

## COMPARISON BETWEEN ULTRASONIC AND WAVELETS ANALYSIS FOR CHARACTERIZATION STAINLESS STEEL ALLOYS

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### Abstract

In this paper we characterize 3 samples used in petrochemical industry by NDT method with ultrasonics. The 3 samples are P5, 16Mo3 and 4541 in European norm for which the chemical composition is known by spectral analysis.

The experimental set-up is supplied by PAC (IPR-100, AID 100 and SMC4). The method used here is a pulse-echo technique by direct contact. We use transducers of 4 MHz and 10 mm diameter.

We determine acoustic parameters like the propagation velocity and the attenuation at the working frequency in 10 points (every point is the mediated value of 8 measurements).

### Introduction

Ultrasonic microstructural characterization in polycrystalline samples has significant practical implications in determining the quality and structural integrity of materials. Based on the various compensations and corrections for a series of losses and errors, a number of studies examined the correlation between the ultrasonic attenuation, velocity and microstructures. Although the attenuation and velocity measurement techniques provide an investigated microstructure test, they are limited by strict measurement conditions. Another approach is the attenuation and velocity measurements by spectral analysis.

Ultrasonic spectral analysis. Ultrasonic spectroscopy is the study of ultrasonic waves resolved into their Fourier frequency components. The purpose of ultrasonic spectroscopy is to determine the frequency dependent properties of materials (attenuation, velocity). Since many material properties manifest themselves as amplitude or phase changes in ultrasonic waves used to interrogate a sample ultrasonic spectroscopy has proved to be valuable for structural characterization and property testing.

In ultrasonic testing the frequency dependence of the attenuation in some materials can also be regarded as a filtering effect. The transform function of the material is used to evaluate physical and geometrical properties of the medium. A typical ultrasonic spectral system includes a great number of components, most notably the test sample. The Fourier transform  $F(f)$  in the frequency domain is computed from  $f(t)$  in the time domain by the direct integration of the relation :

$$F(f) = \int_{-\infty}^{+\infty} f(t) e^{-j2\pi ft} dt \quad (1)$$

All the information and characteristics contained in  $f(t)$  are also exhibited in  $F(f)$ . The power spectrum function  $G(f)$  is linked by the following relation with  $F(f)$  :

$$G(f) = \frac{2}{T} |F(f)|^2 \quad (2)$$

The power spectrum shows the energy distribution in the frequency domain and highlights the main frequency in the signal. The detected signal (the output of the system)  $s(t)$  is the convolution of the input signal  $e(t)$  and the impulse function of the system which includes the test function  $h(t)$  and the medium function  $p(t)$ . The whole transmission characteristic can be shown by the following relation:

$$s(t) = e(t) * h(t) * p(t) \quad (3)$$

Before the measurement, we recorded a reference signal, the output signal  $s_0(t)$  without the test sample; such as a Fourier transform of the signal from pure water, used as a normalizing function to filter out the characteristic of the source. The reference signal is a fundamental requirement before using such systems:

$$s_0(t) = e(t) * h(t).$$

By taking advantage of the associative property of the convolution product:

$$s(t) = s_0(t) * p(t) \quad (4)$$

Based on the relation of deconvolution and the Fourier transform, the spectral normalization can be realized by the following equation:

$$P(f) = S(f) / S_0(f) \quad (5)$$

where

$P(f)$  = the Fourier transform of  $p(t)$

$S(f)$  = the Fourier transform of  $s(t)$

$S_0(f)$  = the transform of  $s_0(t)$ .

### Experimental set-up

Figure 1 shows a block diagram of the ultrasonic spectral analysis system constructed. Results presented here were obtained by the contact method using siliconic gel as the sound coupling medium with the pulse-echo technique. This apparatus consisted of a IPR-100 signal generator, A/D 90 converter and

SMC-4 of the PAC. The signals received at the transducer, of 4 MHz fundamental frequency, from the sample were sent to an oscilloscope, where their amplitude and velocity was read directly from the sampler. Signals from the sampler were transmitted to the spectral analyzer where the spectrum of the signal concerned was loaded.

