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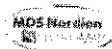
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An Evaluation Approach to NDT Ultrasound Processes by Wavelet Transform

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Abstract

The possibility of employing wavelet analysis in ultrasonic nondestructive applications has been studied since the beginning of the eighties, giving interesting results at least in laboratory applications. Nevertheless, in order to apply this technique efficiently as an analysis tool supporting the diagnosis process in routinely Quality Control applications, it is necessary to further assess the applicability conditions. To this purpose, within the frame of the European IMT Research Program INDUCE, an evaluation and development activity is running, focused on some nowadays production critical diagnosis targets. This paper reports the preliminary results obtained. In particular, one-dimensional signals (pulse-echo waveforms) were investigated; features from scale-time plots were studied; a prototype of graphic interface for the control of the processing of two-dimensional signals and programs for file management and data processing were developed; operating correlation with a global NDT data organisation model was established. Some flaws (delamination, bridging, insert) in carbon fibre composite components were investigated, with special reference to the discrimination between micro-voids and resin enrichment zones and to some critical time-position of flaw peaks (e.g. small void signal near the front-echo one). Moreover, taking into account the impracticability of collecting a sufficiently high number of experimental representative situations, a semi-empirical modelling was formulated, in order to provide known defect/structure/flaw-location configurations able to address wavelet transform applications. MATLAB Tools were used. Results encourage deeper investigation, aiming particularly at the possibility to automate some flaw-extraction algorithms, both in terms of detection and characterisation.

Introduction

The possibility of employing wavelet analysis in ultrasonic nondestructive applications has been studied since the beginning of the eighties, giving interesting results at least in laboratory applications. Nevertheless, in order to apply this technique efficiently as an analysis tool supporting the diagnosis process in Quality Control applications, it is necessary to further assess the applicability conditions, refining them on the base of specific diagnosis targets.

In particular, the measurement of the porosity is an area of great interest today in the aerospace industry, due to the increasing production of structural and secondary parts in carbon fibre reinforced plastics and to the important role played by the presence of micro-voids on the interlaminar shear strength of composite laminates [1, 2, 3]. In general, void content may be detrimental for some mechanical properties, for example lowering fatigue resistance, increasing the susceptibility to the water intrusion and influencing strength features. In synthesis, the measurement of the void content could be considered as a measurement of the quality of the composite: generally, a good composite does not exceed a void volume percentage of 1% [4].

There is a number of destructive tests for evaluating void content, but they cannot be applied neither to full-scale parts, nor to on-line quality controls. For this reason, the porosity detection and its quantitative measurement (morphology, size and position) is becoming one of the main targets of NDE. Ultrasound testing is far and away the more used one to inspect composite parts, so that it

is of great interest to develop and assess ultrasound techniques able to evaluate the porosity content. Some activities in the Brite INDUCE (Advanced integrated NDT concepts for unified life-cycle, contract N° BRPR-CT98-805) project are just oriented to develop and assess data treatment procedures applied to pulse-echo waves for measuring porosity and resin rich zones. In particular, the general conditions allowing the processing of ultrasonic signals in the wavelet domain are tackled.

To this purpose, an introductory effort has been planned for characterising ultrasound pulse-echo signals from various kinds of defect. Taking into account the impracticability of collecting the features of all the defect-structure-location configurations of interest, we started with a semi-empirical modelling approach, in order to provide a significant number of flaw cases able to address, at a preliminary stage, the wavelet transform applications.

We considered both one and two-dimensional transform, to be applied respectively to A-scan signals and to C-scan maps. One-dimensional wavelet transform has been already used to some extent and it proved to be a useful tool to study and identify the perturbations introduced in a complete ultrasound waveform by the presence of defects [5, 6, 7]; two-dimensional wavelet transform could be used as a spatial filter, able to enhance some features of the processed images.

Modelling approach

The simulation of characteristic spectrum and waveform of the ultrasonic transducer was performed: an accurate reproduction of the transducer waveform is essential both for simulating the wave propagation and for assuring a reliable fitting between simulated and experimental data as well.

$$d_i(f) = \sum_{i=left}^{right} e^{-\frac{(f-f_0)^2}{2\sigma_i^2}} e^{s_i(f_0-f)} + \frac{s_i}{100}$$

The probe frequency spectrum distribution $d(f)$ is created by adding two distorted normal branches (left and right with respect to the central frequency f_0), where the distortion is realised by exponential damping factors and skewness addends:

where σ_i , μ_i and s_i are, respectively the left/right standard deviations, the damping coefficients and the skewness coefficients.

