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DIAGNOSTIC OF CORROSION DEFECTS IN STEAM GENERATOR TUBES USING ADVANCED SIGNAL PROCESSING FROM EDDY CURRENT TESTING

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ABSTRACT

Recently, the Brazilian Angra I PWR nuclear power plant went into a programmed shutdown for substitution of its Steam Generator (SG) which life was shortened due to stress corrosion in its tubes. The total cost of investment were around R$724 million. The signals generated during an Eddy-current Testing (ECT) inspection in SG tubes of nuclear plant allows for the localization and dimensioning of defects in the tubes. The defects related with corrosion generate complex signals that are difficult to analyze and are the most common cause in SG replacement in nuclear power plants around the world. The objective of this paper is the development of a methodology that allows for the characterization of corrosion signals by ECT inspections applied in the heat exchangers tubes of SG of a nuclear power plant. In this present work, the aim is to investigate distributed type defects by inducing controlled corrosion in sample tubes of different materials The ECT signals obtained from these samples tubes with corrosion implanted, will be analyzed using Zetec ECT equipment, the MIZ-17ET and its probes. The data acquisition will use a NI PC A/D CARD 700 card and the LabVIEW program. Subsequently, we will apply mathematical tools for signal processing like time windowed Fast Fourier transforms and Wavelets transforms, in MATLAB platform, which will allow effectiveness to remove the noises and to extract representative characteristics for the defect being analyzed. Previously obtained results as well as the proposal for the future work will be presented.

1. INTRODUCTION

Heat exchangers tubes of Steam Generator (*SG)* frequently present unexpected leaks in their tubes resulting in losses of time and money. The degradation of *SG* tube occurs by different mechanisms such as chemical corrosion, stress, deposits, mechanical fretting, or the combination of these. The corrosion defects are the most common in *SG* causing replacements in nuclear power plants around the world. The main degradation due to corrosion defects are: thinning (*THI*), pitting (*PHI*), inter-granular attack (*IGA*), stress-corrosion cracking (*SCC*), inter-granular attack and simultaneous stress-corrosion cracking (*ISC*). The degradations due to mechanical causes are: wear (*WEA*), impingement (*IMP*) and fatigue. Thinning is a generic term that refers to volumetric material loss. The local chemical conditions are altered before it begins. The attack initiates by the surface material dissolution. There is no evidence of granular border attack. This defect is generally found near the tube support plate and other support structures. The *IGA* plus *SCC* is a generic description for a degradation caused by a combination of factors: susceptible material, corrosive chemical conditions, and localized stress. The *IGA* alone has volumetric shape and is caused by a uniform grain border attack. *SCC* consists of multiple cracks with inter-granular propagations. Pitting defect is due to general corrosion or due to local galvanic differences with acids attack by cooper compounds. It assumes volumetric geometry without granular-border attack and has a limited extension (approximately 0.1 inches). Impingement is a specific degradation type caused by suspended solids that impact tube surface, which often occurs in once-through steam generator. Wear is a degradation caused by the impact of a spurious object or tube interaction with support structure. The associated morphology depends on the shape of the impacting agent [1].

These tubes is inspected through some Nondestructive Testing (*NDT*). The Eddy-Current Testing (*ECT)* is an electromagnetic method largely applied to volumetric defect detection (with loss of material) or not [2]. In the *ECT*, a bobbin coil probe is introduced into the tube and signals are generated allowing the localization and sizing of defects, resulting in a safe heat exchanger operation. The signal interpretation in general is made by inspectors. However, these signals are usually corrupted by several types of noise [3] resulting in decision doubts and early tubes plugging. So, reducing signal noise, signal analysis is more accurate and erroneous decisions are minimized.

In this work the signals processed will be generated by a Zetec *ECT* equipment MIZ-17ET. Figure 1 shows the complete hardware used for data acquisition. The probe used has two circumferential bobbin coils connected to a differential self-compared model.

Figure 1 - Data acquisition hardware.

