Defect Detection by Split Spectrum Processing and Discrete Wavelet Transform in Coarse Grains Materials

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Abstract

In this work, we propose in one hand, to develop algorithms based on Split Spectrum Processing (SSP) with Q constant method associated to "Group delay moving entropy" (GDME), and on the second hand, to develop a method based on Discrete Wavelet Transform (DWT). These algorithms allow detecting and locating imperfections echoes drowned in the structural noise of materials.

Introduction

In some metallic materials with coarse grains, signal energy is lost due to scattering so the detection of defects by ultrasounds is often difficult. This noise can mask the defect signal and creates a constraint in its detection. It is thus necessary to increase the visibility of the defect by techniques based on the analysis of defect echo spectrum.

In this work, we propose in one hand to develop, algorithms based on Split Spectrum Processing (SSP) with Q constant method associated to "Group delay moving entropy" (GDME) [1], on the second hand, to develop a method based on Discrete Wavelet Transform (DWT) [2]. These algorithms allow detecting and locating imperfections echoes drowned in the structural noise of materials. The defect echoes frequency is varied around the frequency of the input signal in order to evaluate, by SNR calculation, the robustness of the detection method.

1. Noise and defect signal modeling

The noise generation used in this work is based on the simple clutter model presented in [3].

In the Rayleigh region ($\lambda >> D$, where λ is the wavelength and D is the average diameter of material grain), the attenuation is proportional to ω^4. Omitting multiple reflections, the frequency response of structure noise is expressed by

$$N(\omega) = H_t(\omega) H_t(\omega) \sum_{k=1}^{K_{tot}} \beta_k \frac{\omega^2}{x_k} \exp(-\alpha_s 2 x_k \omega^4)$$

$$\exp(-j\omega\, 2 x_k / c_l) \qquad (1)$$

where α_s is a material scattering coefficient (constant), c_l is the velocity of longitudinal waves, x_k is the particle positions, $k=1,\ldots,K_{tot}$ (K_{tot} is the particle number). β_k and x_k are random variables. $H_t(\omega)$ is the frequency response of ultrasonic transducer. $H_t(\omega)$ occurs twice since the transducer is used as transmitter and receiver. $H_t(\omega)$ is modeled as a band pass Gaussian shaped spectrum, in practice, it can be measured using a flat surface reflector positioned at the far field of the transducer. The central frequency of this transducer is 5 MHz.

Then, we have added to the simulated noise signal a real defect signal of 1mm diameter located at 6.2µs. Figure 1 shows this input signal. The SNR of defect signal (time sequence) y(n) is calculated as the energy within the range containing the defect divided by the total signal energy [4]. It is expressed as:

$$SNR = \frac{\sum_{k=T-P/2}^{T+P/2} y^2(k)}{\sum_{n=0}^{N-1} y^2(n)} \qquad (2)$$

where T is the target location and P its pulse-width.

Tests have been undertaken with different levels of noise added to the input signal. As example, input signal illustrated by figure 1 have as SNR=0.16.

2. Discrete Wavelet Transform

This algorithm is based on Mallat decomposition algorithm on different levels using Daubechies window. The used algorithm is described in ref.[5]. Figure 2 shows the output signal. We have obtained a good SNR of 0.4.

3. SSP technique with GDME algorithm

This technique splits the received wideband signal into a group of frequency-diverse narrow band signals exhibiting different SNR, and subsequently recombines those using non linear techniques in order to increase this SNR [1].

To improve the results of the SSP in the echo defect detection, it is efficient to develop an adaptive algorithm, which can detect the spectral variations of the defect signal. The expression of the used group delay describes the characteristics of the received signal. Thus the group delay of the noise will be random variable, while the defect echo one will be a constant.

Since the entropy is an adequate measurement for the random aspect, we propose a technique which estimates the randomness of the group delay by entropy using a moving window along the frequency axis. The steps of this algorithm are described in [1].

Figure 3 shows the output signal. We have obtained a good SNR equal to 1.