The transducer waveform $w(t)$ - amplitude vs. time - was obtained adding sine contributions:

$$w(t) = e^{-\delta(t-t_0)} \sum_f d(f) \cdot \sin(2\pi f t + \varphi)$$

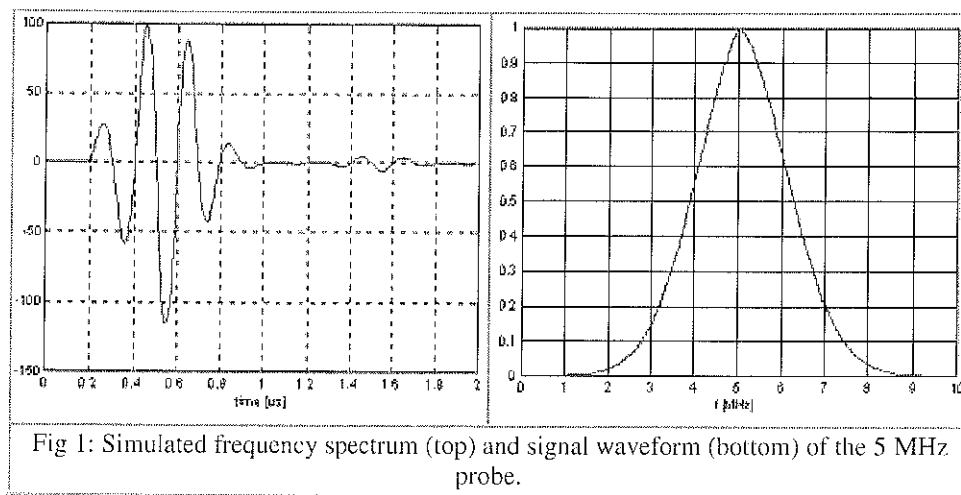
where:

δ = wave damping coefficient,

t_0 = delay

φ = phase.

The examples shown in the following are based on the simulation (Figure 1) of the 5 MHz narrow band transducer (of ACCUSSCAN "S" Panametrics sort); this kind of probe is characterised by a relatively low frequency and low axial resolution, so that the ability of wavelet processing in resolving A-Scans containing information on small and/or close defects can be tested under critical conditions.



The analytical model deals with only the very simple situation of a single (or none) defects in homogeneous materials. Really, a level of complexity was introduced in a heuristic way. The physical description of the wave propagation was approached by means of the set of reflections and transmissions (due to part and defect front/back surfaces) that affect the initial incident wave. Generally speaking, component homogeneity is not applicable to carbon composite materials. Nevertheless, for a probe low frequency probes (e.g. 5 MHz) this approximation can be adopted [8] at least for assuming that wave velocity and mass density (and then the reflection and transmission coefficients) are constant through the materials.

However, also at low frequency, experimental data show "structured" waveforms also in undefected zones: this indicates that interactions between wave and internal structures with comparable wavelength cannot be neglected. This is due probably to reflections across each wavelength of part material. To this purpose, on the base of a similarity with experimental waves, a corrective sine-like factor was introduced, to take into account both the behaviour of wave amplitude vs. time and attenuation influence.

We considered the amplitude (pressure) reflection coefficient and transmission coefficient for ideal interfaces having infinite thickness

Part was treated as having infinite thickness, while it was assumed that defects behave as frequency filters [9]. The filtering action was formulated as a change in reflection and transmission coefficients as follows

- for low wavelength transmission and reflection coefficients are unchanged;
- for high wavelength wave is completely transmitted, that is it does not interact with the defect;
- for intermediate wavelength, reflection/transmission coefficients decrease/increase linearly..

They were considered the multiple reflections due to first echoes, as well as the attenuation of sound waves as they travel away from their source. To reflect the "structure" of experimental waveforms and noising perturbations, an heuristic corrective factor $F_c(t, f_0)$, depending on the central frequency of the transducer, was introduced that multiplies the wave propagating through the part-defect configuration The front echo has been calculated by:

$$w_{fe}(t) = w(t) \cdot P_{ca} \quad (c = \text{couplant}; m = \text{part material})$$

The echo $w_{dus}(t)$ caused by the defect upper surface was calculated using a reflection coefficient that depends on the number of reflections in the examined time range, each negative reflection coefficient introducing a phase change of π .

