The ANSYS De-noising Processing Based on the Mathematical Morphology

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Abstract

By using ANSYS finite element analysis software, the defect and zero defect models has been established are loaded the same current value. Meanwhile, with changing the input current value, the current distribution, magnetic flux density distribution, electromagnetic force and crack deformation of the two models are analyzed comparatively. Hence, the loading mechanism is proved by the analysis result of metal plate stimulating acoustic emission signal under the heavy current. This paper combines the wavelet analysis and mathematical to cancel noise for the moderating effect of external noise will influence subsequent processing signals in the signal transmitting by the electromagnetic excitation. Simultaneously, we deal with the signal by the hard threshold and soft threshold function to get the denoising results contrast figure. It not only can eliminate the noise signal of high and low frequency, but also keeps the details of the characteristics of the original signal. And it is conductive to subsequent processing of the signal.

Keywords

ANSYS finite element analysis software; Mathematical morphology; De-noising.

1. Introduction

Under the conditions of electromagnetic load, the frequency range and amplitude range of the excited acoustic emission signals are both wide, most of the acoustic emission signals are wideband short pulses which contains all kinds of information of the wave source[1].

In the process of metal plate crack's signal detection, There are a lot of interference of outside noise, which has also determined the importance of the external noise signal processing and recognition, furthermore, effective signal processing can avoid unnecessary errors in judgment, and so this makes it urgent problems to remove the noise signal effectively and to analyze the test results exactly[2].According to the characteristics of the noise, this paper has proposed a de-noising program contrapuntally which combines wavelet packet analysis and mathematical morphology.

2. Combined de-noising method based on the wavelet analysis and mathematical

In this section we have proposed a de-noising program contrapuntally which combines wavelet packet analysis and mathematical morphology according to characteristics of electromagnetic Acoustic emission noise signal.

2.1 Filter of morphology

When applied to the signal processing, mathematical morphology will only transform some specific shape characteristic in analyzing and processing signals. The local transformation is applied to analysis complete signal, and then we will get each component, simplify the complex signals, reserve the detail feature of original signal perfectly[4].However, the signal will be attenuated gradually in its transformation. The method will not suitable for signal processing any more when it is very weak, because it is difficult to distinguish directly between noise and vibration attenuation pulse from the shape feature by mathematical morphology signal processing.

Generally, mathematical morphology morphological transformation can be divided into erosion, dilation, morphological opening / closing and morphological closing / opening. As for one-dimensional signal processing, morphological transformation can be described as follows:

Assume that input sequence $f(n)$ and sequence structure element $g(n)$ are defined discrete function on $F=\{0,1,...,N-1\}$ and $G=\{0,1,...,M-1\}$ respectively, and $N \ge M$ .Then the erosion and dilation of $f(n)$ about $g(n)$ are respectively defined [5]:

$$(f \otimes g)(n) = \min\{f(n+m) - g(m)\}\big|_{m=0,1,...,M-1} \quad (1)$$

$$(f \oplus g)(n) = \max\{f(n-m) + g(m)\}\big|_{m=0,1,...,M-1} \quad (2)$$

Among them: $\otimes$ represents erosion operator; $\oplus$ represents dilation operator.

The opening and closing operation of $f(n)$ about $g(n)$ are respectively defined：

$$(f \circ g)(n) = (f \otimes g \oplus g)(n) \quad (3)$$

$$(f \bullet g)(n) = (f \oplus g \otimes g)(n) \quad (4)$$

Among them: $\circ$ represents morphological opening operation operator; $\bullet$ represents morphological closing operation operator.

Morphological opening and closing operation can not only effectively inhibit signal positive impulse noise, but also prevent negative impulse noise, in this way it can achieve the achievement of smoothing. Filters of morphological opening - closing and closing – opening are respectively defined:

$$OC(f(n)) = (f \circ g \bullet g)(n) \quad (5)$$

$$OC(f(n)) = (f \bullet g \circ g)(n) \quad (6)$$

Although these two filters can both effectively eliminate positive and negative pulses, there are drawbacks existing individually, output amplitude of opening – closing filters is small due to the effect of opening operation shrinkage; Conversely, output amplitude of closing – opening filters is large due to the effect of closing operation expansion. It make statistics deviating and then reduce the performance of its noise suppression. In order to avoid this deviation, we can combine the opening – closing and the closing – opening to form a kind of more effective filter defined:

$$y(n) = \left[OC(f(n)) + CO(f(n))\right]/2 \quad (7)$$

In addition to selecting different forms to change the effect of morphological filtering, It is also generally associated with the shape, width, and height of the structural elements. The structure elements can be divided into many kinds such as linear, triangular, semi-circular, sine type and so on, among which the most widely used is the linear type. However, and only those structural elements that match the signal primitives can be effective. Therefore, we should observe and analyze the signal to be processed, and then select the structural elements matched. The calculation of structure elements is determined by its complexity and length.