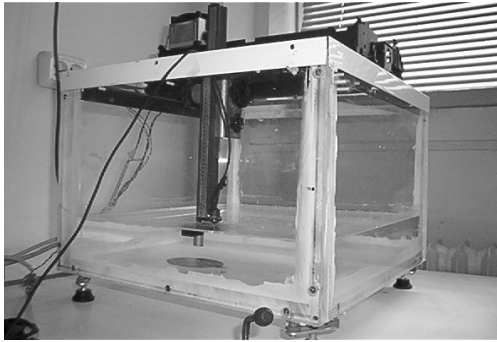


Figure 1. Experimental set-up

**Samples.**

The measurements were performed on three structures of austenitic steel types: P5, 16Mo3 and 4541 in European Norm (EN). Their chemical composition is given in Table I.

Table I

	P5	16Mo3	4541
Fe	93.48	98.08	60.25
C	0.035	0.12	0.067
Si	0.34	0.30	0.70
Mn	0.47	0.68	1.55
Cr	4.85	0.085	24.20
Ni	0.029	0.11	12.84
Mo	0.57	0.26	0.026

The acoustic parameter measurements were made in the 10 points for each sample. At each of the measurement points the ultrasonic attenuation and the velocity were measured by the pulse-echo technique in direct contact.

**Wavelet Transform**

Ultrasonic NDE signals contain reflections from discontinuities which manifest in the A-scans as abrupt time localized changes resulting in time varying spectral characteristics. Consequently, the conventional Fourier decomposition technique is not an appropriate tool for analyzing these signals. The discrete wavelet transform (DWT) is a multiresolution analysis technique which is one of several approaches that can be used to obtain the time frequency representation of a signal.

The Wavelet Transform (WT) is a new method of processing transient nonstationary signals simultaneously in time and frequency domains. This

method has generated much interest in various applications such as multiresolution analysis, image compression and speech coding. Also during the last time the wavelets have become a popular de-noising (or noise reduction) tool [1], [4].

The WT use scaling in the time domain to scale a single function in frequency. This function, commonly referred to as mother wavelet (in our case we use the Meyer wavelet function of order 3), is used to extract details and information on time and frequency domains from transient signal under analysis. This approach results in a more natural description of the signal, since the size of the window in the time domain is now a function of the scaling.

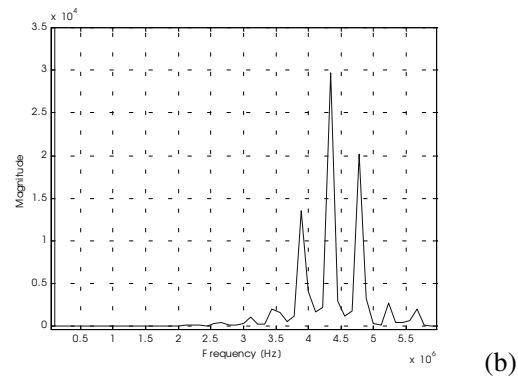
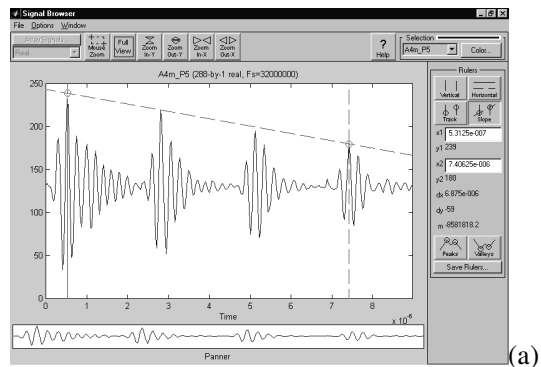


Figure 2 Ultrasonic echo waveform (a) for P5 material and his spectrum (b).

