Enhancement of Pulsed Eddy Current Response Based on Power Spectral Density after Continuous Wavelet Transform Decomposition

A. Benyahia, M. Zergoug, M. Amir, M. Fodil

***Abstract*—**The main objective of this work is to enhance the Pulsed Eddy Current (PEC) response from the aluminum structure using signal processing. Cracks and metal loss in different structures cause changes in PEC response measurements. In this paper, time-frequency analysis is used to represent PEC response, which generates a large quantity of data and reduce the noise due to measurement. Power Spectral Density (PSD) after Wavelet Decomposition (PSD-WD) is proposed for defect detection. The experimental results demonstrate that the cracks in the surface can be extracted satisfactorily by the proposed methods. The validity of the proposed method is discussed.

***Keywords*—**NDT, pulsed eddy current, continuous wavelet transform, Mexican hat wavelet mother, defect detection, power spectral density.

I. Introduction

PEC is one of the famous Non Destructive Testing and Evaluation NDT-E methods used to detect cracks in conductor structures. It is used to diagnose structures in lot of applications mostly in petroleum industry, pressure vessel, aerospace structure…

The PEC technique is a reliable and mature technique, and has the advantages of not necessitating any contact, providing a wide spectrum, possessing a high identification rate, requiring less complicated operations. Because of its wide range of frequencies, both surface and sub-surface flaws of material can be detected by this technique [1]. PEC testing technical uses a pulsed excitation with different range of frequencies. It allows more penetration in structure than classical eddy current methods [2]-[4]. The PEC response signals gives information on the state of the material, inside and outside [1]. Advanced signal processing methods are applied to extract the specifications of defects from PEC response. PEC response is in time domain, it is according to the depth of defects. The representation of PEC response in frequency and time-frequency domain improved the quality of signal and facilities features extraction. Yang et al. presented a new feature, which is frequency spectrum separating point, to improve the accuracy of defect classification [5]. Kiwa et al. have used the spectrum of PEC signal to visualize defects on different depths and cross-sections of conductive materials [6]. Tian et al. have investigated the spectral response of PEC under varying probe lift-off, directional tensile stress and material properties (magnetic permeability and electrical conductivity) [7]. Yang et al. have employed features in time and frequency domain to process the PEC measured signals for automatic detection of small cracks in multilayered structures [8]. Qiu et al. have used spectrum analysis and WD for feature extraction [1]. Liu et al. have investigated the empirical mode decomposition method to recognize various hidden defect in the rail specimen [9]. Our method in this work is to use the Continuous Wavelet Transform using Mexican Hat wavelet mother (Continuous Mexican Hat Wavelet Transform-CMHWT) as time-frequency representation of PEC response. CWT allows PEC response denoising and generates a large quantity of data compared to time domain. PSD is used as spectrum analysis. PSD and PSD after CMHWT (CMHWT-PSD) are proposed for enhance PEC response.

The rest of the paper is organized as follows. Section II describes the methodology. Section III details the proposed CMHWT-PSD algorithm. Experimental works are depicted in Section IV. The results and discussion are presented in Section V. Finally, conclusion of this work is given in Section VI.

II. Methodology

A. Wavelet Transform

Wavelet Transform (WT) is a time-scale representation that decomposes a function in continuous or discrete time into time-scale basis defined by the mother wavelet. The fact that WT is a multiresolution analysis makes it very suitable for analysis of non-stationary signals. The function of WT is defined as

$$CWT(a,b)=1/\sqrt{a}\int x(t)\psi((t-b)/a)dt \tag{1}$$

CWT(a,b) is Continuous Wavelet Transform (CWT) of a function x(t) at scale (a>0) and translational value "b" with mother wavelet $\psi(t)$.

CWT is used to divide a continuous-time function into wavelets. It possesses the ability to construct a time-frequency representation of a signal that offers very good time and frequency localization. In (1), the parameter "a" is the scaling factor that stretches or compresses the function. The parameter "b" is the translation factor that shifts the mother wavelet along the axis [10].