2.2 Combined de-noising based on the wavelet analysis and mathematical

The threshold value processing of wavelet coefficient has been the key of wavelet threshold de-noising. Now, the common wavelet threshold function is divided into hard threshold function and soft threshold function. The hard threshold method is setting a threshold value, all wavelet coefficient components that below that value are forced to zero, other wavelet coefficients are not processed. The soft threshold method is that the wavelet coefficients are gradually approaching zero and the reconstruct the processed wavelet coefficients.

The hard threshold function expression is:

$$\eta(x,\lambda)=\begin{cases}x,|x|\ge\lambda\\0,|x|<\lambda\end{cases} \tag{8}$$

The soft threshold function expression is:

$$\eta(x,\lambda)=\begin{cases}x-\lambda,x\ge\lambda\\0,|x|<\lambda\\x+\lambda,x\le\lambda\end{cases} \tag{9}$$

Among them, the x is wavelet coefficient, the λ is threshold value.

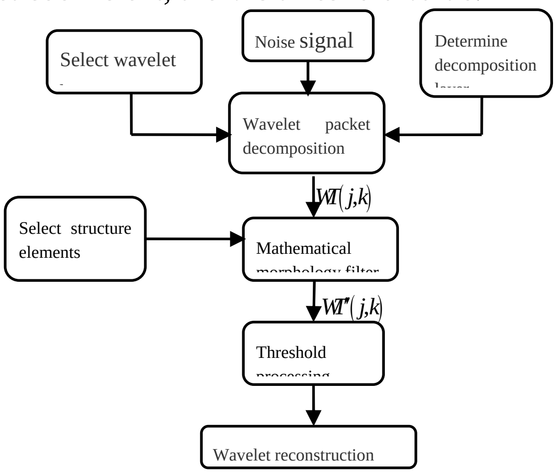

Figure 1. Flow chart of combined de-noising

This paper has combined the advantages of wavelet analysis and mathematical morphology. The concrete steps of combined de-noising as follows:

(1)Select wavelet bases and scales j ,determine decomposition layer N ,and decompose acoustic emission signals of cracked metal plate generated under condition of electromagnetic loading, and then extract wavelet coefficients $WT(j,k)$ of each layer；

(2)Select the flat structural elements of certain length, use mathematical morphology filter to filter wavelet coefficients $WT(j,k)$ of each layer, then we will get the new wavelet coefficients $WT''(j,k)$；

(3)Define the λ_j of threshold, and then multiplied by coefficient $k(0<k<1)$, work out the coefficient $k(0<k<1)$ through adaptive algorithm, threshold wavelet coefficient $WT''(j,k)$ through hard threshold method;

(4)Reconstruct the processed wavelet coefficient $WT''(j,k)$ from step ③,then we can get the signal after de-noising.

We need to consider various factors while applying the method to the actual situation, such as signal stability and SNR will both affect the effect of de-noising, so it is essential to take the adaptive strategy. As for the non-stationary signals, threshold should be appropriately small. This paper has taken the Automatic threshold function to estimate threshold:

$$\lambda_j=m_j\sqrt{2\ln(n_j)}\Big/0.6745 \tag{10}$$

In the formula, λ_j is the value of the j layer's wavelet decomposition threshold; m_j is the median of the j layer's wavelet decomposition coefficients; n_j is the number of the j layer's wavelet decomposition coefficients.

3. Results of simulation and analysis

In order to verify the effect of wavelet - morphological fusion algorithm, we have taken the simulated electromagnetic acoustic emission signals involved in the front part of this paper, and then add white noise with SNR of -7dB to the basis of the original signal, as shown in Figure 1-5.

In order to verify the effectiveness of this method, we can use the mean square error (MSE) of signal pulses to measure the level of de-noising and waveform distortion, the formula of mean square error (MSE) as follows, that is

$$e_{MSE} = \frac{\sum_{i=1}^{N} \left| Y(i) - X(i) \right|^2}{length\left(Y(i)\right)} \times 100\%$$

$Y(i)$, $X(i)$ are signals with noise and after de-noising respectively.

