

REMOVING EDDY-CURRENT PROBE WOBBLE NOISE FROM STEAM GENERATOR TUBES TESTING USING WAVELET TRANSFORM

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ABSTRACT

One of the most important nondestructive evaluation (NDE) applied to steam generator tubes inspection is the electromagnetic Eddy-Current testing (ECT). The signals generated in this NDE, in general, contain many noises which make difficult the interpretation and analysis of ECT signals. One of the noises present in the signals is the probe wobble noise, which is caused by the existing slack between the probe and the tube. In this work, Wavelet Transform (WT) is used in the probe wobble de-noising. WT is a relatively recent mathematical tool, which allows local analysis of non stationary signals such as ECT signals. This is a great advantage of WT when compared with other analysis tools such as Fourier Transform. However, using WT involves wavelets and coefficients selection as well as choosing the number of decomposition level needed.

This work presents a probe wobble de-noising method when used in conjunction with the traditional ECT evaluation. Comparative results using several WT applied to Eddy-Current signals are presented in a reliable way, in other words, without loss of inherent defect information.

A stainless steel tube, with 2 artificial defects generated by electro-erosion, was inspected by a ZETEC MIZ-17ET ECT equipment. The signals were de-noised through several different WT and the results are presented. The method offers good results and is a promising method because it allows for the removal of Eddy-Current signals probe wobble effect without loss of essential signal information.

1. INTRODUCTION

Steam generator tubes bundles can be inspected by several different types of non destructive evaluation (NDE). However, for in situ inspection, due to layout restrictions as well as to operational conditions, Eddy-Current Testing (ECT) is one of the best choices applicable to this equipment defect detection. Classification and localization of the defect by the ECT inspection allows for corrective actions to be taken in due time in order to assure reliable and safe operation of the steam generator [1].

However, when the signal is contaminated by noises, the interpretation of the *ECT* signals are done subjectively by the inspectors which can induce, for the sake of conservatism, to premature closure of tubes. To avoid such a situation, the lesser amount of noise in the signal, the interpretation of the signal will be more precise, the lesser the chances of an incorrect decision being taken. One of the most common noise, which is always present, is due to the probe wobble inside the tube caused by the needed gap between the probe and the inner wall [2]. The probe wobble produces a low frequency fluctuation in the signal, which changes the voltage amplitudes of the reactive component jeopardizing the correct localization and dimensioning of a defect. In this work we use the Discret Wavelet Transform (*DWT*) [3] as an alternative to the traditional phase discrimination method [4]. *DWT* removes efficiently the noise caused by the probe fluctuation without losing original information contained in the signal, about the defect being sought.

A *DWT* applied to signal processing is a relatively new technique and allows for localized time frequency analysis of non stationary signals such as the *ECT* signals. This is the greatest advantage of *DWT* when compared to other analysis tools such as the Fourier transform, for example, which relies on the periodicity of the function to obtain an acceptable result. *DWT* is sensible to discontinuities in the time domain, which is a important characteristic of *ECT* signals. Using *DWT* requires, however, the correct choice of the wavelet functions $\psi_{j,k}(t)$ and the selection of the transformed coefficients $C(j,k)$ at a given scale decomposition level.

The objective of this work is to present *DWT*, as a fundamental tool to remove the noise generated by *ECT* probe wobble, and to show the effects of using different wavelet functions. The signals processed in this present work were generated by a *ECT* inspection equipment from ZETEC using probes with circumferential coils in a differential mode arrangement. Only the inductive voltage components, X_L of the inspection coil circuit was considered in this work. The voltage changes in the signal are caused by discontinuities found by the probe, which change the material properties, in particular the electrical conductivity (σ). The inspections were carried out on a stainless steel tube *ASTM-A-249-316L*, 19,05 mm in diameter, 1,24 mm wall thickness (*BWG 18*), with 2 artificially implanted defects produced by electro erosion, in the form of full through wall holes with 0,9 mm and 1,1 mm in diameter, properly separated from each other.

