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Wavelet threshold enhancement by an energetic characterization of ultrasonic signal Ndt analysis

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In ultrasonic NDE of industrial components, the visibility of flaw echoes is corrupted by noise due to multiple scattering. Grains boundary can reach size of the same order of magnitude than discontinuities to be detected, becoming scatters of ultrasonic noise and could be confused with defect indications. Many studies have been conducted on the use of the wavelet theory for ultrasonic signal de-noising, but no one has been done on the structural noise features and its analyzing wavelet function. In the framework of the automation of the ultrasonic signal analysis project, we have followed the exploration of the wavelet theory, from the continuous transforms to the discrete ones, and the experiments give us some ambivalent results. So for a best threshold control, our idea was directed to the investigation of the noise analyzing function. In this work the noise features were extracted by an algorithm which has allowed the examination of the noise analyzing function. By this idea the random nature of the noise in the spatial domain will be avoided. The energetic characterization of the noise and the defects lets an improved filtering process. The new smoothing algorithm performs an accurate signal reconstruction in an interesting computing time.

1 Introduction

The performance of ultrasonic examination techniques in stainless steel, austenitic structures, clad components, and welds are often strongly affected by the materials anisotropy and heterogeneity. The major problems met are beam skewing and distortion, high and variable attenuation and high background noise [1]. Therefore, to distinguish the signal reflected by the defect against the background of structural noise, we must analyze both the signal and the structural noise. Structural noise is called a correlated one because signals reflected by structural heterogeneities and forming the structural noise repeat the form of the initial pulse and have the same energy spectrum as the defect signal.

Ultrasonic techniques have been routinely used in industry for nearly 50 years and yet, cast or welded austenitic components remain difficult to reliably and effectively examine. In some components grains orientations cause deviation and splitting of the ultrasonic beam. It is especially true in the case of multi-pass welds when the re-melting process after each pass causes complex solidification process fig.1. The large size of the anisotropic grains, relative to the acoustic pulse wavelength strongly affects the propagation of ultrasound by causing severe attenuation, changes in velocity and scattering of ultrasonic energy. At the grain boundaries, refraction and reflection of the sound beam may occur resulting in defects being incorrectly reported, specific volumes of materials not being examined, or both.

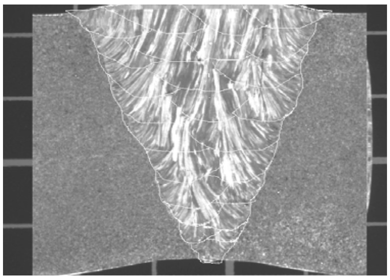


Fig.1. Macrograph of a multi-pass weld in a steel plate

Conventional ultrasonic techniques are less applicable on these materials, because of the commonly very low signal to noise ratio and flaw location uncertainty [2]. And while the ultrasonic signal is naturally non stationary, the extraction and analysis of the useful information could be inaccurate. Due to its computational efficiency, one powerful tool to enhance the signal noise ratio of ultrasonic signal is the multi resolution analysis [2]. The wavelet analysis is a multi-resolution time scale method which enables to perform a signal time localized analysis [3]. It is a powerful tool for signal filtering, but requires increasing test speed with greater test validation data bank. However, to enhance the flaw characterisation, methods based on “thresholding” have given good results only when the signal to noise ratio is high [2, 5, 11, 12] and for some specific materials grain noise reduction. In this work a multiresolution ultrasonic signal analysis is performed and the structural noise features are extracted by an enhanced energetic smoothing algorithm which has allowed the identification of the noise analyzing function. In this stage the random nature of the noise in the spatial domain has been bypassed. The energetic characterization of the noise and the signal information has allowed an easiest filtering of the ultrasonic signal with enhanced defect detection.

2 The ultrasonic multiresolution analysis for signal de-noising: data and results

Many studies have been conducted on the use of the wavelet theory for ultrasonic signal de-noising, but no one has 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 multiresolution theory, from the continuous transforms to the discrete ones without disregarding the wavelet packet.