2. SIGNALS GENERATION

The *ECT* is a fast and widely used inspection method based on the magnetic induction of circular Eddy Currents in the tubes as consequence of a primary magnetic field generated by a bobbin coil probe [4] as shown in figure 2.

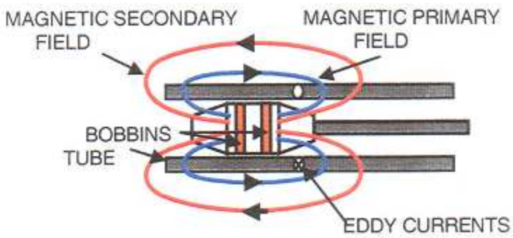

Figure 2. ECT principles [1]

ECT signals have both the resistive (R) and inductive (X_L) components and when they are presented in the complex plane, they have the form of a Lissajous figure with a typical "8" shaped curve when no noise is present, in an ideal setting. The phase angle and the total amplitude of a signal are read according to the definition shown in figure 3.

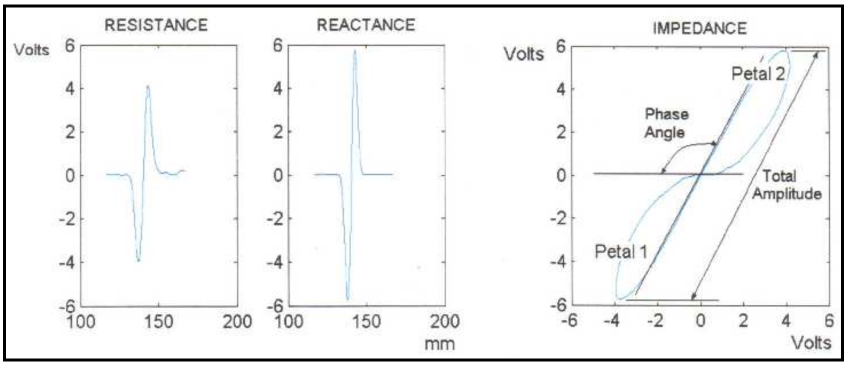

Figure 3. A typical noise free ECT signals and its characteristics [1]

The angle phase is the angle formed by the straight line common to the two petals of the Lissajous figure and a horizontal line, measured counter clockwise. The total amplitude is the measurement in Volts between the two extreme points of the Lissajous figure petals [4]. The phase angle allows for the determination of the position of the defect either at the internal wall or at the external wall of the tube. The phase angle also allows for the determination of the defect depth by using the inspection instrument calibration curve, according to the figure 4, which is standardized by ASME Code, Section V, Article 8, Appendices 1. According to the calibration curve, a full depth defect presents a phase angle of 40º.

3. NOISE REMOVAL

Actually, *ECT* signals acquired during an inspection contain noises, which can strongly interfere in their analysis [3]. These noises have many origins like those introduced by the data acquisition instrumentation [1] or by the radial movement of the probe inside the tube, called Wobble. Two types of noise related to the material itself are: those caused by chemical deposits on the surface and those caused by non-homogeneities of the material itself. These noises can produce distortions in the Lissajous figure to such an extension, where phase angle and amplitudes readings are simply impossible at all.

Some methods can be used for noise removal [3]. One of them is the Fourier analysis, a mathematical tool which allows changing the signal from a time based to a frequency based point of view through several harmonics signal decomposition. The Fourier analysis offers good results when the frequency domain information is important. However, the time information of a signal is lost and is not possible to determine when an event occurred. In stationary signals with constant period, the above mentioned deficiency is not important. However, Eddy Current signals present transient characteristics and stationary Fourier analysis is not adequate [1].

