Signal Processing Techniques for the Characterization Ultrasound Complex Materials

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Abstract— This article focuses on the application of different signal processing techniques to improve the visibility of the echoes during travel time between the echo of entry (opposite echo), and the back wall echo (back surface) of longitudinal and transverse waves, it is easy to calculate the speed and longitudinal cross respectively, and then determine the elastic constants (Young modulus, Poisson's ratio,) that allow us to describe the development of properties and split spectrum processing method.

Index Terms— Echoes, Ultra sound, Split spectrum processing, Wavelet transformation, Hilbert transformation

I. INTRODUCTION

During the production of certain products made of raw materials, several defects can penetrate inside the material (grain, crack,). So it is necessary to know the characteristics of the materials and identify the presence of defects and to determine their nature and their positions.

It is within this framework that the work we have developed to implement the various techniques of signal processing to improve the signal to noise ratio (Split spectrum processing, wavelet transformation), which then allows us to measure the delay different echoes.

II. SPLIT SPECTRUM PROCESSING

In the late 70's, a technique called Split Spectrum Processing was developed for the implementation of the concept of diversity frequency (frequency diversity), to improve the signal noise in order to process signals from granular materials such as concrete [1-3].

A whole range of frequencies is created from a single input signal to broadband, using a number of parallel band 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 W_1, W_N . These factors are chosen such that the amplitude of each signal band is close to a standard unit N narrowband signals $W_1X_1(t), \dots, W_NX_N(t)$ are processed and recombined using several linear and nonlinear for an output

Figure 1. Patterns art of Split Spectrum Processing

Among the important characteristics of the filter and recombination algorithm, we can cite:

- Minimisation

$$Y(n) = \min (|X_1(n)|, |X_2(n)|, |X_3(n)|, \dots, |X_N(n)|)$$

- Maximisation

$$Y(n) = \max (|X_1(n)|, |X_2(n)|, |X_3(n)|, \dots, |X_N(n)|)$$

- Medium

- Géométrical mean

$$Y(n) = (|X_1(n)|, |X_2(n)|, |X_3(n)|, \dots, |X_N(n)|)^{1/N}$$

III. WAVELET TRANSFORM

Wavelet transform can be defined as the projection on the basis of wavelet functions. The wavelet coefficients are defined as follows:

$$TO(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t) \psi\left(\frac{t-b}{a}\right) dt \quad (1)$$

$$\text{avec } a, b \in \mathcal{R} \quad a \neq 0$$

$$TO(a, b) = \int_{-\infty}^{+\infty} f(t) \psi_{a,b} dt$$

$$\text{avec } \psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \quad (2)$$

The wavelet coefficients ($TO(a, b)$) depends on two parameters a and b , where a is the scale factor and b the translation factor. The no translation at a is b/a .

The functions are obtained from the expansion and the translation of the mother wavelet function. The are sometimes called wavelet girls.

The scalogramme is a time-scale (time on the horizontal axis, the scale on the vertical axis and the value of gray level of color range).

The scalogramme is expressed from the continuous wavelet transformation. It is defined as the square of the module of the wavelet transformation.

$$|TO(a, b)|^2 = \left| \frac{1}{a} \int_{-\infty}^{+\infty} f(t) \psi\left(\frac{t-b}{a}\right) dt \right|^2 \quad (3)$$

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The wavelet transformation is a multi-resolution representation of a signal. It has become a very powerful tool for non-destructive testing and monitoring by ultrasound. It allows you to filter the signal to detect and characterize the types of defects (planar or volumetric) of materials and improve the signal to noise [4-5].

IV. APPLICATIONS OF CORRELATION FUNCTIONS

It defines the function of cross-signals of $x(t)$ and $y(t)$ finite energy by:

$$R_{xy}(\tau) = \int_{-\infty}^{+\infty} x(t) y^*(t - \tau) dt \quad (4)$$

The applications of correlation functions are very high by achieving practical results. Among the applications of essential intercorrelations is comparing and measuring the gap between two signals $x(t)$ and $y(t)$ delayed. This delay is the abscissa of the maximum of the cross, the two signals observed [6].

V. HILBERT TRANSFORMATION

This technique uses the properties of the Hilbert transform of a signal to determine the time gap between two signals. It is studying the Hilbert transform of the impulse response of the system [7].

The four signals (Figure 3, 4, 5 and 6) show the results obtained by the technique of prism on samples from a cube of departure (45x45x45 mm³), and using a transducer center frequency of 1MHz.

a-Echo of the front:

Figure 2. Echo of the front of the sample

Q1: Is the flight time in the water with the sample in his place (normal reflection of the front of the sample).

b-Echo reflector

Figure 3. Echo reflector

Q2: Is the flight time in the water sample (normal reflection of the reflector)

c-Echo on longitudinal waves:

Figure 4. Longitudinal waves

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

tL: is the flight time with the presence of the sample, where the refraction occurs at an angle of 45° within the sample.