Therefore, the original ultrasound image is transformed into multiscale wavelet domain, the wavelet coefficients are processed by a threshold method, and the de-noised image is obtained from the inverse wavelet transform of the threshold coefficients.

Consequently, by using the discrete transforms the original signal was decomposed in approximations and details coefficients which represent the low and high frequencies respectively. This decomposition in effect halves the time resolution and doubles the frequency resolution. The signal reconstruction performed only on the approximations, has released the information brought by the details in many experiments [7] with distorted signals generation.

In reverse, the wavelet packet algorithm which was recursively applied to the high and low pass results at each level of the original signal decomposition, has provided a better signal reconstruction without information failure.

Indeed, the continuous wavelet transforms has presented good filtering results only for the highest frequencies, but involved a discriminating noise threshold study for the low frequencies, which has needed many experiments on each defect signature [8].

Thus in the purpose to overcome these critical situations we have chosen to perform a combination of continuous and wavelet packet study, i.e. In a first step, a filtering by a continuous filter bank of the frequencies that are outside the frequency band, and in a second step a filtering by the wavelet packet transform of the frequency band. Here the tree decomposition has needed only 3 levels which have been considered as a threshold limit, with an improved computing time [8]. But, as the selection of the analysing wavelet affects the success of the filtering, we have chosen for the continuous filtering process the 8th derivative Gauss function after a correlation procedure between ultrasonic signals and the Gauss wavelet family described in [8]. And for the discrete filtering, 3 different mother wavelets were investigated in an attempt to find out that the best matches the shape of the analysed signal. These wavelets are the Symlet, the Coiffet and the Debauchees. The Debauchee of order 8 was the most suitable and was selected as an analysing function for the wavelet packet filtering process with the 'SURE' threshold selection rule method using at least 3% (0, 03) of the threshold level [8].

3 The new energetic smoothing denoising algorithm

However, if the above analysis is suitable its implementation is very complex, it needs several algorithms and lot of experiments, for finding out the best analysing functions and the optimized algorithms for the threshold regulation. At this stage, a look at "Hwang, Mallat" theorem [5] points to the presence of a maximum at the finer scales where a singularity occurs; and if the wavelet is the nth derivative of a Gaussian, the maxima curves are connected and go through all of the finer scales [5]. This approach offers to us the opportunity to investigate the spirit of the minima maxima smoothing analysis, which is basically an image processing technique, and attempt to evaluate its effect on the field of the multiresolution theory for signal denoising.

These investigations direct us to the construction of the new filtering method that we called the "minima-maxima energetic smoothing" algorithm based on the energetic content of the wavelet coefficients, an energetic threshold of the signal and an energetic smoothing of the noise function [10].

How it works? As the ultrasonic energies are concentrated in the frequency band, so the different frequencies beside the band are represented in the transform domain by very weak amplitudes and can be scattered without loss of information.

But in that case, how the structural noise will be differentiated? The idea is to approximate it with an analysing function. The proposed algorithm in fig. 2 admits the development of a noise analysing function with an easy filtering process.

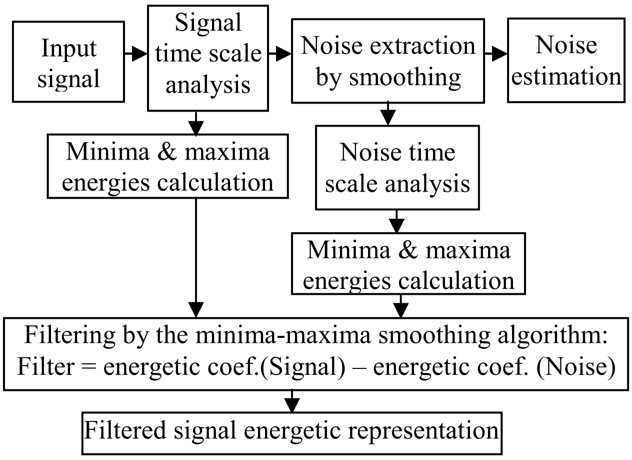


Fig. 2 Energetic Smoothing Algorithm

In this algorithm, the extraction of the noise energetic coefficients is based on the removal of the maximum energetic coefficients vector from the input signal which has been decomposed by the 8th derivative gauss function.

