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Time Domain Processing of Pulsed Differential Eddy Currents Testing Signals

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Abstract **-** The use of pulsed stimulus on Eddy Currents Testing is currently applied on multiple applications from conductivity measurements to defects detection on metallic parts. This type of stimulus is frequency rich since it is composed by multiple harmonics and this allows testing with different depth concentration of the eddy currents as they are subject to the skin effect. In this paper, pulsed stimuli are used while testing with a custom probe. The probe output signals are acquired and processed digitally in the time domain using a simple feature, its RMS value. Two-dimensional scans were performed allowing the imaging of a tested metallic part with different defects.

I. Introduction

Non-Destructive Testing (NDT) is used on many applications whose failure of components would lead to disastrous consequences. There are several NDT methods with different physical principles to interact with the part under test and to sense some change in a part characteristic. This modification allows either to estimate a specific characteristic or to detect small defects and imperfections. The detection of defects on welding joints is usually done using the Eddy Currents Testing (ECT) method which is based on electromagnetic principles [1]. In this method, a coil is used to generate an alternating primary magnetic field near the part under test which is responsible for the induction of electrical currents on the part surface. When a defect is found, the induced eddy currents will be changed leading to modifications on the resulting magnetic field (which includes the eddy currents own magnetic field). The resulting magnetic field is often sensed in the same coil which has generated the primary magnetic field by a change in its electrical impedance [1]. However, this approach has several drawbacks due to the small relative variations of the probe impedance and the inability to individually fine-tune the two properties of the probe (generation and sensing).

ECT has received growing attention from the scientific community and has suffered substantial improvements through the use of digital technology. Test frequency is an important parameter on ECT since it determines the density profile of the induced currents within the tested part. Due to the so called skin effect, higher frequencies lead to the concentration of the induced currents at the part surface leading to improve detection of surface defects and lower detection capabilities for defects located deeper in the test part. For detection purposes, frequency is usually chosen so the induced currents have maximum interaction with the expected defects. As the defects may have very distinct dimensions and can be located at different depths, the use of a single test frequency may lead to unsatisfactory results. This can be done using a regular instrument and repeating the testing sweep for each different frequency. However, this results on loss of efficiency by substantially increasing the overall measurement time. The use of pulsed stimulus instead of the original single-frequency stimulus has been applied during the last decade [1]. This so called Pulsed Eddy Currents (PEC) technique has been recently used on several applications such conductivity measurements, thickness estimation and detection of defects and irregularities. The primary motivation for using pulsed stimulus on eddy currents relies on its frequency richness which enables different depth analysis with a single acquisition for each probe location. In addition, recent developments in the pulse generator circuitry have made them very simple, small and power efficient.

Processing of PEC signals is done predominantly on the time domain using features of the measured signals. The defects detection is done by measuring changes on the selected features which can also be used on its characterization. Testing of riveted joints with a rectangular waveform stimulus with variable duty cycle is reported in [2]. On each measured location, the probe signal is digitalized and a feature is extracted from the acquired samples array. In this paper, a feature based on the standard deviation between the acquired samples and a calibration set is computed. The measured values are then used to generate a two dimensional color map to

highlight the tested part profile. A similar processing was done in [3] but using a feature as simple as the maximum registered sample on each measurement. Some references reported of features that have a more explicit physical mean. For example, in [4] the evaluation of PEC using the time measured between the driving current pulse and the rising start on the probe response is proposed. It was shown that this time delay is related with the time required to propagate the eddy currents and the magnetic field along the depth of tested part until it reaches a defect. Another interesting feature was investigated in [5] which uses a specific time instant on the probe response whose amplitude is independent of the probe lift-off with the tested part. A theoretical analysis and the discussion of possible applications for the called lift-off point of intersection were later addressed in [6].
In the previous examples, the defect detection or characterization is based upon a single feature. However, improvements were found if a combination of features is used as explored in [7] to estimate the corrosion level of steel plates. A total of seven features were evaluated and two of them were selected as the input of the corrosion level estimator. The effect of diverse defects on an extended set of features was evaluated in [8]. It was also shown that the proper selection of the features should attend on the defects properties that should be estimated. Moreover, important improvements over the use of a single feature were demonstrated on the different defects conditions.
In this paper, the use of the PEC technique with a custom probe, previously presented in [9], is investigated. Simple features extracted directly from the probe response are used to form two-dimensional maps of the tested surfaces.