B. Mexican Hat Wavelet

The second derivate of a Gaussian called the Mexican hat

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wavelets, based on CWT, are symmetrical, having specific expression, and furnish an exact analysis in time-frequency domain. Hence, Mexican Hat Wavelet (MHW) can be scaled and shifted smoothly during the calculation into the analysis domain, for this reason we choose it to be the most appropriate mother wavelet function for PEC response analysis. The MHW is admissible with two vanishing moments and in single dimension, the mother function is defined as

$$\psi(t) = \frac{2}{\sqrt{3}}\pi^{-\frac{1}{4}}(1-t^2)e^{-\frac{t^2}{2}} \quad (2)$$

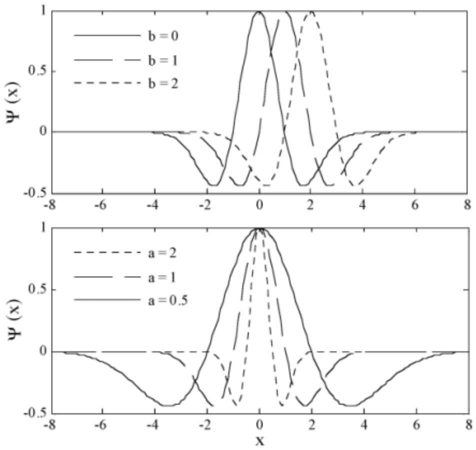


Fig. 1 Translated and dilated versions of MHW basis function [11]

C. Power Spectral Density (PSD)

PSD of a signal is the square of magnitude of the Fourier transform of the signal which is given by

$$\emptyset = \frac{1}{2\pi}\int_{-\infty}^{+\infty}\left|f(t)e^{-i\omega t}\right|^2 = \frac{F(\omega).F^*(\omega)}{2\pi} \quad (3)$$

where ω is the angular frequency and F is the Fourier transform of f(t).

The normalized PSD (PSDn) is expressed by:

$$PSDn=PSD/|max(PSD)| \quad (4)$$

The advantage of using PSD analysis is the ability to enhance medium and small depth defects [12].

III. The Proposed CMHWT-PSD Algorithm

PEC response is in time domain and it can be decomposed in time frequency domain. This response can predict the state of simple under diagnosis. The response from surface with flaw is different to the response from surface without flaw. The role of signal processing methods is to clarify the signal and become simple to detect the flaw. In time frequency resolutions of WT, the signal can be separated from noise and other unwanted signals. Signal from flaw has specific characteristics, whose present important parameters in PEC technique. Our method here in step 1 is to calculate the CWT using MHW of the PEC signal. We get CMHWT signal. The Mexican Hat was chosen as mother wavelet because it is easily implemented and satisfied with many profit do it performing to be used in our case. In the step 2 we calculate the power of the local spectrum obtained with CMHWT of the original PEC signal. Therefore, the PSD of the extracted CMHWT matrix in the selected frequency band is in (3).

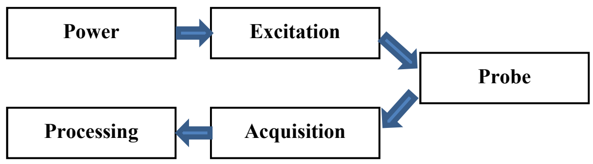
In the wavelet domain, the characteristics of the surface defects of the PEC responses acquire more information. The PEC detected depth in each frequency component is dependent on skin effect and it is defined as [13]