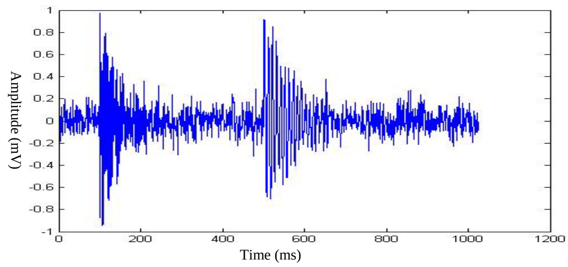

Figure 2. Signals contain noise

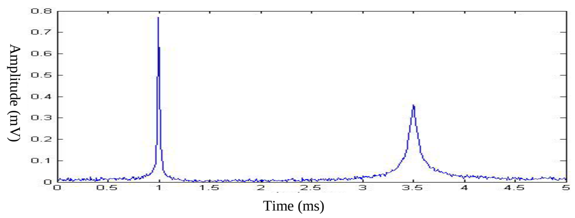

Figure 3. Spectrogram of noise signal

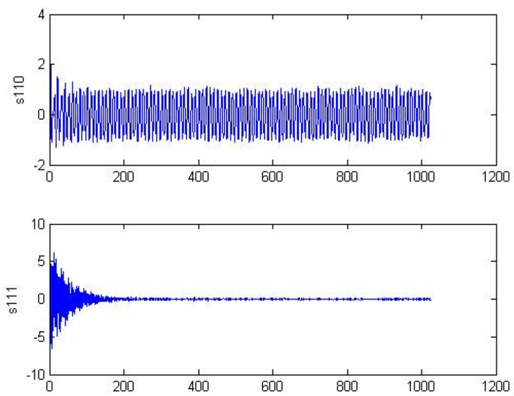

Figure 4. Decomposition waveform of wavelet packet's first layer

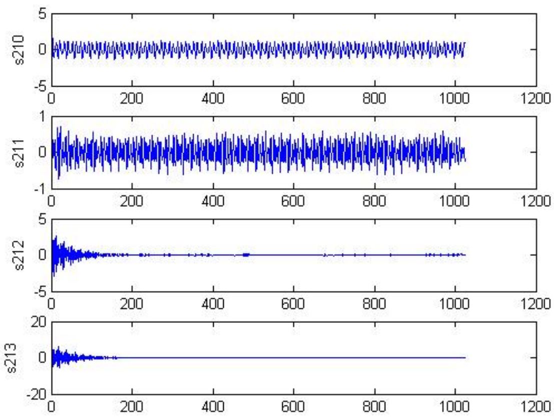

Figure 5. Decomposition waveform of wavelet packet's second layer

Apply wavelet hard threshold de-noising, wavelet soft threshold de-noising, wavelet-morphology fusion algorithm to pending noise signal respectively. The wavelet basis function takes wavelet of sym6 and the number of wavelet packet decomposition layers is 3. Figures 6-11 are decomposition waveform of wavelet packet's first, second and third layer respectively.