II. Measurement Setup

On the used probe, stimulus are created using a driver trace carrying the stimulus current while the magnetic field sensing is done using two planar coils. The sensing coils are wired in a differential configuration so the output voltage is zero when no defects are under the probe coverage area (or in symmetry situations around the excitation and sensing coils). In practice, this is not totally achievable since some unwanted contributions may appear from the probe interconnections asymmetries and cabling. Nevertheless, the output voltage is very close to zero in this situation. A detailed discussion on the probe principle operation can be found in [9].
Measurements were performed using a dedicated instrument whose details can be found in [10] and [11]. The instrument is connected by USB to a computer running an interface application which allows configuring the generated stimulus, controlling the probe location and acquiring the probe output signal. The processing core of this system is a Field Programmable Gate Array (FPGA) with special features for Digital Signal Processing. Generation of the stimulus is ensured by Direct Digital Synthesis (DDS) within the FPGA logic and converted using a 14-bit 125 MS/s Digital to Analog Converter (DAC). The generated stimulus can be changed by simply reprogramming the DDS lookup table. After amplification, the probe output signals are converted using an Analog to Digital Converter (ADC) with the same bit resolution and sampling rate.
The selected stimulus is a rectangular waveform with 20% duty cycle and 100 kHz frequency. The amplitude of the current stimulus was set to 1 A. On each measurement location, a segment of 8192 points of the probe output voltage is acquired and stored in the computer for processing. The instrument ensures that the acquisition is triggered always in the same instant of the stimulus to enable coherency between different acquisitions. The post-processing of the segment is done using a MATLAB script.
Each segment is filtered to remove high frequency components that are present in the electromagnetic background. Using the available computational packages, a Fast Fourier Transform (FFT) was computed and the high frequency components were made equal to zero. The time domain signal is recovered recurring to an inverse FFT routine. After filtering, the segments are compensated using a calibration segment acquired on a non-defective situation. This operation is used to remove the unwanted asymmetric contributions previously referred caused by liftoff and imperfections in the probe symmetry. After the compensation stage, the Root Mean Square (RMS) value of each acquired segment is computed and used to represent the probe response in two-dimensional scans.

III. Experimental Results

The described setup was applied on the testing of some aluminum standards. Figure 1 shows an acquired segment over a non-defective location in the time domain. To compensate this signal, a calibration segment was computed by low pass filtering several segments (of the non-defective location) as described before and averaging them point by point (which can only be done since there is a precise and accurate trigger to begin the acquisition process). The compensation stage is simple done by subtracting each segment later acquired by the calibration one which results from this initial calibration step.

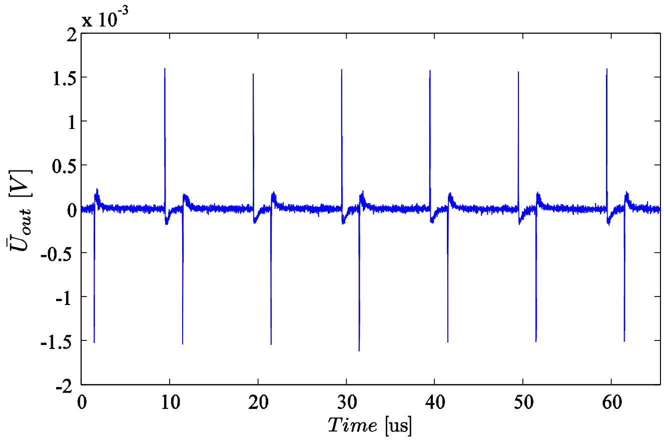

Figure 1. Probe output voltage on the time domain. The 8192 samples acquired at 125 MS/s correspond to approximately 65 µs and there are 1250 points per period.