$$\delta=1/(\sqrt{(\pi f\mu_r\sigma_r)}) \quad (5)$$

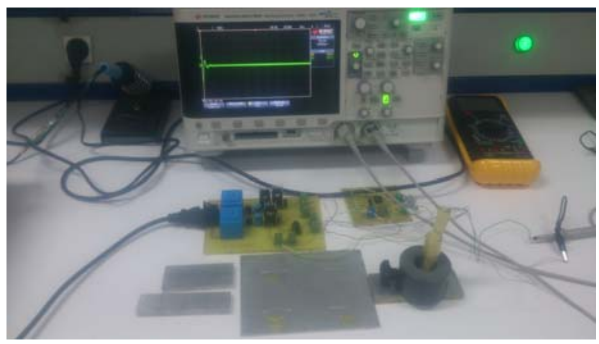
f is the frequency of the excitation source (Hz), μ_r is the magnetic permeability (H/m), and σ_r is the electrical conductivity (S/m). Equation (5) proves that high-frequency components have low penetration depth; in contrary low-frequency components have deep penetration depth. This equation passes us a way to identify the defects at different depths. High-frequency components are affected by close surface defects, while low-frequency components are affected by both far and close surface defects. The PSD of CMHWT indicates that decomposed levels, in totality, are important contributors to the process signal. PSD of CMHWT is analogous to PSD which represents the rate of change of the mean square value with frequency (3).

The computational time in the CMHWT-PSD algorithm is almost similar with other time–frequency methods.

IV. Experimental System



(a)



(b)

Fig. 2 PEC feature extraction experiment (a) the overall block diagram and (b) experimental photo

We have applied the PEC control method. We implement experiments on standard simple which will allow extracting as best as possible the results and allow evaluating the reliability of the PEC technique. To this aim, we have put in place an experiment that allows the creation and measurement of PEC response and, on other, to record signals in order to process them digitally. The measurement chain has been designed to identify sensor response due to defects and structural changes (Fig. 2).

A large number of parameters are involved in the control by PEC technique. In our case the peak value of response is used to indicate the state of simple surface. We use an aluminum sample (29A028) with three defects: 1, 1.5 and 2 mm and we try to detect them by PEC method and enhance the response with CMHWT-PSD signal processing algorithm.

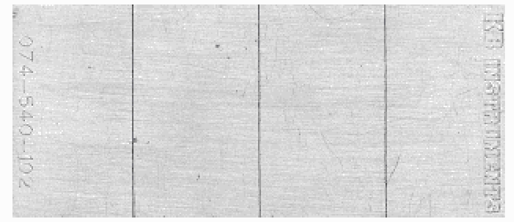


Fig. 3 Aluminum sample (29A028) with three defects

V. Results and Discussions

The results of the CMHWT-PSD algorithm applied to PEC experiment signal are discussed. Figs. 4 and 5 present the PEC responses from Aluminum sample (29A028) with three 1, 1.5, 2 mm and without defects.

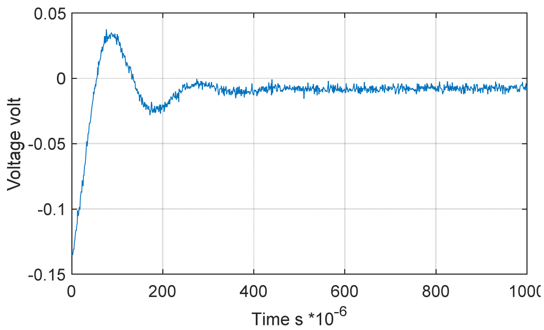


Fig. 4 PEC response from Aluminum sample

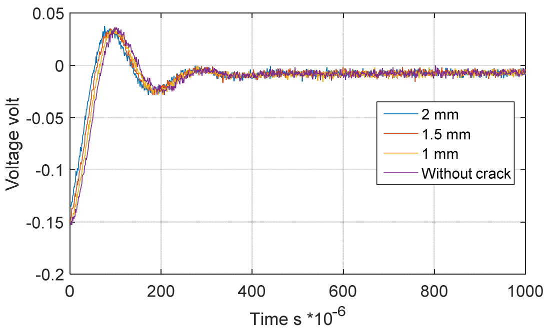


Fig. 5 PEC responses of three and without cracks

Figs. 4 and 5 show the experiment PEC signals of the three defects in addition the PEC response without defect. Fig. 6 presents the PSD of the experiment PEC signals in Fig. 5. Fig. 7 displays the results after applying the denoising procedure to wavelet transformed data. Fig. 8 presents the proposed method CMHWT-PSD of the experiment PEC signals in Fig. 5.

