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PULSED EDDY CURRENT EVALUATION OF CONDUCTIVE MATERIALS USING VIRTUAL INSTRUMENTATION

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Abstract: *Non-destructive testing (NDT) refers to testing a component without impairing its worth or functional properties. Pulsed eddy current (PEC) testing is a new electromagnetic NDT method. This method is powerful technique used for detection of surface and sub-surface corrosion and cracks mainly in aerospace structures. This paper introduces PEC method as a new approach in non-destructive evaluation of conductive materials. Created software solution for PEC data analysis using virtual instrumentation-LabVIEW is presented.*

Key words: *Non-destructive evaluation, pulsed eddy currents, material defect, transient response, LabVIEW*

INTRODUCTION

In order to improve quality, components and structures are regularly inspected for defects or faults which may reduce their structural identity. Among the methods of testing developed for maintenance and inspection purposes, non-destructive testing (NDT) techniques present the advantages of leaving the components undamaged after inspection. NDT refers to testing a component without impairing its worth or functional properties. Non-destructive evaluation (NDE) refers to quantitative inspection in which the defect is not only detected, but also characterised with respect to its size, shape and orientation. Such techniques find applications in the aerospace, transport, nuclear and offshore industries [1].

The eddy current testing (ECT) method uses principle of electromagnetic induction to inspect a component. Eddy current is a cost-effective versatile NDT modality, providing fast, accurate, repeatable inspection results without the need for a couplant or contact with the test material [2]. It is capable of inspecting all metals for surface and near surface flaws, for heat treatment variation, and for detection of certain test piece features (such as thread detection). ECT method is used for

inspection of raw materials, quality control of finished products, and for maintenance inspection.

Pulsed eddy current (PEC) technology has several key advantages over conventional single and multi-frequency eddy current inspection techniques. These advantages against the conventional eddy current testing are more extended detection depth, rich information about defects and high robustness of anti-interference. Also, in contrast to the conventional eddy current testing with sinusoidal excitations, pulsed eddy current testing taking pulses as excitation can minimize power consumption, which is more promising in the development of portable instruments [3] [4].

Because it is also an induced electromagnetic technique, it is generally used to inspect conductive materials. There is the greater depth of penetration thanks to the low frequencies contained in the drive pulse. PEC allows excitation of a wide spectrum of frequencies with a single pulse, effective subsurface cracks detection and corrosion detection, possibility of multi-frequency analysis after scan is completed and other features. Material object is multifrequency tested. Single pulse signal frequencies are harmonic components of driving pulse. Thus, more complex information about material defect is obtained [5].

Pulsed eddy current testing differs from sinusoidal eddy current testing in that a pulse of current is induced in the metal test specimen instead of the sinusoidally varying current used in single frequency or multiple frequency eddy current testing. The use of a pulse produces various advantages over the sinusoidal waveform and some disadvantages. In theory, a pulse can be analyzed into an infinite train of sinusoidal waveforms that are related harmonically. This means that all the information that could be obtained from a large number of sinusoidal tests at various frequencies is already available to the pulsed eddy current test equipment. Since the pulse usually has a short duration compared to the duration of the duty cycle, the pulse can be relatively powerful without excessively heating the test probe. On the other hand, wideband electronics are needed to handle the pulse. This wideband circuitry is more susceptible to electronic noise than the narrow band circuitry that can be used by sinusoidal eddy current equipment. As in all eddy current tests, a current field is induced in the specimen that is to be tested, usually by a current carrying coil called the field coil. The field in the test specimen is detected by a current induced in another coil called the pickup coil. Sometimes a Hall detector is used for this purpose. Often equipment is designed so that one coil acts both as field coil and pickup coil. In all cases, changes in the field in the test specimen caused by physical or conductivity variations in the test specimen are what the eddy current equipment must then process and present as useful information to the operator. In far effect eddy current tests, the pickup coil is purposely located a significant distance from the field coil, but the equipment described here uses a pickup coil very close to the field coil. The pulsed field that the field coil induces in the test specimen travels relatively slowly into the metal test specimen. The diffusion of the current in the metal is much more analogous to the diffusion of heat into a conducting medium. In fact, the same equations can be used to describe both actions. The metal acts as a dissipative medium, weakening the current field rapidly and changing its shape as a function of time. This makes a rigorous definition of the velocity of the pulse in the specimen difficult. The diffusion of current is much faster than the diffusion of heat in the same medium, however [6].

