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## REDUCED FALSE CALLS IN EDDY CURRENT IMAGES USING SIGNAL PROCESSING

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### ABSTRACT

*Non-destructive testing methods are used largely in component manufacturing industries like Aerospace, Renewables and Power to evaluate the properties of a material or the quality of a component by inspecting for cracks and discontinuities without causing damage to the part. Among the many non-destructive testing methods, Eddy current imaging enables efficient flaw detection for surface and sub-surface cracks. However, in typical eddy current inspection, there can be significant number of false calls arising from variation in lift-off and surface anomalies. Discriminating defect signals from false calls can be very challenging. This paper describes a method to reduce false calls by using a wavelet based denoising algorithm and combining it with statistical-based features extracted inside a sliding window in the time domain to efficiently identify the cracks. The results are verified on specimens with cracks of different sizes that are oriented randomly along with locations available for baseline noise measurements.*

Keywords: Eddy Current Testing (ECT), lift-off (LO), Assisted defect recognition (ADR), Non-destructive Evaluation (NDE), signal processing, Wavelet Transform (WT), low cycle fatigue (LCF)

## 1. INTRODUCTION

Eddy current inspection is widely used for non-destructive evaluation (NDE) of surface and sub surface flaws in metallic components. The probes used for inspection are typically scanned over the part to be inspected. An eddy current probe consists of one or more conductive coils through which an alternating current of a certain frequency flows, generating an oscillating magnetic field around the coils. The probe induces eddy currents in the metallic component which get perturbed by the presence of discontinuities. Cracks, material property variations, changes in the spacing between the probe and the sample (referred to as lift-off) can all contribute to variations in the eddy current signal [7]. In situations where the purpose of Eddy current inspection is to detect cracks in the sample, it becomes necessary to be able to separate out false calls due to effects other than cracks that can contribute to the signal. Conventional systems with manual interpretation of Eddy Current probe signals are being replaced by automated defect recognition (ADR) systems.

ADR is a rapidly developing area of research in the NDE area and largely used in manufacturing industries to automatically interpret the NDE signals (eddy current, Ultrasound, X-ray etc.) to fully automate the inspection and assist in the decision-making process of detecting potential cracks or flaws in the inspected part. Today this automated process is borrowing algorithms from areas like machine learning, computer vision and signal processing to learn characteristics of what constitutes a defect from a noise. This paper demonstrates algorithms using signal processing to remove false calls while detecting low cycle fatigue cracks

A signal or an image obtained from eddy current probe typically has significant noise in addition to the flaw signals of interest [1]. While there are several factors that impacts the eddy current signal like frequency, conductivity and magnetic permeability of the material being inspected, variations in the signal due to noise can bring about undesirable variations while inspecting the EC images for flaws. Fig 1.0 shows an example of noise that can occur due to lift-off during probe movement. These variations mask the defect or may appear like a defect making it difficult to interpret flaw signals.

Several strategies and approaches have been developed in the past to reduce or eliminate undesirable noise while analyzing an eddy current image. Marco Ricci et.al demonstrated the phase-analysis based imaging procedures were robust even in the presence of high LO variations [2]. An approach using normalization and two reference signals to reduce the noise due to lift-off problem with pulsed eddy current techniques was demonstrated by Tian G.Y and Sophian A [3]. P Zhu et.al proposed the use of Convolutional Neural network and compared approaches with different dropout strategies [4] This paper demonstrates the use of signal processing on the eddy current images reducing the signal variations due to noise and improving the overall signal-to-noise ratio.

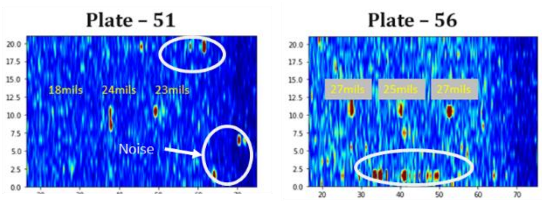


**FIGURE 1:** EXAMPLE OF EDDY RAW CURRENT IMAGES WITH NOISE

## 2. MATERIALS AND METHODS

In order to demonstrate the effectiveness of the algorithms for denoising the signal variations, Inconel samples with different sizes of surface cracks were used in the study. To make the cracks representative of real cracks, the samples were subjected to different loading conditions and low cycle fatigue (LCF) cracks of different sizes were created. A microscopy study of the cracks shows most of LCF cracks in the study to be less than a micrometer in opening. An eddy current array probe with absolute coils was mounted on a scanner to move the probe over the sample at a fixed speed. Each scan covered 3 LCF cracks at 0.5" separation. The excitation frequency was set to 2MHz. The complex voltage from the different elements in the array were recorded using an Eddy current instrument and analyzed for flaw detection. Data was acquired at the rate of 150 samples per second

In eddy Current Inspection, when a coil of impedance $Z_o$ at a certain frequency interacts with the electrically conductive test material, the impedance of the coil changes to $Z_c$. Both $Z_o$ and $Z_c$ are complex valued two-dimensional variable, with real and imaginary parts that can be represented on an impedance plane [8]. Algorithms outlined below use the complex valued signals.