The Wavelet Transform (WT) of a function  $f$  corresponds to the decomposition of  $f$  on the family of wavelets  $(\psi_{a,b}(x))_{a \in \mathbb{R}^+, b \in \mathbb{R}}$  generated from one single function  $\psi$  (namely the mother wavelet) by dilation and translations [2],

$$(W_{\psi} f)(a, b) = \int_{-\infty}^{+\infty} f(x) \psi_{a,b}(x) dx \tag{6}$$

$$\psi_{a,b}(x) = a^{-\frac{1}{2}} \psi\left(\frac{x-b}{a}\right) \tag{7}$$

The DWT analyzes the signal by decomposing it into its coarse approximation and detail information. This decomposition is accomplished by using

successive highpass and lowpass filtering operations in the frequency domain.

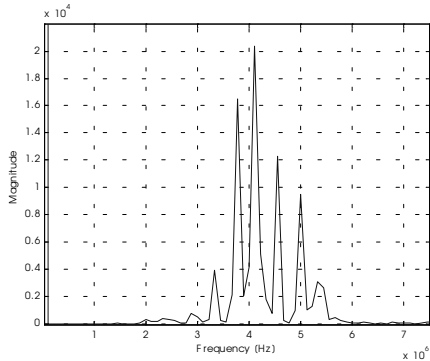


Figure 3 Ultrasonic spectrum for 16Mo3 material

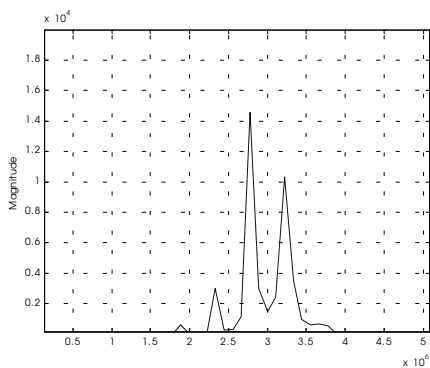


Figure 4 Ultrasonic spectrum for 4541 material

This decomposition in effect halves the time resolution and doubles the frequency resolution, because the frequency band of the signal now spans only half the previous frequency band. The above procedure is repeated for further decomposition of the lowpass filtered signals. The highpass filtered signals constitute the DWT coefficients. At every level, the filtering and subsampling results in half the number of samples spanning half the frequency band resulting in reduced time and improved frequency resolutions.

Ultrasonic NDE signals was filtered using de-noising procedure principles in three steps:

- 1) Decompose. We chose Meyer wavelet of order 3 and the 3<sup>rd</sup> level. Compute the wavelet decomposition of the time series at level 3<sup>rd</sup> (see fig. 5).
- 2) We impose the threshold detail coefficients for each level from 1 to 3 and we apply soft thresholding to the detail coefficients.
- 3) We reconstruct the time series by computing the original approximation coefficients of level 3 and the modified detail coefficients of levels from 1 to 3.

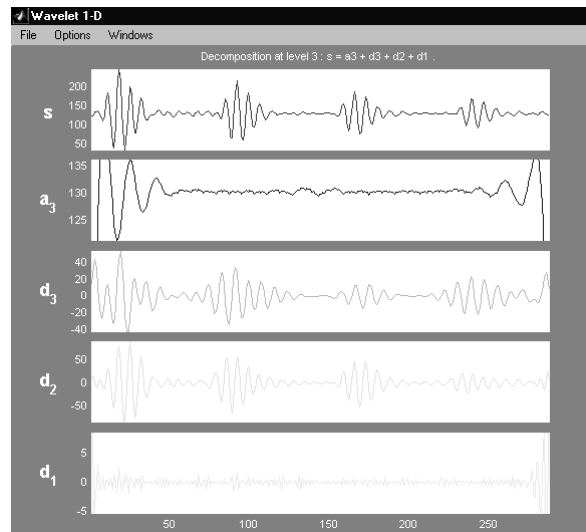


Figure 5. Decomposition on 3<sup>rd</sup> level using wavelets

In figure 5, we present the Discrete Wavelet Transform of the ultrasonic signal for P5 material and the decomposition of the ultrasonic signal affected by noise using Discrete Wavelet Transform to level 3.

The signals was filtered and compressed (a good fitness between the original and transformed data is obtained using less than 25% of the wavelet coefficients) using Meyer wavelet function and heuristical soft thresholding technique.

