Signal Processing Techniques and Non-Destructive Testing by Ultrasound for the Characterization of Complex Materials

L. Zaghba, A. Bouhadjera
Department of Electronics, Laboratory of Non-destructive Testing, University of Jijel
Ouled Aissa, Jijel 18000 Algérie
Email: Layachi40@yahoo.fr

Abstract

This article focuses on the application of different signal processing techniques to improve the visibility of the echoes of ultrasonic wave propagation in the presence of noise of a prismatic sample (Split spectrum processing, wavelet transform), we can then measure the time delay of the different echoes. (Transformation of correlation, Hilbert transform). From measuring the thickness and travel time between the input echo (echo front), and Back Echo (backsurface) of longitudinal and transverse waves, it is easy to calculate the longitudinal velocity and transverse respectively, and then determine the elastic constants (Young’s modulus, Poisson’s ratio, ...) that allow us to describe the evolution and mechanical properties of materials.  

Keywords: mortar; Ultrasound; Split spectrum processing, wavelet transform, the cross-correlation; Hilbert transform; non-destructive testing

1. Introduction

In materials characterization, measurements of longitudinal and transverse velocities are of great practical importance since they lead to the determination of elastic constants from the formulas well known. Measurement techniques in the field of nondestructive testing are not universal. They vary from one application to another as needed [6]. Each method has advantages and disadvantages when compared to other methods for a single application. These methods are designed to detect flaws and characterize materials. Among the many existing methods, ultrasonic testing is one of the most used due to its high sensitivity, its ease of use and reasonable cost. For our work we used the pulse-echo mode, and specifically the technique of prism. During the production of certain products of raw materials, many defects can be introduced inside the material (grain, cracks, ...) [6]. So it is necessary to know the characteristics of materials and identify the presence of defects and determine their positions and their nature. In nondestructive testing, the presence of noise due to the internal structure of some complex materials often obscures the signal from the default, which makes difficult the detection and identification of the latter.

2. Split spectrum processing

In the late 70’s, a technique called Split Spectrum Processing has been developed for the implementation of the concept of diversity of frequencies (frequency diversity), to improve the signal to noise ratio, in order to process the signals from granular materials as concrete [1][3]. A whole range of frequencies is created from a single input signal to broadband, using a number of parallel bandpass filters Gaussian shape as shown in Figure 1. The resulting spectra were processed in time domain using the inverse Fourier transform, they are then multiplied by factors W1, ..., W_N [1][3].

![Figure 1. Schematic diagram of Split Spectrum Processing technique](image)

The N narrow band signals W1X1 (t) ..., WNXN (t) are processed and recombined by using multiple linear and nonlinear operations to obtain an output signal versus time [2].
3. Wavelet Transform

The transform can be defined as the projection on the basis of wavelet functions [4].

\[ TO(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t) \psi(t-b/a) dt \]  
\[ \psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi(t-b/a) \]  

The wavelet coefficients \( TO(a, b) \) depending on two parameters \( a \) and \( b \), where \( a \) is the scale factor and \( b \) the translation factor. The step of translation to the scale is \( b/a \).

The scalogram is the time-scale (the time on the horizontal axis, the scale on the vertical axis). The scalogram is expressed from the continuous wavelet transform.

\[ |TO(a,b)|^2 = \left| a^{-1/2} \int_{-\infty}^{+\infty} f(t) \psi(t-b/a) dt \right|^2 \]  

The wavelet transform is a multi-resolution representation of a signal. It has become a very powerful tool for nondestructive testing and monitoring by ultrasound [3].

4. The Cross-Correlation

The cross correlation function of two signals \( x(t) \) and \( y(t) \) :

\[ R_{xy}(\tau) = \int_{-\infty}^{+\infty} x(t) y^*(t-\tau) dt \]  

Among the applications of intercorrelation is essential to compare and measure the gap between two signals \( x(t) \) and \( y(t) \) delayed.

5. Experimental procedure and measurements by the Prism Technique

The schematic of the ultrasonic measurement consists of various elements which are depicted in Fig.5. It consists of an Ultrasonic Pulser/Receiver, an immersion Transducer (Panametrics, 1 MHz), a Digital Oscilloscope (Tektronix TDS 1002), a PC with WaveStar software for data-acquisition. The transducer is connected to the hardware as shown in Fig. 5, so that the first measurement can be taken few

- Prism Technique

It is based on pulse-echo technique, and application of reflection and refraction of waves between two media liquid/solid separated by an interface [5].
faces of the prism with length $(a)$, are reflected at the Prism/Water interface, and propagate back to the receiver using exactly the same travel path as before [5].

$$V_{1,T} = \frac{a}{(T_{1,T} - t_1)} \quad (5)$$

a- The face Echo :

b- Reflector Echo signal :

c- Echo of longitudinal wave

If we increase the angle of incidence (the translator by rotating around the sample), it appears a third echo, representing the longitudinal waves.

d- Echo of transverse wave:

If we increase the benefit incidence angle, the third echo disappears (longitudinal waves), and there will appear a fourth echo representing the transverse waves.