The Short Time Fourier Transform (*STFT*) is an adaptation of Fourier Transform (*FT*) which analyses a signal in steps or windows, mapping the signal as a function of time and frequency. Through this method, some information about time event occurrence is obtained but the precision is limited due to window dimension. Under *STFT* analysis, the window width is fixed and is the same for all frequencies. The *STFT* is definite as follow:

$$STFT(\tau,f) = \int_{-\infty}^{+\infty} f(t)g(t-\tau)e^{-2\pi f t}\, dt \qquad (1)$$

Where f (t) is a stationary signals placed in a window of fixed dimension $g(t-\tau)$.

The Wavelet Transform (*WT*) is a type of time-scale transformation and it combines the use of variable time windows and variable scales, allowing the use of large time intervals when precise lower frequency information is needed as well as smaller time intervals when high frequency information is required. A *WT* is very sensitive to discontinuities in the time domain, which is typical of *ECT* signals. It is a method where the transformed time frequency domain can be varied, in the other words; the resolution of the time frequency domain is not constant, allowing for a more detailed description of the time frequency behavior of the signal being analyzed. Using this tool, one can analyze the signal in as many separated frequency bands as needed [1]. For a given *ECT* signal s(x), the *WT* is a convolution of $s(x)$ with a set of Wavelet functions $\psi_{a,b}(x)$ resulting in a set of coefficients $C_{a,b}$ as follows:

$$C_{(a,b)} = \int_{-\infty}^{+\infty} s(x)\psi_{a,b}\,(x)\,dx \qquad (2)$$

4. METHODOLOGY

In the paper published by Lopez [1] Wavelet Transform was used successfully to remove noises in processing ECT signals. There are several type of wavelet functions to signals processing, as Daubechies, Biorthogonal, Symlet and Haar. The figure 5 shown a typical ECT signal seriously affected by material noise of a full depth hole with Ø 0,9 mm where the phase angle cannot be read due to strong noise.

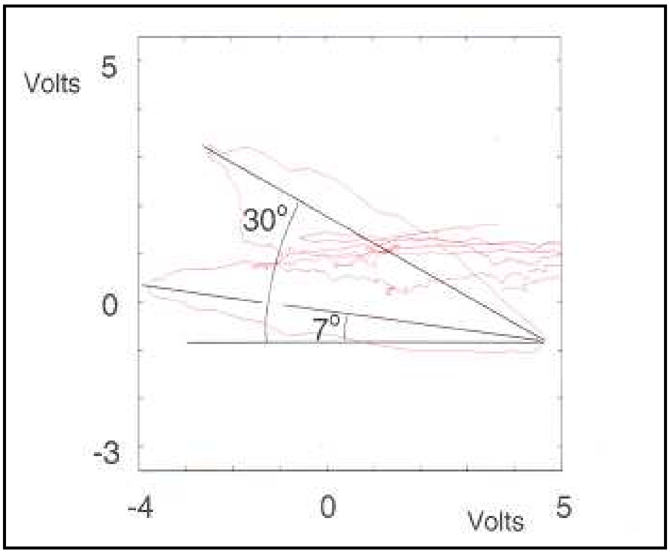

Figure 4. A typical ECT signal affected by noise [1]

The first step is to separate the resistive component (R) and inductive component (X_L) of the ECT signal. After applying TW using the MATLAB program, good denoising results are presented, such as shown in the figure 6 and 7, using Daubechies wavelets.