In the same way we calculated the echo $w_{dls}(t)$ caused by the defect lower surface and finally we computed the back-wall echo $w_{bw}(t)$.

The complete radio-frequency A-Scan w_{rf} is obtained adding all the previous contributions, each time shifted of a proper time:

$$w_{rf}(t) = w_{fc}(t - t_c) + w_{dm}(t - t_c - t_m) + w_{db}(t - t_c - t_m - t_d) + w_{dw}(t - t_c - t_m - t_d - t_{db})$$

where $t_c = 2 \cdot d_c / v_c$, $t_m = 2 \cdot d_m / v_m$, $t_d = 2 \cdot d_d / v_d$, $t_{db} = 2 \cdot d_{db} / v_m$, and:

d_c = distance between probe and part;

d_m = distance between part and defect upper surface;

d_{db} = distance between defect lower surface and part back surface;

v_c = longitudinal wave velocity through couplant;

v_d = longitudinal wave velocity through defect;

v_m = longitudinal wave velocity through the part.

We calculated several waveforms and we compared them with the US signals obtained by inspecting some composite material, typically used during manufacturing of Eurofighter 2000 Typhoon (EFA) parts. In particular, we report two examples relative to EFA laminated area of a sandwich made of Hexcel 8552/IM7 carbon epoxy material (see Figure 2). To inspect the part, a contact scanning was performed, using a Krautkramer USD15 pulser-receiver.

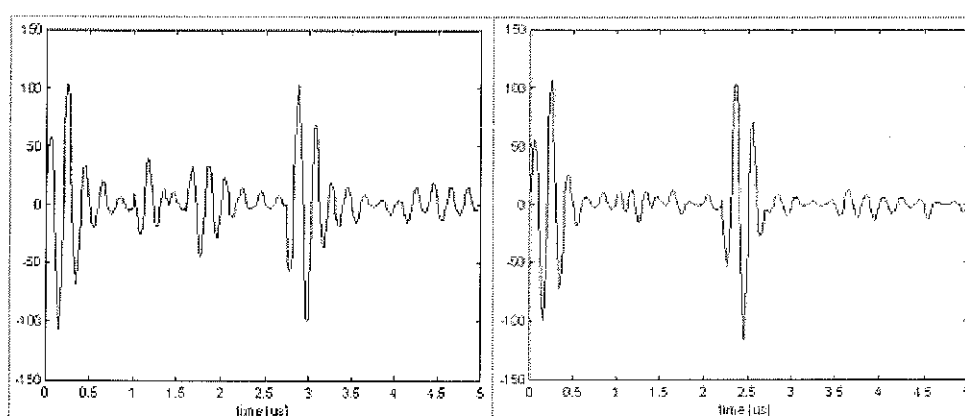
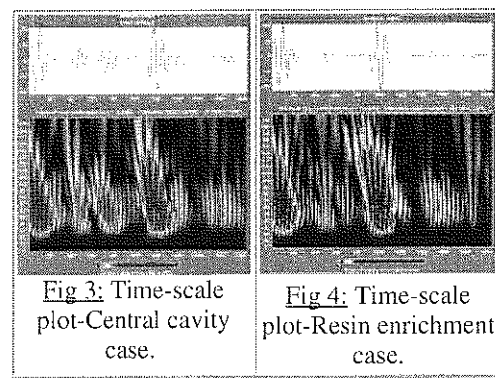


Fig 2: Left. Central cavity (air), with part thickness = 3.3 mm, defect-part front face distance = 1.5 mm, defect thickness = 0.1 mm. Right. Resin enrichment area, with part thickness = 3.3 mm, defect-part front face distance = 1.5 mm, Defect thickness = 0.1 mm.

Preliminary One-Dimensional Wavelet Analysis

Matlab tools were used; the Daubechies 5 wavelet was chosen, because it seem to approximate in a realistic way experimental data.