When a crack or a material defect occurs, the coil impedance experiences a change generating a change in signal levels compared to non-defect areas. The challenge occurs when the noise due to lift-off, surface anomalies or edge effect has signatures close to a defect. Edge-effect occurs at the end of the test piece and can be avoided. But noise due to lift-off or surface anomalies that can occur randomly will have to be handled and denoised before the signal is used to detect cracks or material defects.. The following sections outline the key steps and algorithms in the order used to denoise the eddy current image and use the denoised imaged to detect the flaws or defects. These methods were implemented as a part of the ADR system to assist in crack or material flaw detection

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### 2.1 Wavelet based denoising

To make sure high frequency noise in the signal does not cause an increase in false alarms, a Wavelet based denoising technique was applied. The wavelet denoising method uses a wavelet transform of the original signal, concentrating the signal or image features in a few large-magnitude wavelet coefficients while removing the noise.

A wavelet transform (WT) is a linear transformation in which the signal is decomposed into a set of basis functions consisting of contractions, expansions, and translations of a mother function ψ(t), called the wavelet (Daubechies, 1991). The wavelet families differ from each other since for each family a different trade-off has been made in how compact and smooth the wavelet looks like. This means that we can choose a specific wavelet family which fits best with the features we are looking for in our signal. Each type of wavelets has a different shape, smoothness and compactness and is useful for a different purpose.

Mathematically, a wavelet can be written as:

$$X_w(a,b) = \frac{1}{|a|^{1/2}} \int_{-\infty}^{\infty} x(t)\overline{\psi}\left(\frac{t-b}{a}\right) dt \qquad (1)$$

Where (a, b) are dyadic wavelet coefficients, a is dilation or scale and b is translation

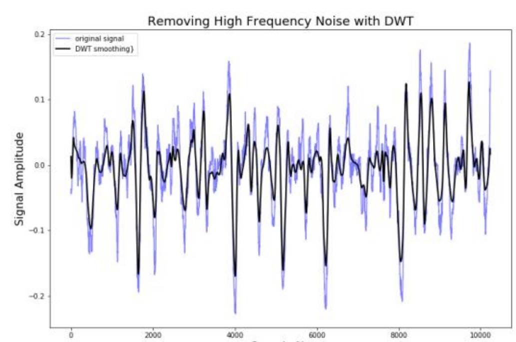


**FIGURE 2**: A SAMPLE NOISE REDUCTION FOR ONE OF THE SIGNALS IN THE CURRENT DATASET

Basically, when DWT (Discrete Wavelet transform) is used as a filter bank, deconstruction of a signal into low pass and high pass coefficients (upto level n=8) is done to get the approximation coefficients. Further the original signal is reconstructed from the approximation coefficients, leaving out some detail coefficients beyond particular frequency thresholds.

The frequency thresholds in the current case is kept to be 1 Hz after making sure there is not too much distorion/characteristic change in defective/non defective signal post filtering. The main advantage the above technique provides the usage of many wavelets. In the current case, since the defective signal characteristic mostly visually represents close to a Symlet shape, it was considered to make sure the convolving is done considering that shape

## 2.2 Peak Detection

Significant step in crack or flaw detection is the location of peaks where there is a high probability of defects. A 'peak' is defined as a local maximum in the magnitude by simple comparison with neighboring values. Peak detection algorithms here are implemented in the time domain with a specified magnitude threshold and set range to fine tune the peak searching algorithm [5]. With peaks detected across all the eddy current probe coils, sorting of peaks based on threshold greater than a band-level was done and the selected coils/locations were considered for further processing.

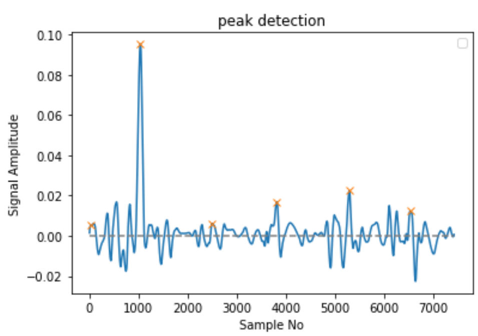


**FIGURE 3**: DETECTED PEAKS IN THE SIGNAL MARKED WITH CURSORS

## 2.3 Statistical Thresholding

Finally, in addition to the wavelet denoising and peak detection using local maxima and minima, a statistical feature extraction algorithm was developed to detect any outliers present to eliminate any possible false calls.