1 PEC SENSING

1.1 PEC data analysis

PEC data analysis is mainly carried out in the time domain, Fig.1. The response signal with the probe located on defect-free area is taken as a reference response. A differential response is obtained by subtracting the reference response from the testing sample response. This differential response is used for feature extraction as well as for defect classification and quantification. A differential transient response must be first analyzed. In contrast to conventional ECT, pulsed eddy current techniques allow time domain data analysis as well as frequency domain analysis.

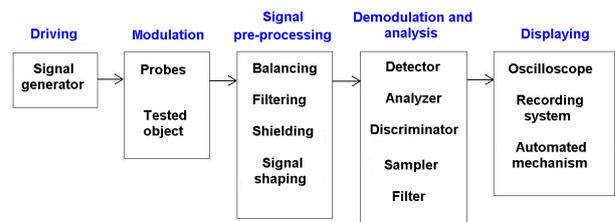


Fig.1: Data processing using PEC

Using of harmonic analysis gives rich information about all of the spectral components which are contained in the driving pulse. Information rate of PEC measurements depends on various factors (frequency of the driving pulse, time duration, repetition frequency, lift-off distance). Because of pulsed characters of the driving signals, current peak values can reach up to tenths of amperes.

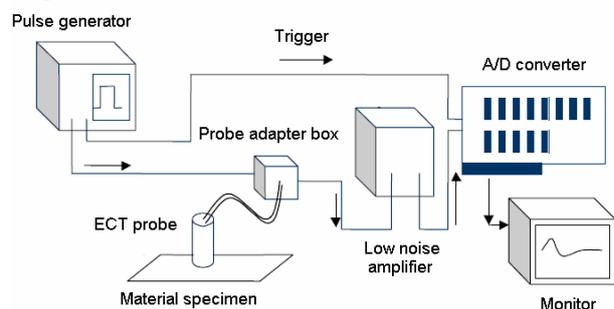


Fig.2: PEC apparatus

Due to this fact, windings of system probes have to be accordingly dimensioned. The most commonly used shapes of driving signals are square and triangular signals, Fig.3.

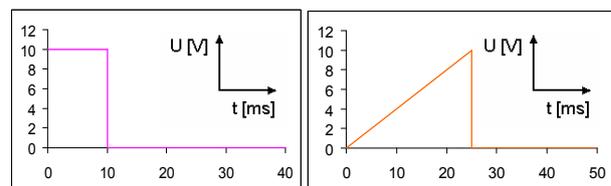


Fig.3: Driving signals of the coil

PEC taking pulses as excitation and thus can minimize power consumption, which is more promising in the development of portable instruments. PEC testing applies a broad band pulse and analyzes the transient voltage response, which can yield a signal with frequency contents from DC to 100 kHz or higher. Because the penetration depth of ECs depends on excitation frequency, thus, PEC testing can detect deeper and fetch more information. Meanwhile, pulses can be easily generated and controlled by the intensity of excitation and starting time for data synchronization and interpretation, Fig.2. Responses of a pulse often come when step excitation is over and no overlap between excitation and response will occur, so PEC testing is more robust to interference.

1.2 PEC data processing and virtual instrumentation

LabVIEW (abbreviation for Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for visual programming languages. The graphical language is named "G". Using of virtual instrumentation in cooperation with prototyping platform (ELVIS II) present relatively easy and fast way to create software solutions and to perform various measurements. An advantage of such conjunction is that there is no need of external device (PEC analyzer). Because of low values (hundreds of microamperes) of PEC differential responses signals, it is a necessity to be all the PEC apparatus components low-noised. Individual components of measuring apparatus, such as digital filters, pre-amplifiers and other devices are created as virtual instruments. Thus can be created such software solution which can be used as PEC virtual instrument analyzer.