Simulated signals were processed so to obtain time-scale plots, where x-axis represents time, y-axis represents the scale and the colour at each x-y point represents the magnitude of wavelet coefficient. The analysis of time-scale plots permits to point out similarities in wave's structures. This can be used as basis for recognising, and for some aspects characterising, the defects.



Figures 3 and 4 show the analysis for the two cases previously reported. Following considerations can be made comparing the two time-scale plots:

- Void signals - upper and lower defect surfaces - are shown well both by A-Scan and time-scale. On the other hand, wave velocity in air is sufficiently high to separate the two reflections.
- Resin signals are revealed only by time-scale plot and not by A-Scan. This is due to the higher wave velocity in resin, causing reflection from upper and lower defect surfaces interfere.
- In both cases, the defect signals in time-scale plots present a compressed spectrum indicating that the defect-wave interaction occurred only for high frequency components.

Preliminary Two-dimensional Wavelet Analysis

In order to obtain a C-Scan map, the ultrasound transducer is moved along two directions across the specimen to reach the scanning position (i, j) , and the peak value $P(i, j)$ of the echo signal inside a predefined time gate is measured. The map is represented by a multi-level digital image, whose pixels have a luminance value proportional to $P(i, j)$.

Assuming that the time gate is located in correspondence of the back-wall echo, the signal measured in presence of porosity is smaller than that obtained in normal conditions: hence, the C-Scan map shows a pattern, normally irregular, of small round blobs, darker with respect to undefected areas.

In order to assess the porosity content of the inspected specimen, an image processing procedures should extract from the image some geometrical and photometric features and to analyse them. The two-dimensional wavelet transform can be used as an intermediate step to filter and reduce data; for this purpose using the MATLAB environment and the Wavelet and Image Processing Toolboxes we begun to study the effectiveness of this approach and we developed a graphic interface and some modules for file management and data pre-processing.

In particular, the interface allows to select the wavelet family and to define a set of weighting parameters w_k in order to process an input image S and to obtain the output image O , given by

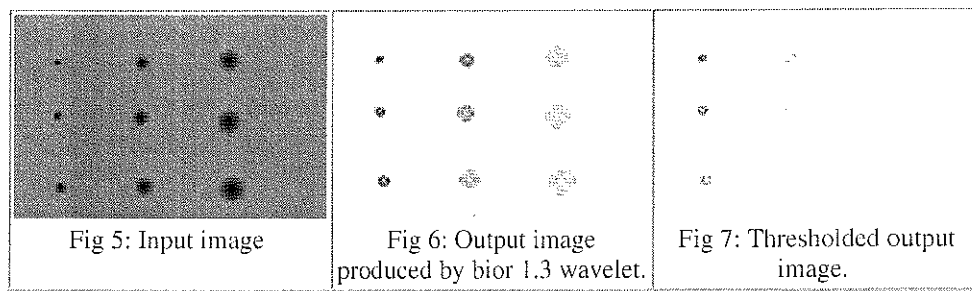
$$O = w_1 H + w_2 V + w_3 D$$

where H , V and D are the horizontal, vertical and diagonal detail images produced by wavelet analysis.

In the following example, the input image (see figure 5) contains 9 round blobs with diameter increasing from 5 to 21 pixels in steps of 2 pixels; the minimum value of luminance of all blobs is zero.

Figure 6 shows the sum of the horizontal and the vertical detail images at level 1 obtained by applying the wavelet bior 1.3 to the input image; the pixel values of the image in figure 6 are expanded to the full interval 0-255.

Using a 53×48 rectangular area centred on each blob of figure 6 we calculated the histograms of photometric values; table 1 reports the minimum luminance value of the filtered blobs.



Finally, using the threshold value $T = 36$, the 255 levels image of figure 6 is transformed into the binary image shown in figure 7: due to the properties of wavelet filtering, in figure 7 appear only the details relative to the blobs with diameter ranging from 5 to 13 pixels.

Diameter (pixel)	Lmin
5	0
7	0
9	0
11	0
13	0
15	33
17	107
19	107
21	107

Table I: Minimum value of luminance L_{\min} of filtered blobs of figure 6.