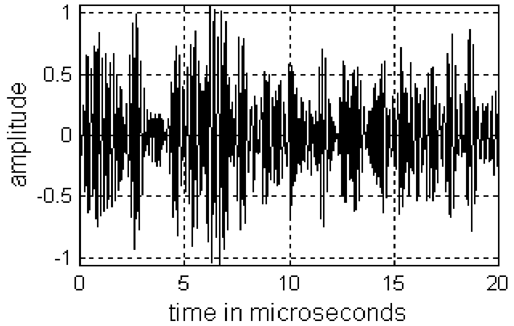

Fig.1. Input signal with defect echo at 6.2 µs.

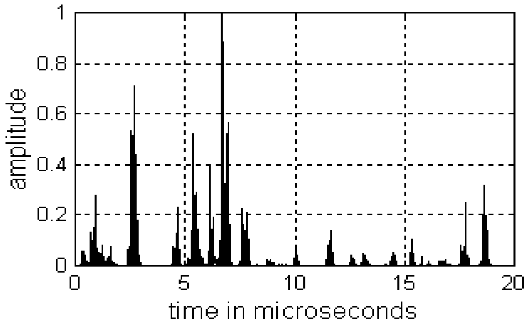

Fig.2. Output signal obtained by DWT. SNR=0.4

5. Statistical study and conclusion

The robustness is measured by the SNR and the detection probability of 100 signals. Simulations are carried out on defect echoes having the same central frequency and bandwidth but various positions and amplitudes. Their positions are distributed randomly between 1 and N, where N is the number of samples equal to 1024. The amplitudes of the noise and defect echo are normalized to unity. The central frequency of noise is more or less equal to 5.6 MHz. The bandwidths at -3dB of defect echoes have 1.8MHz. The central frequency of the defect echo is varied between 3 MHz and 9MHz.

Figure 4 and 5 respectively show the results of the detection probability and the SNR calculation of the defect echo according to the frequency.

We can note that for SSP-GDME, the SNR reaches very appreciable values apart around the central frequency of the noise. At 6 MHz, SNR values decreases to 0.6, and the probability of detection decreases also to 0.6.

However for DWT, the SNR keeps almost constant values in the band of the studied frequencies.

In conclusion, the results confirm that SSP with Q-constant associated to GDME is optimal to find spectral regions for process. It can be applied to detect defects and it can be noted that it is an effective method compared to DWT algorithm.

References

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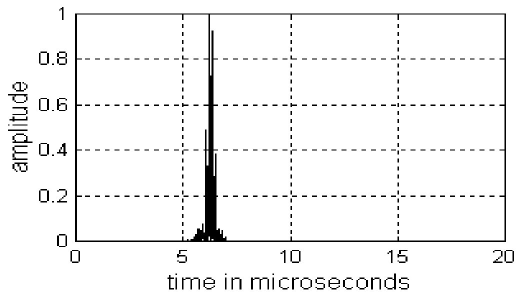

Fig.3. Output signal obtained by SSP-GDME. SNR=1

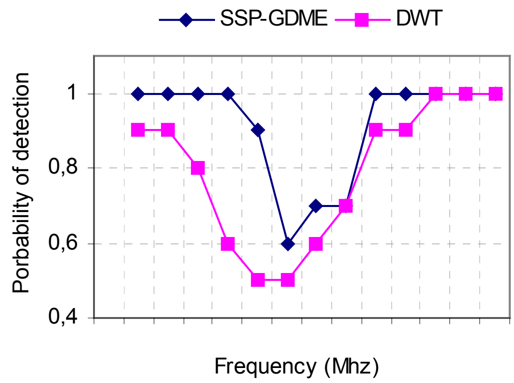

Fig.4. Probability of detection

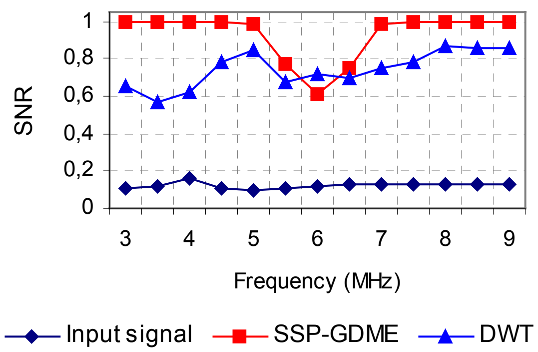

Fig.5. SNR measurement in Statistical study