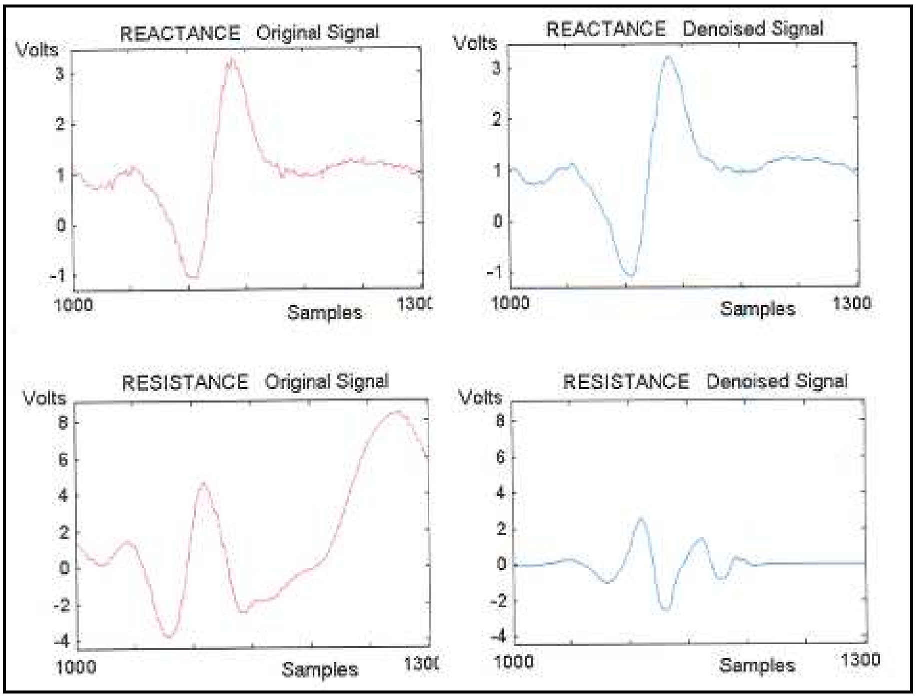

Figure 5. Original and denoised resistive and inductive components [1]

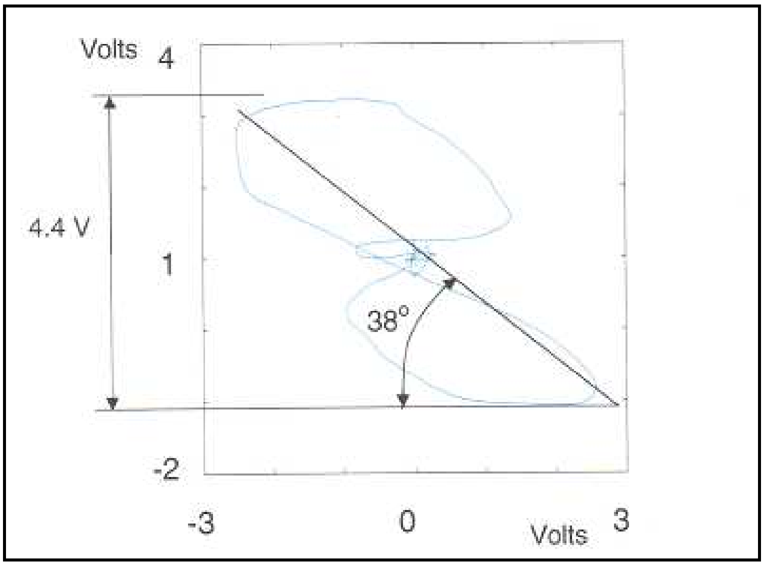

Figura 6. Final denoised signal [1]

3. CONCLUSIONS

As presented, Wavelets Transform can be used successfully in de-noising Eddy-Current signals. The other wavelet functions can basically be used to perform noise removal. However, the defects related with corrosion generate a even more complex signals that are difficult to analyze. A future work to be developed, is about a methodology that allows for the characterization of corrosion signals by Eddy-Current Testing (ECT) inspections applied in the heat exchangers tubes of Steam Generator (SG) of a nuclear power plant. In this future work, the aim will be to investigate distributed type defects by inducing controlled corrosion in sample tubes of different materials. The ECT signals obtained from these samples tubes with corrosion implanted, will be analyzed using Zetec ECT equipment, the MIZ-17ET and its probes. The data acquisition will use a NI PC A/D CARD 700 card and the LabVIEW program. Subsequently, we will apply mathematical tools for signal processing like time windowed Fast Fourier transforms and Wavelets transforms, in MATLAB platform, which will allow effectiveness to remove the noises and to extract representative characteristics for the corrosion defect being analyzed.

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