Conclusions

The described modelling approach seems encouraging. Of course, it can be considered satisfactory only within the strict approximations adopted. At this stage it is not able to simulate correctly complex defect-material configurations or composite materials with high frequency probes. In addition, the nature finite of transducer and ultrasound beam should be examined. On the other hand, while all the previous aspects could be progressively introduced in the model, it should be taken into account that the aim of the simulation was only to obtain a quick way for building waves having frequency and amplitude behaviours reflecting some features of ultrasonic waves, in order to address the wavelet applications. Anyhow, some improvements are in progress, particularly aiming at facing the above mentioned features, as well as at determining the structure of undefected waveforms in terms of the interaction of the ultrasonic wave with a sequence of "strata", each having dimension comparable with the minimum effective interacting wavelength and properties obtained by statistical processing of microscopic local features.

The time-scale plots obtained with the Wavelet Transform of one-dimensional signals show that is possible to detect and measure the difference between the current waveform and the reference waveform, in a simpler way, at least for what concerns the measure, than looking at the A-Scan signals: thus the Wavelet Transform seems to be a possible and useful processing step of the whole automatic process of quality control.

In order to determine the real effectiveness of a data pre-pre-processing based on Wavelet Transform it is necessary to tune the procedure, by solving the inverse problem consisting in the choice of the instruments (type of wavelet, level of analysis, filtering criteria, and so on) that give the best results in this application, that is for recognition, measurement or classification of defects detected by means of a ultrasonic inspection.

To this end it is first necessary to define both the characteristics of the defects to be detected, and the performances of the processing procedure; then it is necessary to examine with different processing parameters a quite large amount of specimens containing known defects, measured also

with other inspection techniques. Considering the final results of the processing procedure, that is in order to minimize the error percentage of defect classification or evaluation, could make the parameter set-up.

The process of quality control should determine either the type of defects, or their spatial position. The last information can be obtained only by the analysis of the set of waveforms obtained during the inspection: since the throughput of such data is quite large (about 1kB for each measurement, with scan step lesser than 1 mm), possible time constraints of on-line control operations will determine the mode of inspection to be adopted. In general, the procedure might perform a preliminary inspection of the specimen by means of peak detection of the signal, contained in a right chosen time gate, and might then execute a full inspection of the areas that contain response anomalies: the Wavelet Transform could be used to analyse and filter the data to be passed to the processing module for defect classification or evaluation, in order to obtain the requested information.

References

1. L. B. Greszczuk, "Effect of Voids on Strength Properties of Filamentary Composites", Proc. of the 22nd Conference, SPI Reinforced Plastics Div., Soc. of the Plastics Industry, New York, 1967, Sect. 20-A
2. N. C. W. Judd and W. W. Wrihgt, "Voids and Their Effects on the Mechanical Properties of Composites - An Appraisal", SAMPE Journal. Vol. 14, 1978, p. 10
3. J. Kollgaard, "Evaluation of Porosity in Composite Laminate Repairs Using Acoustic Substitutes", Materials Evaluation, Nov. 1995
4. ASTM D2734 "Standard Test Method for Void Content of Reinforced Plastics"
5. D. M. Patterson, B. De Facio, S. Neal, C. R. Thompson, "Wavelets an their application to Digital Signal Processing in Ultrasonic NDE", Review of Progress in Quantitave Nondestructive Evaluation, Vol. 12, D. O. Thompson and D. P. Chimenti eds., New York, 1993, 719-726.
6. J. Chao, L. Udpa, S. S. Udpa, "Ultrasonic Signal Analysis using Wavelets Transform", Review of Progress in Quantitative Nondestructive Evaluation, Vol. 12, D. O. Thompson and D. P. Chimenti eds., New York, 1993, 735-742.
7. Sif-Eddine Moubarik, D. De Vadder, Ph. Benoist, "Wavelets and Nondestructive Evaluation ", Review of Progress in Quantitative Nondestructive Evaluation, Vol. 12, D. O. Thompson and D. P. Chimenti eds., New York, 1993, 727-734.
8. M. Qurak et al., "Theoretical and experimental study of composite materials using longitudinal ultrasonic spectroscopy", Rev. of Progress in QNDE, Vol. 12B, p. 1217, 1993.
9. Y. Bar-Cohem et al., "Ultrasonic Testing Applications in Advanced Materials and Process. Ultrasonic Pulse-Echo and Trough Transmission Tests", NDT Testing Hand, II Ed., Vol. 7, UT, Sec. 15, p. 516.