Using a sliding window on the time domain that accounts for the data from the adjacent coils, the absolute value of the imaginary part of the complex voltage was extracted to find the largest and smallest observations within the window. The minimum and maximum value of data within the sliding window are considered as the first and last order statistics and used to detect outliers with empirically determined thresholds. Basically, if the minimum value of the signal in the sliding window is too high with respect to the maximum signal magnitude, there is more noise present in the window with no significant peaks representing defects.

As an example, in the figure 4, the thresholds determine how much the signal peak has changed with respect to the overall noise floor considering all signals from all the surrounding coils within the sliding window.

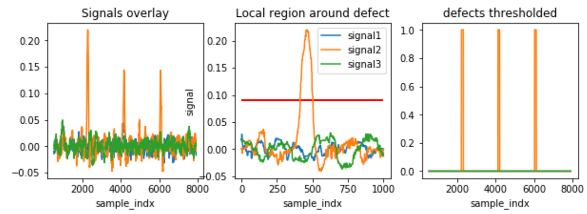


**FIGURE 4**: THRESHOLDING ON DETECTED PEAKS REPRESENTING DEFECTS

## 3. RESULTS AND DISCUSSION

A number of scans of the test plates were carried out and images were analyzed for reduction of false calls that can cause erroneous interpretation of the eddy current image.

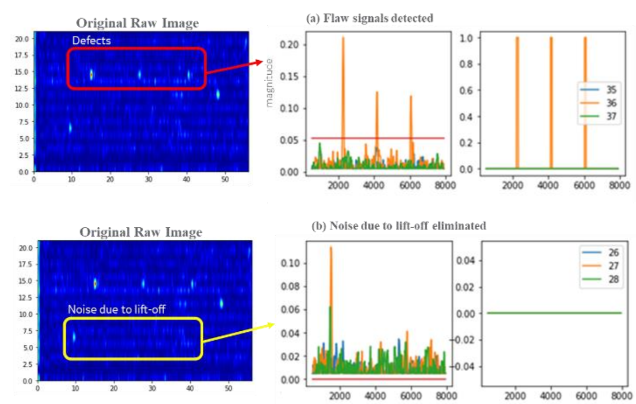


**FIGURE 5**: PEAK DETECTION ON DENOISED SIGNALS ALONG WITH STATISTICAL THRESHOLDING ON DETECTED PEAKS REMOVES UNDESIRABLE NOISE

As can be seen, with the algorithm the false calls are eliminated with the appearance of defect localization. The approach when tested on real data from 14 plates comprising of 42 defects, yielded the following result

| Predicted/Actual | Positive | Negative |
|---|---|---|
| Positive | 45 | 4 |
| Negative | 3 | 0 |

With the above Confusion Matrix, Precision and Recall percentages were 91.83% & 93.75%

 

The starting signal-to-noise ratio in most images were good and further improved by the algorithm. The precision was improved by 25-30% after the implementation of the above algorithm. The subset of these images are shown in figure 6, plates 55 and 68 have one false call that stayed, with plate 56 missing one defect.

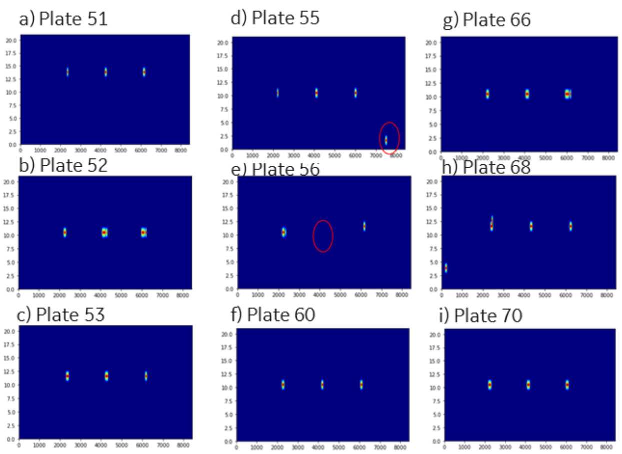


**FIGURE** 6: THE EFFECT OF IMPLEMENTING THE ALGORITHM ON IMAGES CAPTURED FROM MULTIPLE PLATES

## 4. CONCLUSION

Eddy current inspection is affected by undesirable noise from lift-off, edge effect, surface anomalies etc. induced during the inspection. The noise causes the signal to appear in a manner similar to that of a defect and may cause erroneous interpretation of the signals. The paper describes a set of signal processing algorithms that are used to pre-process the raw image from an ECT and remove the noise due to variations caused by the undesirable effects using wavelet-based transformation coupled with peak detection and first and last order statistical thresholding. The algorithm has demonstrated significant improvement in removing false calls and increasing the robustness of the ADR or automatic defect recognition system

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