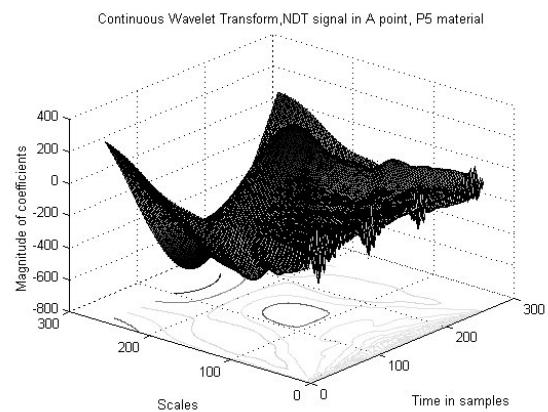


Figure 6 Continuous Wavelet Transform 3D representation of the ultrasonic signal for P5 material

In figure 7 and 8 show determined velocity and attenuation for all sample. Righth insert present legend code for sample (p5, mo16, cr), last two letter represent (v) velocity, (a) attenuation and method of signal processing (eg. no letter original signal, „p” software resampled signal that increase sample rate from 32 to 256 MHz, and „w” wavelets filtered signal).

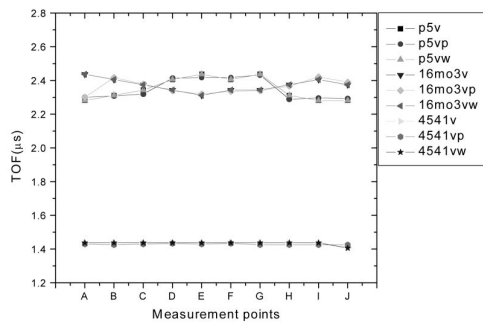


Figure 7. Time of flying for samples in 10 points

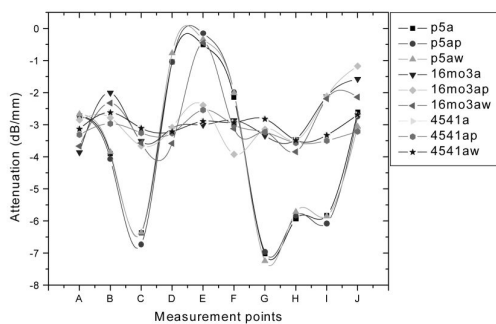


Figure 8. The attenuation variation from samples

**Conclusions**

For the relative attenuation coefficient measurement, the smoothness of the paralelipedic surface and the consistency of size of the samples influenced the results.

Compared with the relative attenuation coefficient measurement, the power spectral analysis technique has significant practical implications.

Computer simulation was utilized to verify the signal detection improvements for an ultrasonic wave embodied in white noise. A typical ultrasonic signal generated using a 4 MHz commercial longitudinal transducer and the random noise was eliminated from the waveform, and the resulting signal was processed using Wavelet Transform. In this simulation we use the Meyer wavelet of 3 order.

The WT, seen as a bank of matched filters, can be extremely efficient in eliminating noise in ultrasonic signals. It thus enhances the detection of flaw signatures that in many cases are buried in noise.

The normalized power spectra of the microstructures from three materials show some similarities. It is found that the peak at 4,125 MHz in 16Mo3 material and another spectral peak at 4,33 MHz in P5 material for the samples with pearlite plus ferrite.

For the 4541 material it is found that the peak at 2,77 MHz and another spectral peak at 3,22 MHz for the sample with quenched martensite.

Experimental results have been presented to evaluate the effect of WT filtering on ultrasonic flaw

detection. In particular we prove that apply the WT it has been possible to detect ultrasonic signal buried in noise, without any loss of accuracy in the time measurement, and thus, in the evaluation of the flaw depth.

However, a large amount of research needs to be undertaken, including examinations of the relationship between the location, amount and amplitude of the spectral peaks and the quantificational microstructure, using classical technique and also using wavelets.

The results have indicated the potential feasibility of the ultrasonic method and wavelets for ascertaining structural differences in stainless steel alloys.

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