Experimental Study And Analysis Of The Structural Noise Of The Ultrasonic Signal.

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ABSTRACT: The precise detection of echo-graphic pulses embedded in background noise is a problem of major importance in ultrasonic NDT. Structural noise is a significant constraint to the visibility of flaw echoes in ultrasonic evaluation of highly scattering materials. In order to enhance the defect to background noise, several methods have been proposed including split spectrum processing, time frequency distributions, and wavelet transform. All this methods give an output SNR improvement when this ratio is high. In the case of ultrasonic NDT, the signal energy coming from the defect fills lower frequencies than the one coming from the material structure, due to dispersion phenomena and the non stationary nature of the ultrasonic traveling wave. We try in this work to extract the noise features by finding its analyzing wavelet function. And we propose a procedure based on an energetic threshold of the ultrasonic signal, then a smoothing of the energetic parameters of the noise function. This algorithm has given a good filtering of the ultrasonic signal as well as the detection of little defects in very noisy signals. The experiments have been conducted on welded pieces and on artificial flaws.

1. INTRODUCTION

Acoustical characterization is an important item in non destructive testing of materials. An often used technique is the echo-graphic one which consists of analyzing the waves reflected by the material heterogeneity. Since, the reflected signal is always corrupted by noise, the process of signal filtering may be the most fundamental task in the framework of material characterization. Numerically, the ultrasonic signal is represented by time dependant functions and filtering is represented as a convolution of the signal and the filter impulse response. The ultrasonic signal is non stationary in nature and the difficulty of its analysis is in the extraction of the useful information. The wavelet analysis is a multi-resolution time scale method which enables to perform a time localized analysis of signals. The result of the wavelet function is the difference between value calculated and the data. The ability of a wavelet filter to exactly reconstruct a signal component depends on how closely the wavelet function approximates the signal.

Since, no signal can be simultaneously and arbitrary localized in time and frequency, so the gauss signal which is the more concentrated one must be interpreted as an elementary carrier signal of a minimum information. The wavelet transform consists in correlating the analyzed signal with a family of wavelets obtained by dilating and oscillating functions of finite

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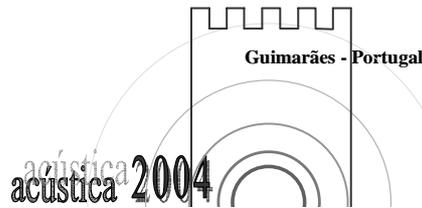
duration [1]. In this respect, the wavelet transform is able to give a quantitative measure of the local appearance of the signal at different scales. Many studies have been conducted on the use of the wavelet theory for ultrasonic signal de-noising, but no one bas been done on the structural noise features and its possible analyzing wavelet function.

In the framework of the automation of the ultrasonic signal analysis project, we haven't make the exception, and we have followed the exploration of the wavelet theory, from the continuous transforms to the discrete ones without disregarding the wavelet packet.

The filter bank of the continuous wavelet transform gives good results for the highest frequencies, but requires a fine study of the noise threshold in the low frequencies, which needs many experiments on each defect signature [2]. Moreover, when we have fixed the SNR at an acceptable level, the speckle noise remains.

The filter bank of the discrete wavelet transforms needs an extensive tree decomposition for each signal, and an amount of time computing for the choice of the best averaging. Even, the reconstruction of the signal components is not complete du to the waste of some useful information from the filter bank tree. And the wavelet packets allows a more biggest decomposition and a lot of time computing with a refined signal reconstruction [3].

The better performance to do in the improvement of the time computing, is to investigate the noise features of an ultrasonic signal measured on welded pieces and on artificial flaws, by an energetic threshold of the signal then a smoothing of the energetic parameters of the noise representation. The proposed algorithm runs on a one cycle for each signal analysis and provides a reconstructed signal without distortion.

2. DESCRIPTION OF THE PROCESS AND RESULTS

A time scale analysis allows a larger view of the signal energetic configuration which permits the ultrasonic noise features extraction [4]. The acoustic noise is supposed to be a gauss random variable with a zero averaging and a limited band power spectrum function [5]. As the ultrasonic energies are concentrated in the frequency band, the different frequencies beside the band are represented in the transform domain by very weak amplitudes and can be scattered without loss of information.