The computation of the noise energetic threshold is achieved from the wavelet coefficients of the noise Morlet representation. An inverse wavelet transform gives the statistical noise characterization (average, standard deviation and variance). The Morlet function was selected after a process of correlation between wavelet bases and a database of extracted noise from ultrasonic signals captured from welds, welding defects and artificial flaws.

Therefore the filtering is performed with the named "minima-maxima smoothing method" based on an energetic subtraction of the maximum noise energetic coefficients vector analysed by the Morlet, from the minimum signal energetic coefficients vector analysed by the 8th derivative of the Gaussian i.e. a subtraction between two continuous wavelet representations of the same signal is performed. Fig. 3 illustrates the obtained filter by the use of the 8th derivative Gauss and the Morlet functions.

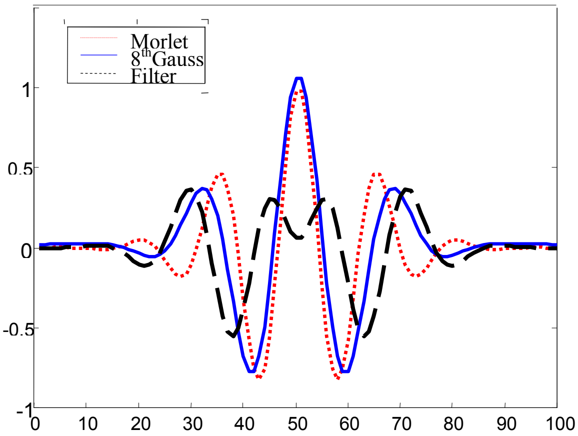


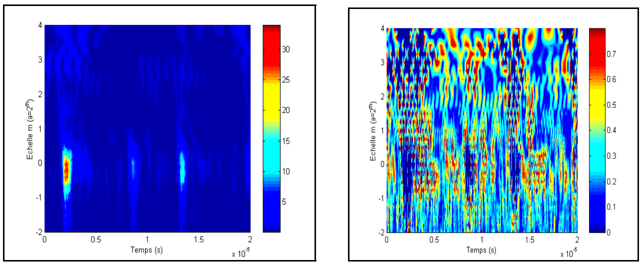
Fig. 3 The filter with the analysing functions

4 Discussion

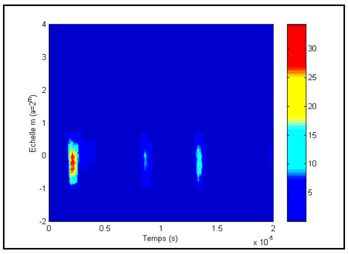
Noise filtering of the original signal is achieved if only a few wavelet coefficients representative of the signal are retained. In this work, the discrete transform has needed extensive tree decomposition for each signal, and an amount of time computing for the choice of the best averaging for the selection of the filter levels. Even, in some experiments, the reconstruction of the signal components was not achieved due to the waste of some useful information from the filter bank tree [8].

The wavelet packet analysis has allowed a largest decomposition, which generates extensive set of data but with a refined signal reconstruction [8]. A combination between continuous transform and wavelet packet transform gave enhanced results but an extensive data bank experiments was required for the use of the appropriate analyzing functions[8, 9] i.e. the signal has been analysed by the 8th derivative Gauss function for continuous resolution, and then reanalysed by the Debauchee of order 8 function for the wavelet packet resolution.