Figure 2 shows the frequency spectrum of the time segment represented in Figure 1. As shown, multiple harmonics appear from 100 kHz up to the highest frequencies of 20 MHz (which is also the bandwidth of the low pass filtering used in the pre-processing of the acquired samples). It should be noted that the expected spectrum sinc function shape (the shape of the stimulus spectrum) is not visible here in the acquired signal because the probe sensitivity increases with the operating frequency. Nevertheless, every 5th harmonic is non-existent since it is not present in the excitation signal.

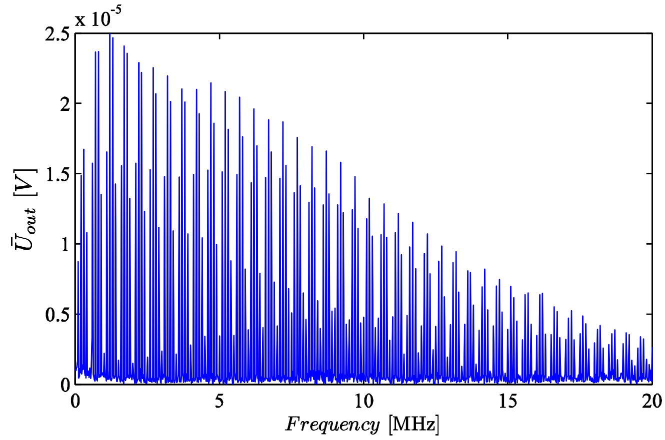

Figure 2. Probe output voltage on the frequency domain.

To illustrate the influence of a defect on the probe output two segments were registered with the probe located in a non-defective location and above a defect. The two segments were processed as described including both the filtering and the compensation steps. This result is shown in Figure 3 where clear differences can be identified on the signals. When no defect is present, the probe output voltage is very close to zero with residual spikes at the transitions of the current stimulus. In the second situation, the probe output voltage amplitude is greatly increased as the chosen defect has considerably high dimensions. These differences on the output signal lead to RMS values which are almost two orders of magnitude apart. Specifically, an RMS value of 7.54 µV was computed without the defect and 644 uV with the defect which corresponds to an increase of almost two orders of magnitude.