The proposed algorithm that we called "energetic smoothing algorithm" is subdivided into the following tasks (fig.1):

1. Evaluation of the signal frequency band by a power spectrum analysis,
2. Evaluation of the signal energetic distribution and estimation of the different coefficients by a time scale analysis. Here the chosen analyzing function is the 8th derivative gauss function,
3. Noise extraction process based on wavelet coefficients regulation by an energetic smoothing of the maximums,
4. Result: time scale mapping of the energetic distribution of the noise,
5. Inverse wavelet transform, and statistical noise characteristics calculation: variance, averaging, standard deviation…
6. Filtering process with the minima's – maxima's calculation method, based on the energetic coefficients reduction between the signal and the noise time scale representations.

7. Optimization of the filter with a selection of the best analyzing wavelet function for the noise representation. The chosen analyzing function is the Morlet

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┌────────────────────────┐              ┌────────────────────────┐
│ Noise B(t) extraction by│◄─────────────│ Signal S(t) time scale │
│       smoothing        │              │ energetic representation│
└────────────────────────┘              └────────────────────────┘
             │                                       │
             ▼                                       │
┌────────────────────────┐                           │
│ Noise time scale       │                           │
│ representation         │                           │
└────────────────────────┘                           │
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┌────────────────────────┐              ┌────────────────────────┐
│ minima's and maxima's  │              │ minima's and maxima's  │
│ B_min, B_max           │              │ S_min, S_max           │
│ energies calculation   │              │ energies calculation   │
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┌──────────────────────────────────────────────────────────────┐
│ Filtering by the minima's and maxima's smoothing method:       │
│ energetic Coef. (filter) = energetic coef. (signal) –          │
│                            energetic coef. (noise)             │
└──────────────────────────────────────────────────────────────┘
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            │ Filtered signal energetic representation│
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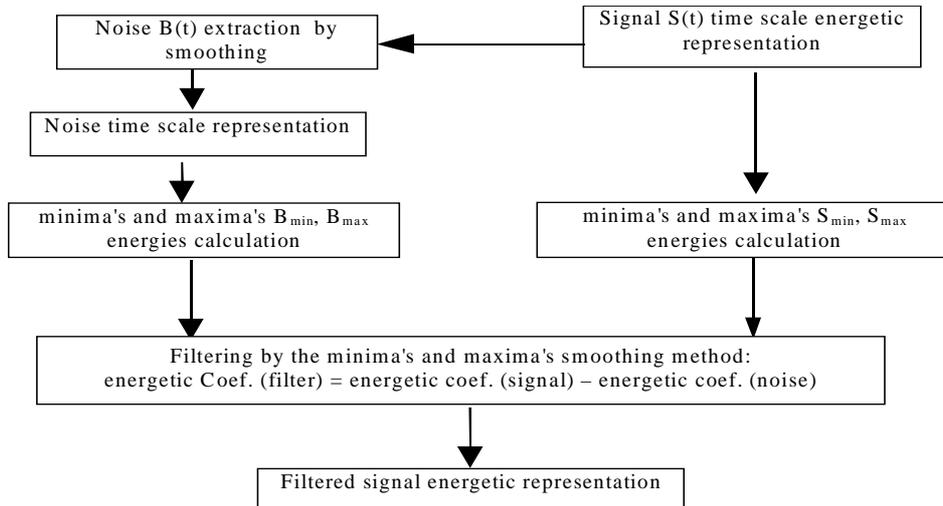
Figure 1- *Energetic Smoothing Algorithm decomposition*

The energetic smoothing procedure for noise extraction, is based on an elimination of the maximum energetic coefficients vector from the signal analyzed by the 8th derivative gauss function (fig 2.a), which generates the noise energetic coefficients. From a time scale noise mapping with the Morlet function, we do a computation of the noise energetic threshold (fig2.b). And by an inverse procedure we go to the time domain for a statistical noise characterization (fig2.c).