As a result, advances in the automatic threshold control were based on the investigation of the noise features [10]. In this study the proposed algorithm based on the level energy concentration of the wavelet coefficients has enabled the identification of the ultrasonic structural noise analyzing function by which the random nature of the noise is overcome. The algorithm runs on a one cycle for each data analysis and provides an output image with high quality parameters, see experiment in fig .4 of an ultrasonic signal time scale representations of 1mm defect signal and the filtering result.



a. '8th Gauss' input signal b. 'Morlet' extracted noise



c. Filtered signal by Mini-max smoothing

Fig.4 Example of 1mm defect signal in steel plate

5 Conclusion

Non linear denoising of ultrasonic signals captured from welds, with multiscale approximation using thresholding, permits an adaptive representation of the signal discontinuities. In this project, a multiresolution analysis has been achieved and new methods for signal filtering are proposed. As a result, a combination of continuous wavelet transform and wavelet packet transform, indicates that the structure noise can be divided into several frequency bands, which are generally different from those of defects echoes, which allows to the defect to be pointed out easily. As well the new minima maxima energetic algorithm involves the energetic matter of the signal and the noise, by means of minimisation of a smoothing functional. In this algorithm no signal decomposition is performed and the threshold level is determined by an arithmetic process of the maximum and the minimum wavelet coefficients energetic level. Therefore the structural noise is approximated by a wavelet function, and the denoising process is carry out by discrimination between two wavelet functions. This algorithm is powerful if the selected analyzing functions are the best matching wavelet functions to signal and noise information.

References

[1] Mike C. Tsao, Measurement and analysis of ultrasonic beam profiles in a solid. Material evaluation, 1998; Vol. 56, N° 5

[2] Abbate, J. Koay, J. Frankel, Signal and noise suppression using a wavelet transform signal processor: application to ultrasonic flaw detection. IEEE, Trans. ultrasonic, ferroelectrics, and frequency control 1997; Vol. 1, N° 1

[3] S. Mallat, A theory for multi-resolution signal decomposition: the wavelet representation. IEEE Trans. pattern analysis and machine intelligence 1989; Vol.11, N°7:674-693

[4] C.S. Burrus, R. A. Gopinath, H. Guo, "Wavelets and wavelet transforms", Rice University, Houston Edition 98.

[5] S. Mallat, "A wavelet tour of signal processing", academic press, 1998, New York.

[6] Donoho, D. L, "De-noising by soft-thresholding", IEEE Transactions on Information Theory, Vol. 41, No. 3 (1995), p. 613-627

[7] P.C.Ching, H.C. So, S.Q. Wu; Wavelet de-noising and its application to time delay estimation. IEEE Trans. signal processing 1999; Vol. 47, N°10

[8] F.Bettayeb, S. Aoudia, S. Haciane, "Improving the time resolution and signal noise ratio of ultrasonic testing of welds by the wavelet packet", NDT&E international, Elsevier, Vol. 38, 2005

[9] F.Bettayeb, T. Rachedi, H. Benbartaoui, " An improved automated ultrasonic NDE system by wavelet and neurone networks" 2004; Ultrasonics, Elsevier, Vol.42: 853-858

[10] F. Bettayeb, D. Benbachir, K. Boussiha, "An energetic smoothing analysis for the ultrasonic signal de-noising and defect detection", in proceeding BB 103-CD of the 9th ECNDT, ISBN 3-931381-86-2, published & copyright by DGZfp e.V, 2006.

[11] A.R. Ferreira Da Silva, "Wavelet denoising with evolutionary algorithms", Digital signal processing, Elsevier, Vol.15, issue 4: 382-399, July 2005.

[12] E. Pardo, J.L. San Emeterio, M.A. Rodriguez, A. Ramos, "Noise reduction in ultrasonic NDT using undecimated wavelet transforms", Ultrasonics, Elsevier, Vol. 44, 2006, 1063-1067.