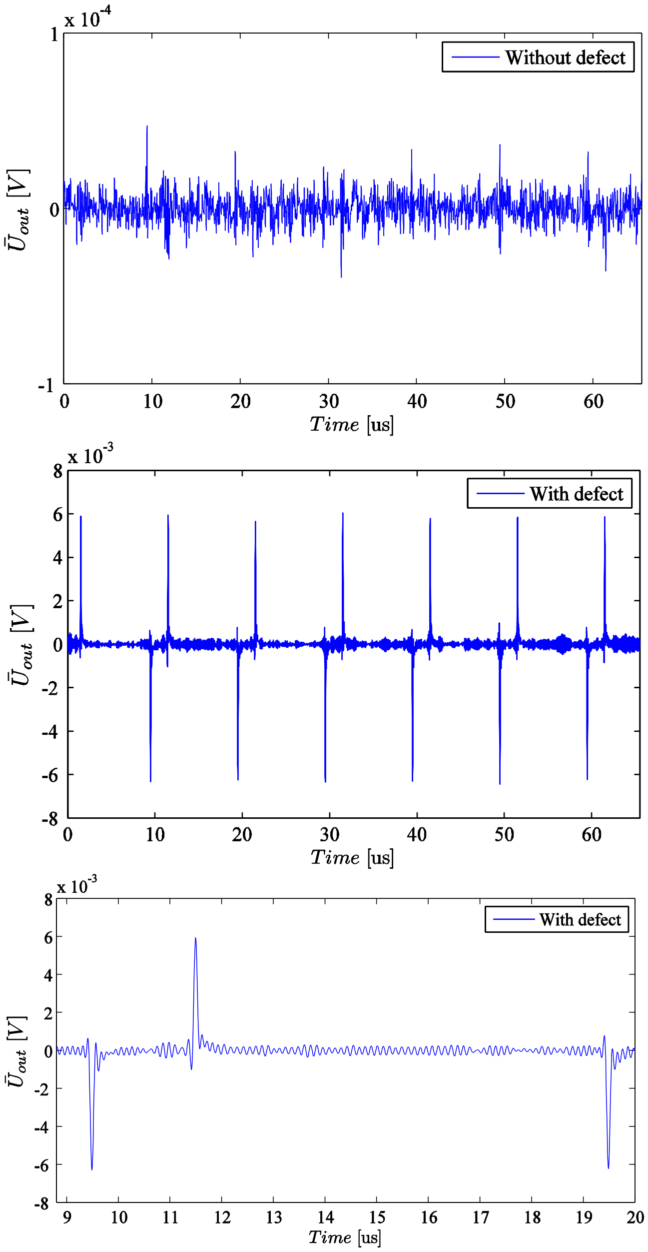

Figure 3. Probe output voltage with (middle) and without (top) a defect underneath after the filtering and compensation step. Notice the much smaller vertical scale used on the non-defective situation. One period detail of the probe output segment with a defect underneath is shown in the bottom figure.

A two-dimensional scan was performed positioning the probe sequentially over a defective part with six drilled holes as shown in Figure 4. The holes were produced on an aluminum alloy AA2024 sample with two different diameters (1 mm and 2 mm).

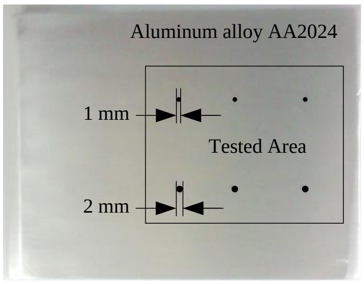

Figure 4. Defective part top view.

The probe positioning resolution is equal to 0.25 mm on the two axis and an area of (60x53) mm was swept. This corresponds to a total of over 50000 different probes locations. The resulting image, obtained by applying the described processing method, is shown in Figure 5. As is shown, the holes whose diameter is greater appear more intensely represented than the smaller ones. The image result for each hole also shows the probe shape outline which resembles two adjacent half circles.

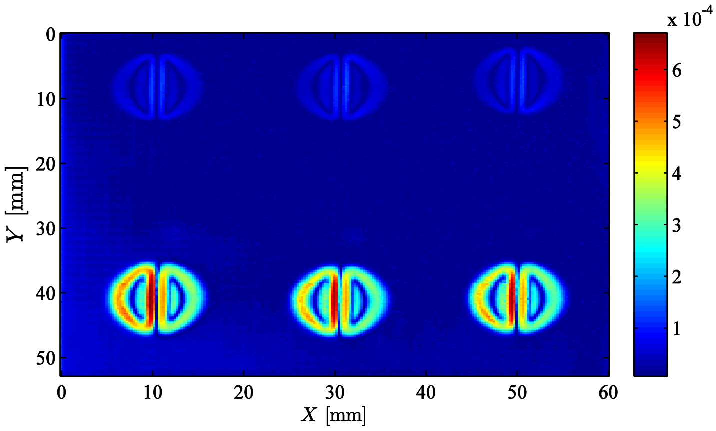

Figure 5. RMS intensity plot for the tested defective part.

IV. Conclusions

The use of pulsed eddy currents technique with a differential sensor was demonstrated. The probe output signals were processed in the time domain using a single, easy to compute feature based on the RMS value. A filtering and compensation step allowed the removal of unwanted contributions present on the acquired signals. Future work will focus in the evaluation of other features and also its extraction in the frequency domain. The implementation of the described processing algorithms in the FPGA of the dedicated instrument is also being considered.

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