2. THE DISCREET WAVELET TRANSFORM (DWT)

The WT of a given signal s is the family of coefficients $C(a,b)$, which depends on the two index a and b . View from a intuitive standpoint, the wavelet decomposition can be considered as the calculation of “similarity indices” between the signal and the wavelet function at each time shift b and scale a . If the index has a high value, the similarity is high and otherwise, it is weak. These indices are named the coefficients $C(a,b)$ and are defined by the equation (1).

$$C(a,b) = \int_R s(t) \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) dt \quad a = 2^j, b = k2^j, (j,k) \in Z^2 \quad (1)$$

Substituting a e b in (1) results:

$$C(j,k) = \int_R s(t) \cdot 2^{-(j/2)} \psi(2^{-j}t - k) dt \quad (j,k) \in Z^2 \quad (2)$$

Equating (1) and (2):

$$\psi_{j,k}(t) = 2^{-(j/2)} \psi(2^{-j}t - k) \quad (3)$$

Substituting (3) in (2) we obtain the definition of *DWT*:

$$C(j,k) = \int_R s(t) \psi_{j,k}(t) \quad (4)$$

To be efficient and useful, an analysis method should be capable of performing the signal synthesis and the *WT* has this capability.

The analysis starts by decomposing and transforming the signal at each scale level resulting in the coefficients $C(j,k)$. The synthesis starts from the coefficients $C(j,k)$ and reconstructs the original signal s by inverse transforming. For finite energy signals the wavelet inverse transform is defined by equation (5).

$$s(t) = \sum_{j \in \mathbb{Z}} \sum_{k \in \mathbb{Z}} C(j,k) \psi_{j,k}(t) \quad (5)$$

From the synthesis equation, one can obtain the approximations and details of the original signal at each level j by summing over every time shift k , from equation (5), which is shown in equation (6) below for the detail part of the decomposed signal:

$$D_j(t) = \sum_{k \in \mathbb{Z}} C(j,k) \psi_{j,k}(t) \quad (6)$$

Performing now the summing over all levels j , one can recover the original signal using all the details as shown in equation (7):

$$s = \sum_{j \in \mathbb{Z}} D_j \quad (7)$$

All the details are therefore considered. Defining a reference detail level J , one can separate two classes of details. Those with level $j \leq J$ corresponding to scales $a = 2^j \leq 2^J$ which can be called refined details. And the others with $a = 2^j > 2^J$, are the coarse details. We grouped these details according to equation (8):

$$A_J = \sum_{j > J} D_j \quad (8)$$

and named it as the approximations to the signal s , which can be calculated by equation (9)

$$s = A_J + \sum_{j \leq J} D_j \quad (9)$$

Equation (9) can be written as:

$$s = D_1 + D_2 + \dots + D_j + \dots + A_J \quad j = 1, 2, \dots, J \quad (10)$$

The decomposition presented by equation (10) allows us to separate the noise from the useful part of the signal. Additionally, the useful part of the signal can be extracted by using the coefficients already calculated from the decomposition.

3. WAVELET TRANSFORM USED TO PROBE WOBBLE NOISE REMOVAL

The probe wobble noise removal was made by using 4 selected wavelet [5]. The wavelet selection took in to account the visible differences among the wavelet as presented in Fig. 1.

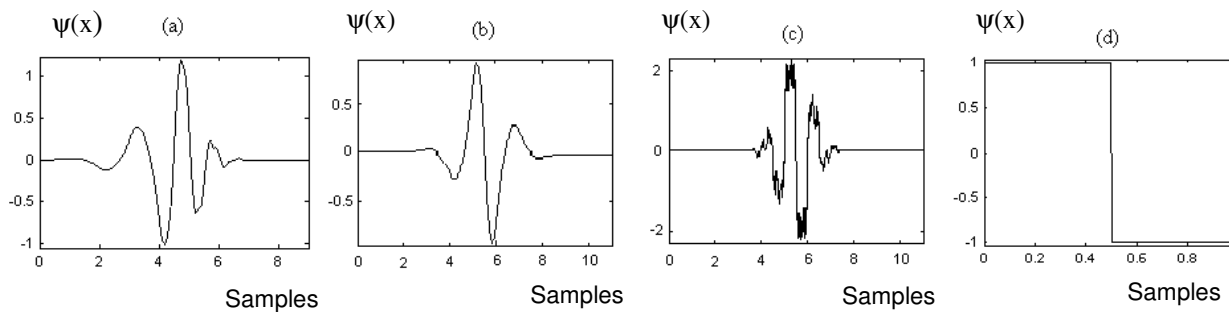


Figure 1. Wavelet used to signal processing: (a) Daubechies 5, (b) Biortogonal 3.5, (c) Biortogonal Reverse 3.5 and (d) Haar

These wavelet were used to processing signals generated though a ZETEC MIZ-17ET Eddy Current test equipment in the inspection of the stainless steel tube described in item 1.