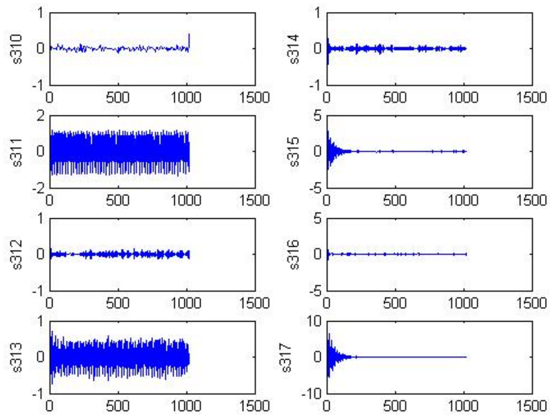

Figure 6. Decomposition waveform of wavelet packet's third layer

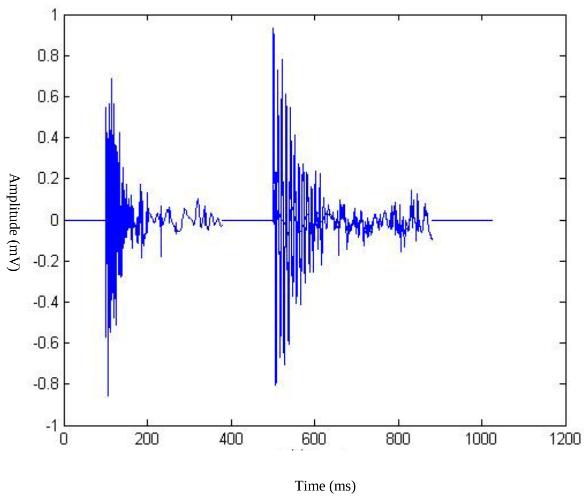

Figure 7. De-noising figure of soft threshold

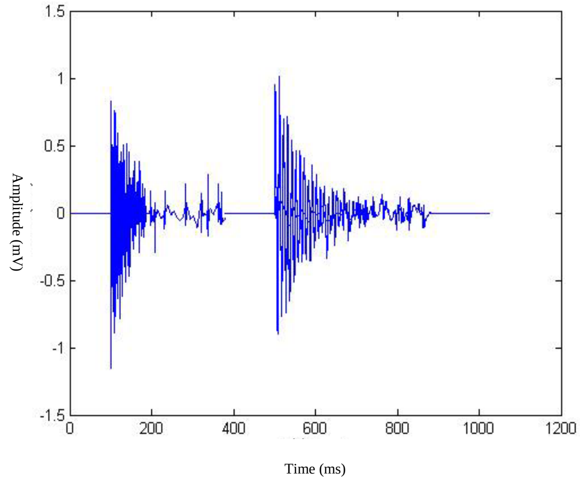

Figure 8. De-noising figure of hard threshold

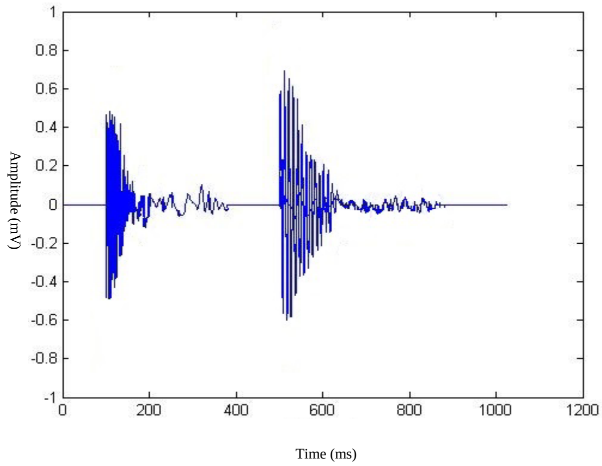

Figure 9. De-noising figure of wavelet – morphology

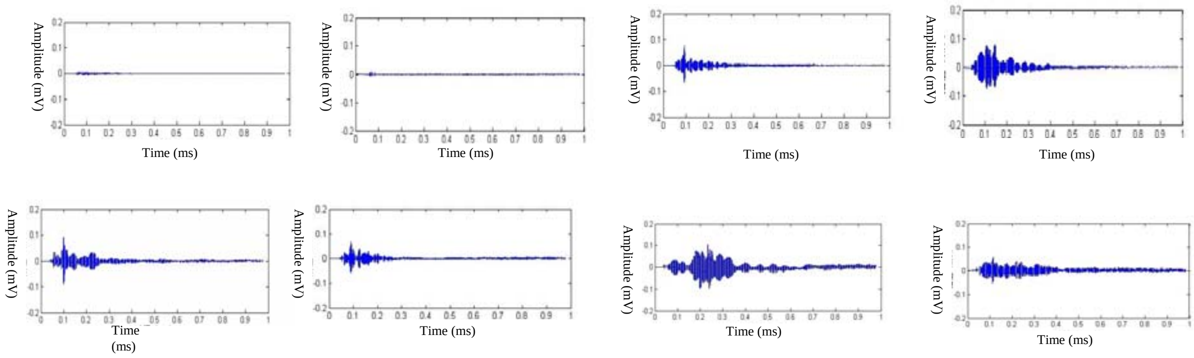

Figure 10. Process of combined de-noising

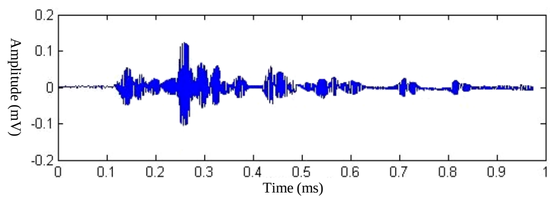

Figure11. Signal waveform of wavelet - morphological processing

4. Conclusion

This paper verify the principle of electromagnetic acoustic emission by using ANSYS finite element analysis software, according to the characteristics of noise signal, combines the advantages of wavelet analysis and mathematical morphology and applies it to the electromagnetic acoustic emission signal de-noising, then compares the combined de-noising program to that of normal soft or hard threshold, The results show that the effect of wavelet-morphology is more apparent. It not only can eliminate the noise signal of high and low frequency, but also keeps the details of the characteristics of the original signal. And it is conductive to subsequent processing of the signal.

Acknowledgment

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