Created PEC analyzer named O.P.E.C.A. (Own Pulsed Eddy Current Analyzer) is based on the LabVIEW in connection with ELVIS II multifunction card. Basic functional blocks creating the apparatus, Fig.4, are following: power amplifier-PA, probe-P, ELVIS II card and personal computer-PC. Signal generator and two-channel digital oscilloscope are located on the card. PEC analyzer is full-controlled using created front panel in LabVIEW.

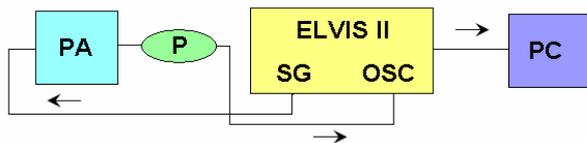


Fig.4: Block diagram of the PEC analyzer

Created software solution is implemented in LabVIEW. Program can be used to displaying measured and computed waveforms, performing selected measurements and for data manipulation with PEC signals. After the differential responses signals are obtained, time-domain analysis as well as frequency-domain analysis can be executed. To obtain a differential response signal, following algorithm is used, Fig.5. Time-domain analysis allows displaying reference, response and differential signal in real-time windows. Because of transient character of PEC signals, some selected measurements (transitions, pulse, cycle, average, amplitude and levels measurements) are available.

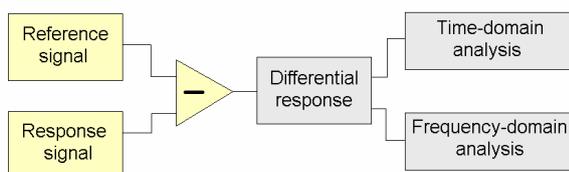


Fig.5: PEC signal processing

Frequency-domain analysis allows performing of the Fast Fourier Transform (FFT), computation of a power spectrum and some spectral measurements (Total harmonic distortion - THD, fundamental frequency definition). Fourier analysis is performed using three various convolution windows – Flat top, Hanning and Hamming window. Appropriate amplitude spectra as well as phase spectra using automatic scaling factor for both (frequency and amplitude) axes are computed.

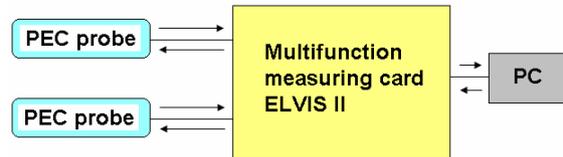


Fig.6: Two-probe PEC measurement

For PEC analysis, O.P.E.C.A. allows two modifications of measurements: Measurement using one probe or two probes (Fig.6). Various software solutions were created to allow this possibility. When using one-probe measuring, following procedure have to be kept: PEC coil is placed over the specimen with place without the defect. Such signal is scanned and saved as a reference signal. Then the coil is placed over the centre of the specimen with place with the defect. This signal is saved as a response signal. After this, analyzer continues with further signal processing. Main difference between one and two-probe design lies in fact that when using two-probe mode, real-time analysis is available. Measured results can be saved and re-load to perform signals post-processing.

2 EXPERIMENTAL SETUP

A conductive specimen, shown in Fig.7, having the electromagnetic parameters of the stainless steel SUS 316L is inspected in this study. The material has the conductivity of $\sigma = 1.35 \text{ MS/m}$ and the relative permeability of $\mu_r = 1$. The specimen contains a non-conductive defect. A coil of absolute type shown in Fig. 8 with $N = 40$ number of turns is used to drive eddy currents and to detect the response. The coil is placed over the centre of the specimen normally to the specimen surface with the lift-off of $d = 1 \text{ mm}$. Amplitude of the driving signal is $U = 10 \text{ V}$. Parameters of the driving signals are shown in Fig. 3. Differential current responses are analyzed.