The number of decomposition levels affects the signal processing [6]. In this word is presented the result of several wavelet application to the signal decomposed in 9 levels, allowing the appropriate selection of D_j and A_j coefficients.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The four wavelet present above were used to signal processing of the original signal obtained from the probe passing through tube inner side, as presented in Figure 2.

Figures (3), (4), (5) and (6) present the results of DWT application through use of wavelets Daubechies 5, Biortogonal 3.5, Biortogonal Reverse 3.5 and Haar to the original signal, removing A_j approximation which is the low frequency and high amplitude signal component.

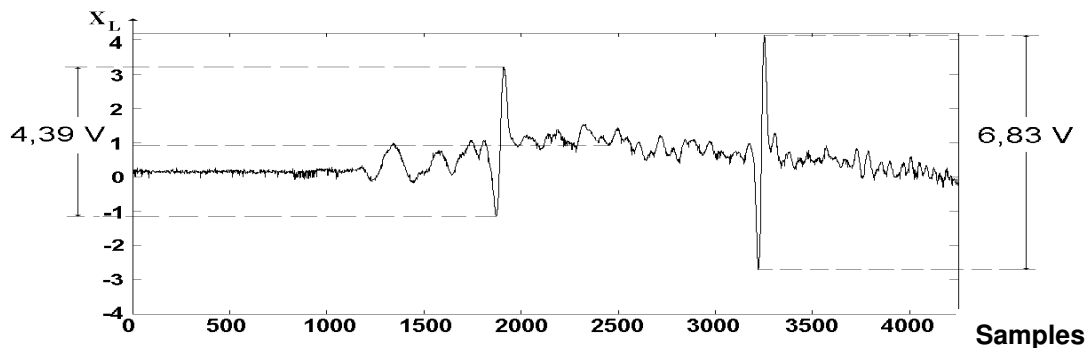


Figure 2. Original Signal

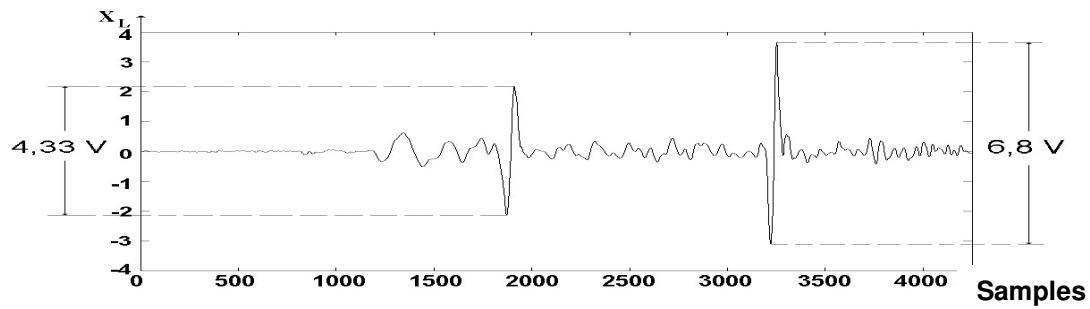


Figure 3. Processed signal through DWT Daubechies 5

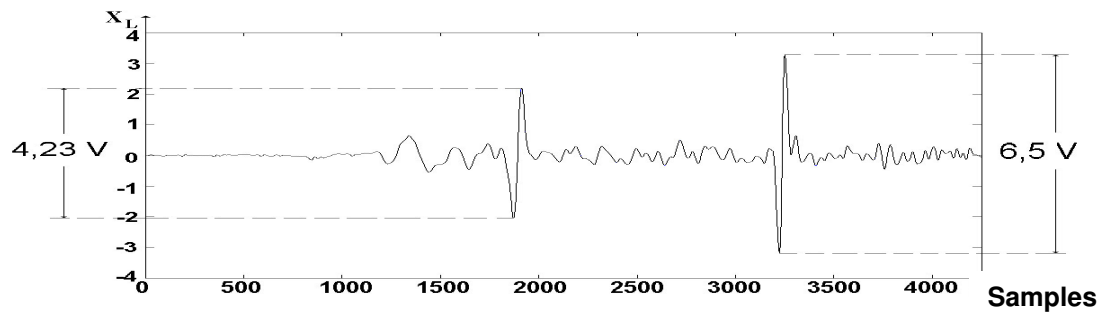


Figure 4. Processed signal through DWT Biortogonal 3.5

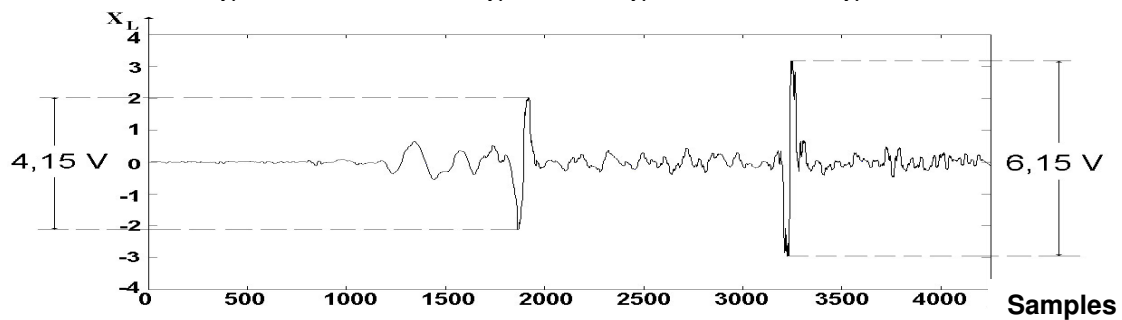


Figure 5. Processed signal through DWT Biortogonal Reverse 3.5

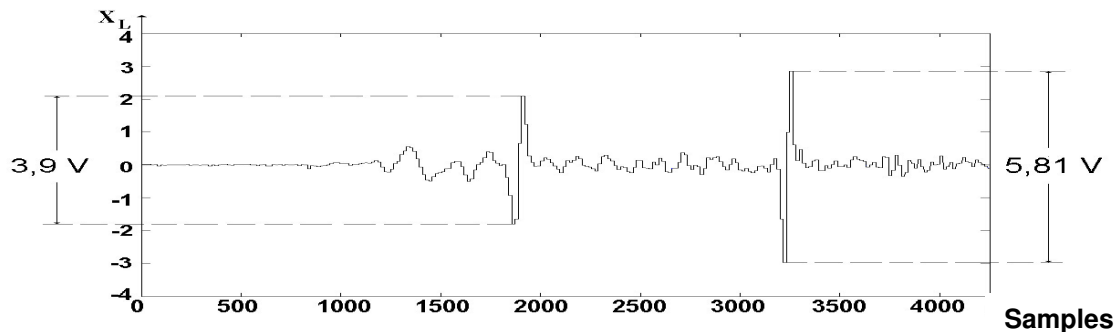


Figure 6. Processed signal through DWT Haar

The most important result that can be observed is the original signal medium curvature removal which is the lower frequency component. Figure 2 presents that there is a low frequency component dislocating the signal till 1 Volt above tension axis in a region where the signal should be around zero Volt. That component is completely eliminated through all processes.

The criterion to distinguish the efficiency of a wavelet application is the signal total amplitude maintenance because this parameter is extensively used by Eddy Current inspectors. Figure 3, which shows Daubechies 5 DWT used, presents the best result by considering that signal amplitude was approximately maintained.

