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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 walls. 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 two 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.

Keywords: Eddy-Current; Probe wobble; Noise; Steam generator; Wavelet Transform

1. Introduction

Steam generators tubes' bundles can be inspected by several different types of nondestructive evaluation (*NDE*).

The most common *NDEs* are Visual Inspection, Ultra-Sound and Eddy-Current testing (*ECT*). For in situ inspection, due to lay out restrictions as well as operational conditions, Eddy-Current testing (*ECT*) is one of the best choices applicable to steam generators' defect detection. Classification and localization of the defect by the *ECT* inspection allow for corrective actions to be taken in due time in order to assure reliable and safe operation of the steam generator (Stegemann et al., 1997).

ECT is an electromagnetic test whose signals are presented in the impedance (Z) plane as "8" shaped Lissajous figures (Stegemann, 1986). Those figures are formed when bobin coil probes passes through the internal side of inspected tubes. Fig. 1 presents the Lissajous figure formation.

ECT signals have resistive (R) and inductive (X_L) components in such a way that:

$$\vec{Z} = \vec{X}_L + \vec{R} \qquad (1)$$

or,

$$|Z| = \sqrt{X_L^2 + R^2} \qquad (2)$$

The Lissajous figure is formed as the impedance values change in the impedance plane as presented in Fig. 2.

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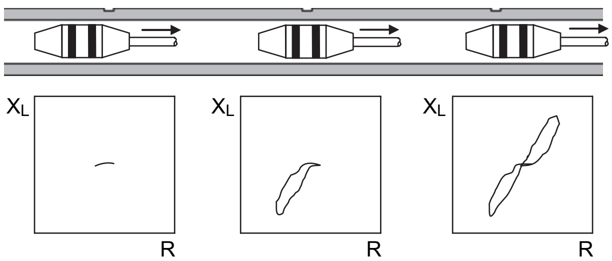

Fig. 1. Lissajous figure formation.

Fig. 3 presents a typical standard noise free *ECT* signal in the impedance plane and its resistive and inductive components.

However, when the signal is contaminated by noises, the interpretation of the *ECT* signals is done subjectively by the inspectors which can induce, for the sake of conservatism, to premature closure of tubes. The unnecessary plugging of tubes reduces capability of heat transmission and can result in equipment scrapping. On the other hand, if a damaged tube is not plugged, it can fail during operation causing leakage and obvious losses.

The noises present in *ECT* signals frequently change strongly the shape of the Lissajous figures. 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.

The most common noises are caused by signal acquisition interference (Lopez et al., 2003), material magnetic characteristics (Lopez et al., 2005) and probe fluctuation (lift-off effect) (Lopez and Mazaro, 2003). Fig. 4 shows an extremely noisy *ECT* signal.

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 (Stegemann, 1986). 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 Discreet Wavelet Transform (*DWT*) (Chui, 1992) as an alternative to the traditional phase discrimination method (Stegemann, 1990). *DWT*

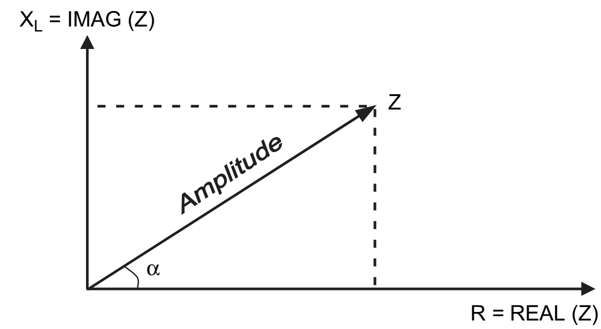

Fig. 2. Impedance plane.

removes efficiently the noise caused by the probe fluctuation without loosing 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 an 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 an *ZETEC MIZ-17ET ECT* inspection equipment, as presented in Fig. 5, using probes with circumferential bobin coils in a differential mode arrangement.

The *ECT* signals were acquired using *LABVIEW* software and the signals were processed through an algorithm (Lopez et al., 2006; Lopez, 2002) specially conceived in *MATLAB* software.

Only the inductive voltage components, X_L of the inspection coil circuit, were considered in this work. The voltage

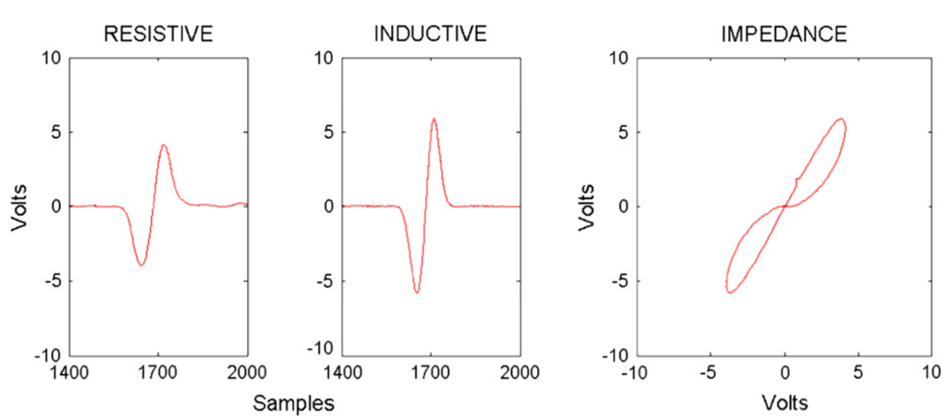

Fig. 3. Resistive, inductive and impedance plan views.