a - *Input signal (8th Gauss)*   b – *Noise (Morlet)*   c - *Noise statistical features*
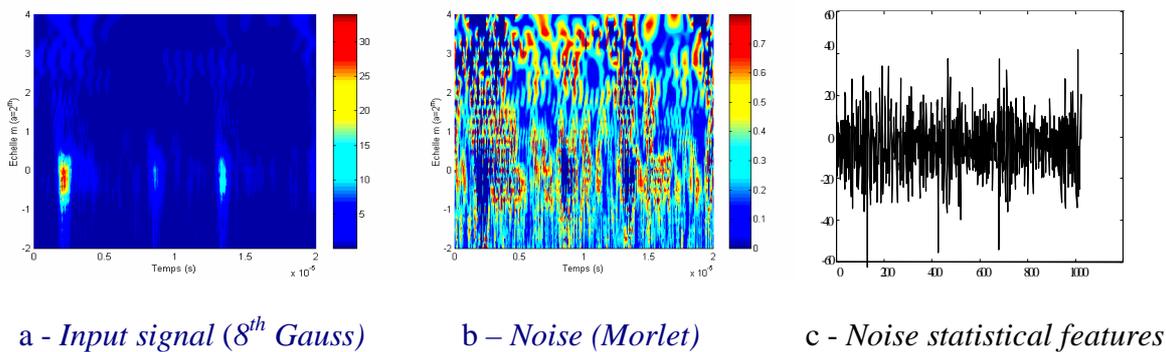
Figure 2 - *Noise extraction and characterization*

After calculation of the noise and signal maximum and minimum energetic coefficients from the two time scale representations, the filtering is performed with the named "minima's - maxima's smoothing method" based on an energetic deduction of the maximum noise energetic coefficients vector from the minimum signal energetic coefficients vector, (fig 4). The de-noising procedure on the following example (fig 3) which design a signal and a noise

distributions, indicates that the obtained filter distribution generates the maximum signal energies with respect of the transducer central frequency without any information loss.

1	2	1	0	3	5		1	2	1	0	3	5		0	0	0	0	0	0
2	5	34	23	29	5		2	5	0	0	0	5		0	0	34	23	29	0
2	1	3	1	2	1		2	1	3	1	2	1		0	0	0	0	0	0

:: Input signal distribution   *b: Noise distribution*   *c:Filtered signal distribution*

Figure 3 - *Example of information distribution*

The zero vector in the noise distribution is the minimal approximated energetic threshold. In reality, the threshold is not set to zero but leads to zero. This example is just an illustration of the "minima's - maxima's smoothing method".
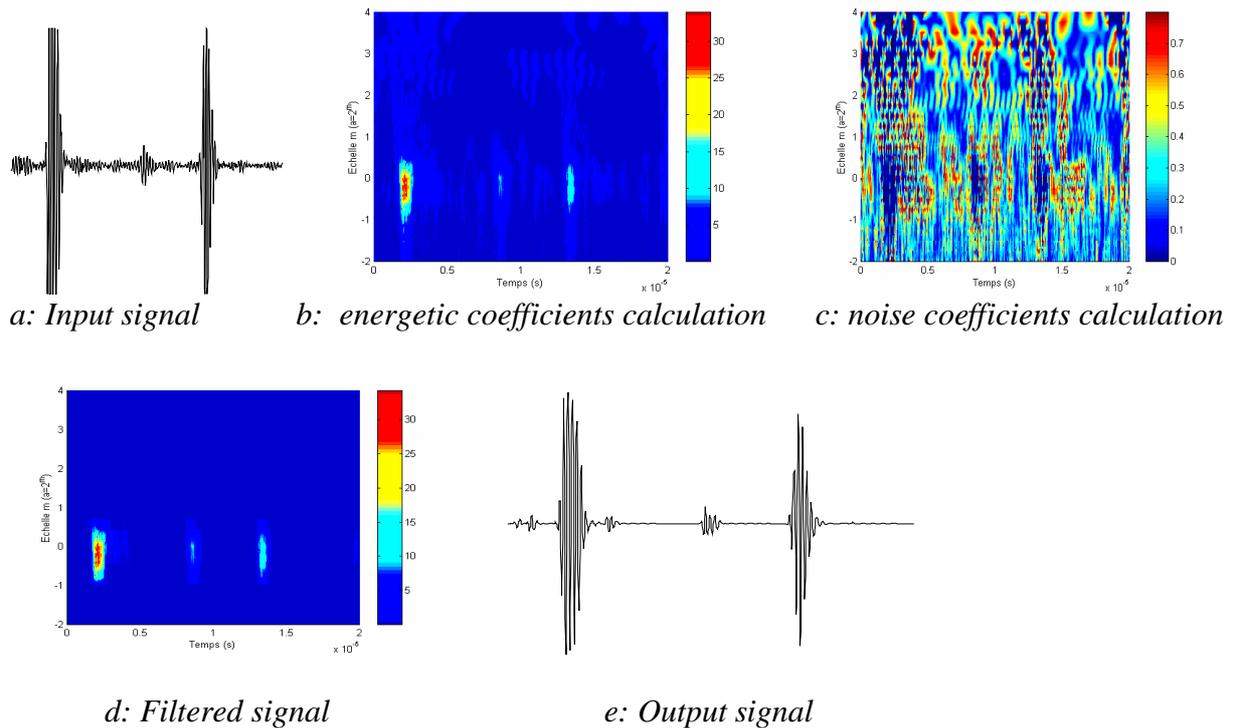
a: Input signal   *b: energetic coefficients calculation*   *c: noise coefficients calculation*