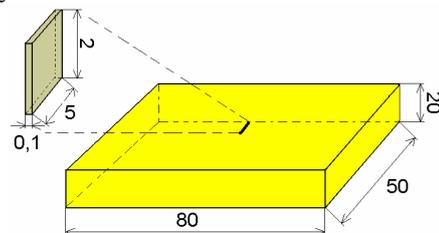


Fig.7: Configuration of the inspected specimen with defect

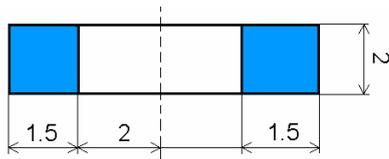


Fig.8: Dimensions of the coil

3 EXPERIMENTAL RESULTS

Selected experimental results performed on the material specimen are presented. Amplitude spectrum of the differential response shows representation of harmonic contents obtained in the driving pulse. Square driving signal with time duration $t=10\text{ms}$ was used to excite pulsed eddy currents in the material. Dominant harmonic content of the spectrum has value $f=100\text{Hz}$.

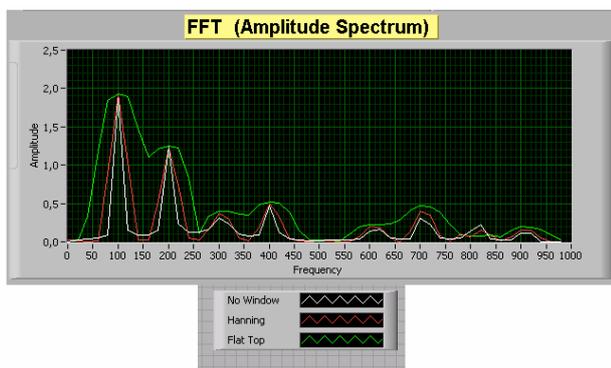


Fig.9: Differential response amplitude spectrum

Dominant peak value in the power spectrum shows is for first harmonic component which is at frequency of $f=100\text{Hz}$.

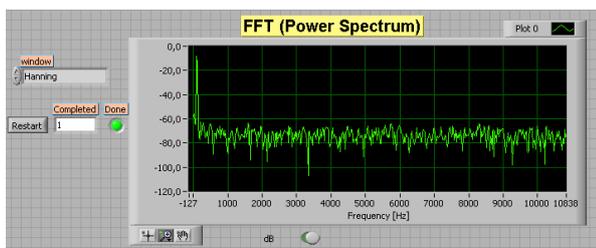


Fig.10: Differential response power spectrum

When computing harmonic analysis, sampling frequency of the signals (according to the Shannon-Kotelnik theorem) is set automatically as well as scaling factor of the axes.

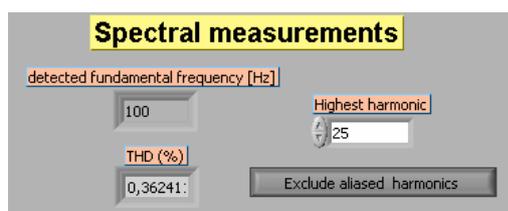


Fig.11: Selected spectral measurements

Detected fundamental frequency value confirm dominant value in the amplitude spectrum. Computed total harmonic distortion value is about $\text{THD}=0,36\%$. Program limits are given mainly by communication speed (USB 2.0).

4 CONCLUSION

Using of pulsed eddy current testing method, PEC as a new method of nondestructive evaluation of conductive materials offers some advantages comparing with conventional eddy current testing method, ECT. This paper presents unconventional approach to creation of simple PEC analyzer. Presented solution was performed using LabVIEW development environment in connection with ELVIS II multifunctional card. Designed platform can be used to perform selected PEC measurements, also to analyze measured signals in the time-domain as well as in the frequency domain. Because of low-values of PEC signals, using of low-noised components of the apparatus is necessity. Performing of various experimental measurements on material specimens with various geometries of defects using various types of PEC probes are the main aims of our future work.

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