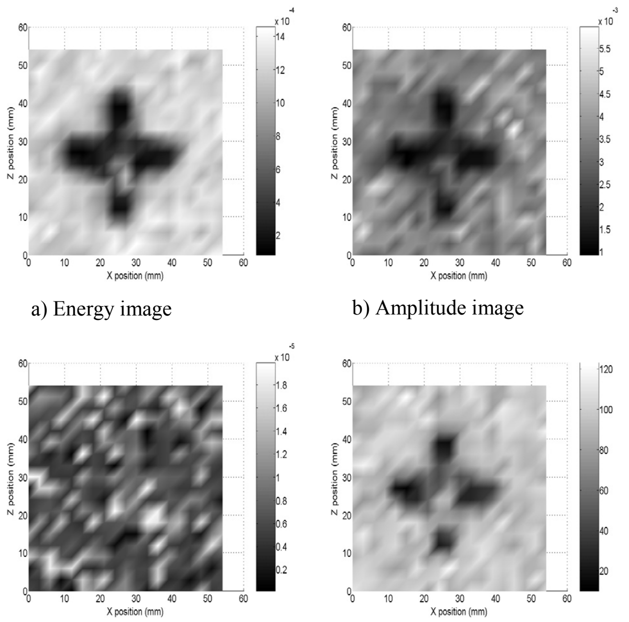
(63 of averaging, SNR of 19.59 dB), time delay image is the best one in which the defect is clearly identified. Finally, Fig. 9 (15 of averaging, SNR of 13.98 dB), Energy and Number of peaks images are the best ones.



a) Energy image b) Amplitude image

c) Time Delay image d) Number of peaks image

Figure 8 : Lamb wave images with SNR = 19.59 dB.



a) Energy image b) Amplitude image

c) Time Delay image d) Number of peaks image

Figure 9 : Lamb wave images with SNR = 13.98 dB.

Conclusions

Temporal information extraction methods from degraded ultrasonic signal has been studied and compared for both through transmission and Lamb wave inspection. It has been seen that, for high level of SNR ratio, all ultrasonic signal parameters are affected by the change in the material characteristics. The method based on the energy and number of cycles of ultrasonic signal exceeding an adaptive threshold has been demonstrated to be the most suitable ones at low level of SNR. Finally, it is not always the same defect identification parameter provides the best image, it is sometimes necessary to study other parameters as they are highly dependent on the material characteristics and the nature of the defect.

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