d: Filtered signal   *e: Output signal*

Figure 4 - *Minima's - maxima's smoothing de-noising method.*

The analyzing wavelet functions have been obtained by a correlation procedure of an ultrasonic signals data bank obtained on welded pieces and artificial flaws[2] and the 8th derivative gauss function was the more appropriate one. Since the noise is supposed to be a gauss random variable, a data bank of extracted noise signals has been correlated with the Gauss wavelet family. The table1 displays some obtained results, the Morlet function seems

to be the more suitable analyzing function of the noise. And has been chosen for the filtering process. Fig 5 displays the hole results of the 40 correlated extracted noise signals.

Table1- *Correlation of the noise data bank and wavelet Gauss family.*

| Noise	Morlet	mexh	Gaus$_3$	Gaus$_4$	Gaus$_5$	Gaus$_6$	Gaus$_7$	Gaus$_8$	Gaus$_9$	Gaus$_{10}$
Bp	2.6493	1.1040	1.2709	1.2220	1.5385	1.4160	1.8749	1.8364	2.2919	2.3291
Bp11	1.6650	1.0519	1.0194	0.8947	0.9284	0.8120	0.9569	0.9319	1.0981	1.2522
Bp12	1.3668	0.9373	0.6738	0.8607	0.7538	0.8334	0.7671	0.8469	0.9718	1.0145
Bp13	2.0540	1.1440	1.1745	1.1923	1.3035	1.2236	1.2525	1.4679	1.7023	1.8808
Bp14	1.4673	1.3069	1.0247	1.1937	1.1341	1.1084	1.2133	1.3090	1.4462	1.4286
Bp15	1.6452	0.9071	0.8966	0.8625	1.0150	0.9361	1.0150	1.1291	1.1105	1.3291
Bp16	1.3719	1.1312	1.1164	1.0842	1.0293	1.0244	1.2126	1.1112	1.3156	1.2712
Bp17	2.9510	1.3383	1.0723	1.6704	1.6851	2.0460	2.2706	2.4563	2.7325	2.7922
Bp18	1.3110	0.8145	1.1175	1.0298	1.2045	1.1095	1.2314	1.1257	1.2983	1.3004
Bp20	2.4817	1.3270	1.4035	1.1272	1.4189	1.6234	1.5233	2.0299	1.4077	2.3504
Bp21	1.8723	1.1334	1.1650	1.0654	1.1145	1.2397	1.5121	1.4850	1.8172	1.7632
Bp22	1.5847	1.2237	0.9519	1.1135	0.9321	1.2432	1.1524	1.4136	1.3953	1.5678
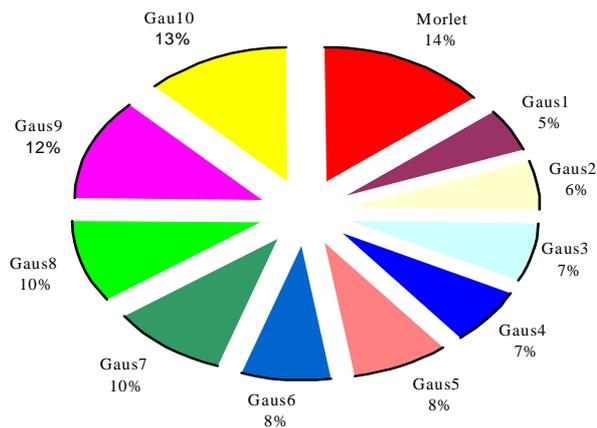
Figure 5 - *Correlation between wavelets and noise signal*

The experiments have been conducted with the following conditions:
1. Steel piece 35 mm width, with artificial cylindrical defects of (10mm, 7mm, 5mm , 3mm, 1mm) diameter
2. Steel piece 35 mm width, with artificial circular defects of (10mm,7mm,5mm ,3mm, 1mm) diameter

3. Steel welded piece 30mm width with welding defects: lack of fusion, porosity, group of porosity and horizontal crack
4. longitudinal transducer 4Mhz frequency and 4 mm diameter, transverse transducers of 4Mhz, 60° & 70° and 8*9mm diameter.