6. Results and discussion

In this work, we opted for the technique of the prism, for the following reasons:

- This technique requires a single transducer to measure the speed of both longitudinal and transverse waves.
- There is an easy coupling between the transducer and the sample (a main characteristic of testing by immersion). The special formula used, indicates that the speed is independent of the angle of rotation of the translator vis-à-vis the sample. This represents a considerable advantage over other methods. The prisms are easy to prepare. We used a mold, in the form of a cube divided into two along the diagonal to yield two prisms. A general view of the measuring device is shown in Figure 7. The samples in the form of a prism is to the right of the figure.

6.1. Split Spectrum Processing (SSP)

a- the face Echo signal

The echo of the face (Figure 11) is transformed to frequency domain using the fast Fourier transform. The spectrum is filtered by Gaussian filters of four same bandwidth $b = 0.29$ MHz, and different central frequencies 5MHz, 10MHz, 15MHz and 20MHz, with an intersection of -6 dB (50% overlap, resulting in four filtered signals. The filtered signals are processed and recombined using the algorithm of recombination (geometric mean) in the frequency range 0 to 25 MHz, using an increment of frequency $f = 10$ kHz to obtain the output versus time (Figure 12)

As you can see, the start signals in this first experiment are clear (echo off). The purpose of this experiment is to demonstrate the power of technology PHC. Based on these results, it is clear that the algorithm of geometric mean (geometric mean) gives echoes more pronounced, and therefore allows a more precise
determination of the time. This will be of importance when the echoes are drowned in noise. One can easily isolate the amplitude peaks, and determine the flight time. We found the following results:
- $T_1 = 53 \text{ us}$ (is the flight time for reflection of the front).
- $T_L = 66 \text{ us}$ (is the time of flight for longitudinal waves).
- $T_T = 77 \text{ us}$ (is the flight time for transverse waves).

6.2. The wavelet transform

In this section, we applied the wavelet transform (scalogram) and Fourier transform sliding window (spectrogram) on the same signals previously treated:
- Echo of the main face
- Echo of longitudinal waves
- Echo transverse waves

The purpose of this technique is the same as PHC. Is to detect and locate the exact location of the echo and noise cancellation (if applicable). Figures (17, 20, 23) represent the shape coefficients of wavelet approximations and details of debauchery. We find that signal changes after the contents of the original signal, where there is a slight variation of the coefficients in the non-noisy, and a large change in the noisy coefficients. The time-scale representation (scalogram) is illustrated in figures (18, 21, 24). Low frequencies are at the top of the image, while high frequencies are at the bottom of it. The representation resulting spectrogram is shown in figures (17, 20, 23). representation, the variation in the frequency coincides with one of the ordinates.

Scalogram and spectrogram indicate that the fundamental echoes are concentrated around:
- Number of samples = 695 ($t_1 = 53 \mu s$), the echo of the front faces (4.20, 4.21)
- Number of samples = 1012 ($t_L = 66 \mu s$) figure for longitudinal waves (4.24, 4.25).
- Number of samples = 1287 ($t_T = 77 \mu s$) for transverse waves Figures (4.28, 4.29). We also note the appearance of vertical stripes (number of samples 500-1000). These lines represent the noise of the main face. You can use the two representations (scalogram and spectrogram) to display the energy level of the signal in the time-frequency plane, where the amplitude is given by the level value of the color gray.

Figure 9. Approximations and details coefficients (3 levels)

Figure 10. Scalogramm

Figure 11. Spectrogramm
6.3. Cross-correlation

To elucidate the delay that may exist between two echoes, we have superimposed on Figure 8 echo emanating from the front of the sample, and the echo from the reflector. Figure 9 shows the intercorrelation between the signals of the front and the reflector. The delay is given by the abscissa of the maximum of the cross correlation between two echoes. The horizontal axis is the number of samples (1185) which represents the difference between the echo from the reflector (sample number = 1880) and the echo of the main face (sample number = 695).

- The number of sample 1880 corresponds to a time t = 101 μs (the echo reflector).
- The number of sample 695 corresponds to a time t = 53 μs (the echo of the main panel).
- The number of sample 1185 corresponds to a time t = 101-53 = 48 μs (the delay between the echo of the reflector and the echo of the main panel).

Figure 8. Two echoes (the input and the back echo)

6.4. The Hilbert transform

Figure 13. Hilbert Transform signal

7. Conclusion

The detection and identification of defects in materials by ultrasonic methods are often limited by the presence of noise in the internal structure of matter. We have presented an overview of a technique known as signal processing Split spectrum processing. This technique is based on the frequency diversity. Once the signal was decomposed into multiple frequency bands, they were then recombined by using recombination algorithms (geometric mean), which helped determine the location of these frequencies and the origin of the echoes. However, their algorithms are sensitive to recombination filter parameters, namely the frequency range increasing the frequency and bandwidth of each filter. We also used the wavelet transform to remove noise and locate temporally the echoes in the samples studied. As we have demonstrated, this technique has the advantage of working with bands that leads to the separation of noise.

REFERENCES