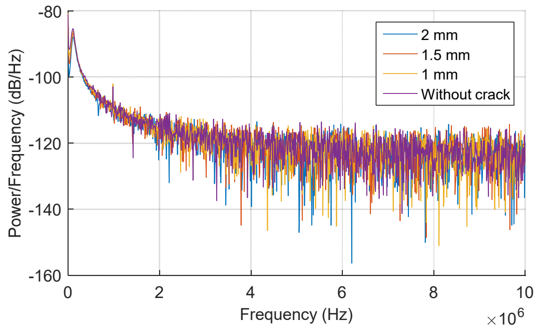


Fig. 6 PSD of PEC responses in Fig. 5

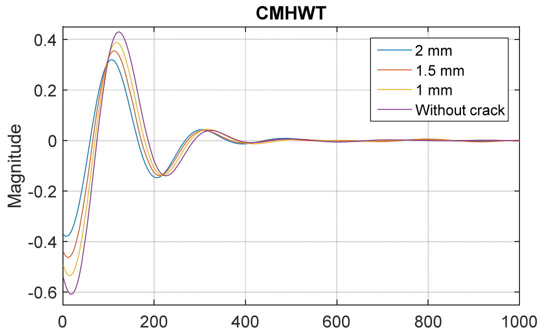


Fig. 7 CMHWT of PEC responses in Fig. 5

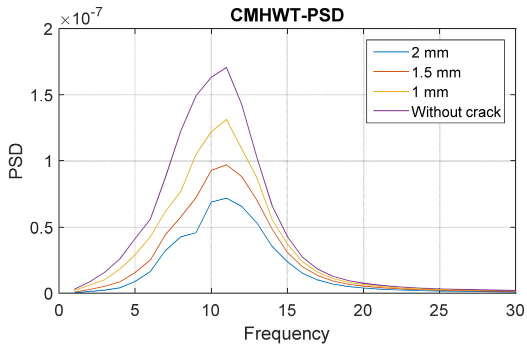


Fig. 8 Proposed CMHWT-PSD algorithm of the PEC experiment responses in Fig. 5

The PSD of CMHWT of the pulse responses at various depths of crack on the tested sample is presented in Fig. 8. The results show the inverse trend as the pulse amplitude versus depth of defect, i.e., the CMHWT-PSD peak of the detected differential pulse is decreased with increasing the defect depth. Fig. 9 shows the result of the pulse responses from the three defects and without defects samples.

The proposed method can be used effectively to describe the state of the sample. The application of PSD after CMHWT improves the quality of PEC signal (Fig. 8) in comparison with the application of PSD directly on the response (Fig. 6). The detection of defects will thus be fast, clear and easy with the proposed CMHWT-PSD method of inspected surfaces.

CMHWT-PSD algorithm gives good improvement in PEC responses which gives a good detection of defect.

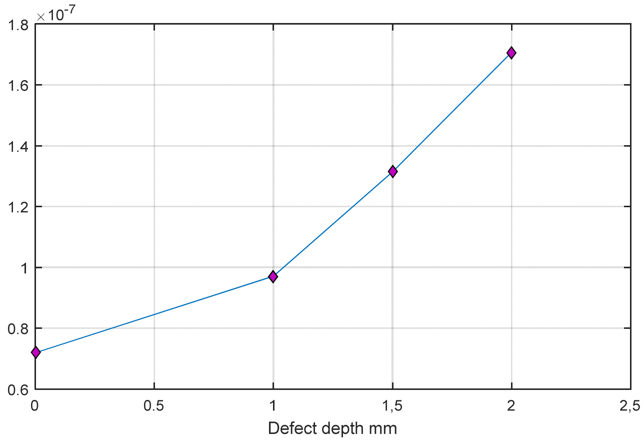


Fig. 9 Result of the pulse responses from the tree defects and without defects samples

VI. Conclusion

In this work, we have applied a technique for PEC response from aluminum sample enhancement. This signal processing technique involves calculating the power spectral density of continuous wavelet transform decomposition using Mexican hat mother wavelet of PEC response. The obtained results in experimental signals confirm that the algorithm gives a proper detection of defects in the surface of aluminum sample. The proposed algorithm verifies the feasibility of the time-frequency techniques for NDT-E applications.

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