The fig 6 displays the ultrasonic signal of 1 mm flaw completely submerged in noise and the obtained signal . Fig 7 shows a very noisy lack of fusion signal, and the obtained filtered signal.
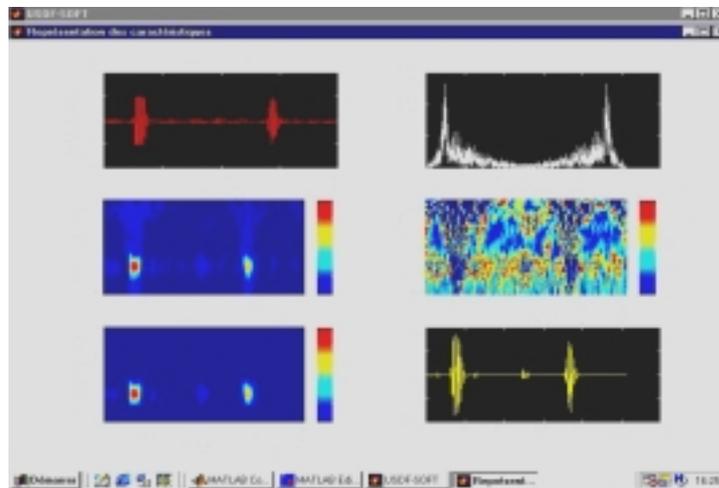

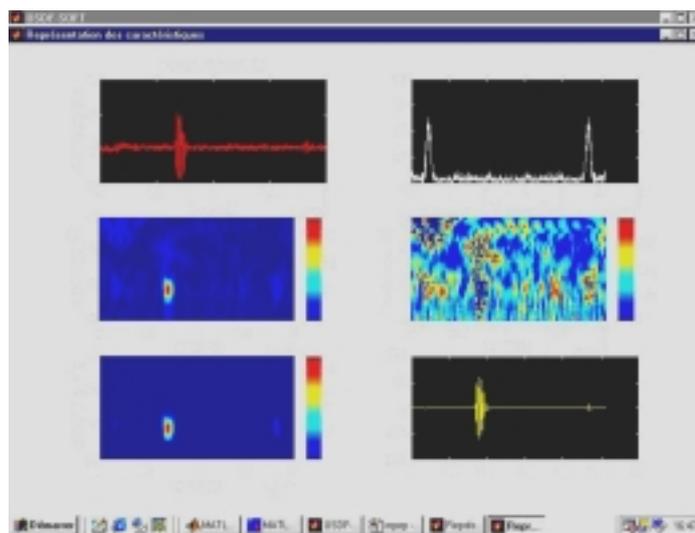figure 6 - *discontinuity of 1 mm experiment*

Figure 7 - *lack of fusion signal experiment*

3. DISCUSSION

We can notice from the different experiments that the 8th derivative gauss function approximates the signal information, and the Morlet function approximates the noise. The above algorithm that has been developed under Matlab environment, shows that this de-noising process gives accurate information and improve the automatic detection procedure for ultrasonic non destructive evaluation of steel material.

4. CONCLUSIONS

The study shows the importance of selecting the proper analyzing wavelet function for best processing performance. The wavelet theory is a powerful tool for noise filtering, but requires an increasing test speed with greater test validation data bank. In this work we have been able to extract the noise features by an improved energetic smoothing procedure and we have been able to develop the noise analyzing wavelet function which was been found different from the signal analyzing one. In this stage we can deduce that the random nature of the noise in the spatial domain has been surpassed. The energetic characterization of the noise and the useful information has allowed an easiest filtering of the ultrasonic signal, and a good flaw detection process. The minima's - maxima's smoothing de-noising new method developed in this study lets an accurate signal reconstruction without any distortion, and is performed in an interesting computing time. Future work in the entire automation process concerns the flaw signature classification on the energetic features of the ultrasonic signal.

5. REFERENCES

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