Figure 5. Transverse wave

d-Echo transverse waves :

If we increase further the angle of impact, the third echo disappears (longitudinal waves), and there will appear a fourth echo representing the transverse waves. tT: is the flight time with the presence of the sample and when refraction occurs at an angle of 35° within the sample for a transverse wave.

VI. RESULTS AND DISCUSSION

The echo of the front (Figure 11) is transformed to frequency domain using the fast Fourier transform. The spectrum is filtered through four filters Gaussians same bandwidth $b = 0.29$ MHz, and different center frequencies 5MHz, 10MHz, 15 MHz and 20 MHz, with an intersection of -6 dB (50% overlap, resulting in four signals filtered. filtered signals are processed and recombined using the algorithm recombination (geometric mean) in the range of 0-25 MHz frequency, using increments of frequency $f = 10$ KHz for the exit as a function of time (Figure 8).

Figure 7. Echo of the front

Figure 8. The results of the technical SSP (Geometric mean)

We will apply the same method on the echoes on longitudinal waves (Figure 9) and transverse (Fig. 10), using the same filters and the same algorithms recombination, with

the same parameters.

The results of this technique are illustrated in Figures 12,13.

b-Echo on longitudinal waves

Figure 9. Transverse waves

Figure 10. The results of the technical SSP (Geometric mean)

c-Echo transverse waves on

Figure 11. transverse waves

Figure 12. The results of the technical SSP (Geometric mean)

As you can see, the signals start in this first experience is clearing (widely reported). The purpose of this experiment is to demonstrate the power of technology SSP. Based on these results, it is clear that the algorithm of the geometric mean (geometric mean) gives more pronounced echoes, and therefore allows more accurate determination of the time. This will be of paramount importance when echoes are drowned in the noise. One can easily isolate the peak amplitude, and determine the

time of flight. It was found the following results:

- $T1 = 50\mu s$ (is the flight time for reflection of the front).
- $64 = tL \mu s$ (is the flight time for longitudinal waves).
- $75 = tT \mu s$ (is the flight time for cross-waves).

The wavelet transformation

In this part, we applied wavelet transform and Fourier transform signals on the same treaties previously:

- Echo of the front
- Echo longitudinal waves
- Echo transverse wave

The purpose of this technique is the same as that of SSP. Is to detect and locate the exact location of the echo and noise suppression (if any).

We also note the appearance of vertical lines (number of samples 500-1000). These lines represent the noise from the front. You can use the two precedent figures to display the energy level of the signal in the time-frequency, where the amplitude is given by the value of the level of gray color.

Intercorrelation

To elucidate the delay that may exist between two echoes. we superimposed on the figure 8 echoes emanating from the front of the sample, and the echo from the reflector. Figure 13

shows the intercorrelation signals between the front and the reflector. The delay is given by the abscissa of the maximum of the cross between two echoes. The abscissa is the number of samples (1180) which represents the difference between the echo of the reflector (number of sample = 1880) and the echo of the front (number of sample = 695).

-The number of sample 1880 corresponds to a time $t = 107 \mu s$ (echo reflector).

- The number of sample 685 corresponds to a time $t = 45 \mu s$ (the echo of the front).

- The number of sample 1185 corresponds to a time $t = 106-53 = 48 \mu s$ (the delay between the echo of the reflector and the echo of the front). See figures 13 and 14

Figure 13. Two overlapping echoes (echo of the front and depth of the reflector)

Figure 14. - Echo longitudinal waves

Hilbert transformation:

It can also calculate the delay time by using the Hilbert transform (Fig. 15). The delay is given by the abscissa of the maximum of the Hilbert transform. The value of the delay by the Hilbert transform is equal to 48

μ s (sample number 1185). It has exactly the same as that found by the previous method.

Figure 15. Hilbert presentation

VII. CONCLUSION

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 diversity of frequencies. Once the signal was decomposed into several bands, they were then recombined using algorithms recombination (geometric mean), which determined the location of these frequencies and the origin of echoes. With the technique Split Spectrum Processing, we got to reduce noise in granular materials (mortar and concrete). However their algorithms recombination are sensitive to filter parameters, namely the range of frequency, increasing the frequency and bandwidth of each filter. We also used the wavelet transformation to eliminate noise and echoes locate temporarily in the samples studied. As we have demonstrated, this technique has the advantage of working with bands that leads to the separation of noise.

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