Figures 4 and 5 show the results of DWT Biortogonal and Biortogonal Reverse use. The signal amplitude limits were reduced from 4.39 Volts to 4.23 Volts and 4.15 Volts in the first defect and from 6.83 Volts to 6.5 Volts and 6.15 Volts in the second defect respectively. This is a reduction which can prejudice the inspector decisions with respect to defect characterization.

The results presented in Figure 6, where it was used DWT Haar, can be considered unacceptable under Eddy Current inspection point of view because present big amplitude reductions. It is important to note that all figures present a remaining noise due to tube imperfections and that was not removed because it is not a consequence of probe wobble inside tube.

5. CONCLUSIONS

From the comparison above, it can be concluded that Daubechies 5 DWT presents the best results due to the non symmetric shape of its wavelet function, which is best adjustable to the transient nature of Eddy-Current signal. This wavelet removes efficiently the noise due to probe wobble without signal characteristics changes. The results presented through Biortogonal Reverse 3.5 DWT use are worst than those presented through Biortogonal 3.5 DWT because wavelet function peaks are not compatible with Eddy-Current signal peaks. The Haar DWT use not only changed hardly signal reactance limits as well hurt its resolution, because besides symmetric, it also present a non continuity.

ACKNOWLEDGMENTS

The authors thank to O. P. Negrão Jr. (Interativa – Manutenção Preditiva Ltda.), for assistance.

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