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CROSS-CORRELATION TECHNIQUE FOR REVEALING DEFECTS IN PULSED EDDY CURRENT DEFECTOSCOPY

Important aspects of the cross-correlation in the pulsed eddy current defectoscopy are analyzed and discussed. The application of the technique is described and illustrated with an example of an artificial defect in an electrically conductive steel plate. The results of the measurements are compared with the data obtained for the reference defect.

KEYWORDS: non-destructive testing, pulse-excited eddy current defectoscopy, cross-correlation technique, magnetic field

1. INTRODUCTION

The non-destructive testing represents a well-known and elaborated technology for the investigation of the current state of many elements and bodies. This technique is applied, for example, when the tested specimen is too expensive to be destroyed or when the continuous examination is demanded (the specimen is a part of the production line). The eddy current defectoscopy is a kind of non-destructive testing of electrically conductive bodies based on the evaluation of their eddy current excitement. The distribution of eddy currents and magnetic field in such bodies is sensitive to inhomogeneities and discontinuities in electric conductivity or magnetic permeability, and also to the shape of the specimen. Then, the evaluation of these quantities can provide sufficiently wide information about the properties and integrity of the body.

Although the excitation was usually performed using harmonic field currents [1–4], in the last ten years also different techniques started to be studied and tested, one of them being excitement realized by pulsed currents. The pulsed excitation is advantageous, among others, for easy generation of the current pulses by a microprocessor (including a very simple output stage) and its energy efficiency (low power loss in the output part of the circuit and small effective value of the switched current).

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The technique was developed and tested by a number of authors, see, for example [5–7]. The crucial problem is, however, how to evaluate the responses again represented by current pulses in order to get the idea about the principal characteristics of the defect (geometry, variations of local physical parameters, etc.). Until recently, the responses were mostly subjected to the spectral analysis and the state of the sample was evaluated on the basis of contents of particular harmonics in the spectrum.

It was shown in [8] that another technique based on the cross-correlation between the real measured response and response to a reference defect can also indicate the character of the real defect.

The aim of the paper is to use this technique for identifying defects in electrically conductive materials and evaluate its advantages and drawbacks.

2. PRINCIPLE OF EDDY CURRENT TESTING

The principle of eddy current testing corresponds to the principle of a transformer. The testing equipment consists of the primary (field) coil carrying the field current and one or more sensors in the form of secondary (measuring) coils or other kinds of devices for the field measurement. Here, the primary coil carries a pulsed current and generates magnetic field of a similar time evolution. When this coil approaches an electrically conductive body, the above field induces in it eddy currents producing there a secondary magnetic field tending to oppose the primary one. Thus, the original magnetic field is weakened. And detailed monitoring of this resultant field by an appropriate sensing device may provide information necessary for evaluation of the state of the inspected body (local changes of its physical parameters such as electric conductivity and magnetic permeability or variations of some dimensions).

3. ILLUSTRATIVE EXAMPLE

The method was tested in an arrangement depicted in Fig. 1. The measuring device consisting of an element containing the excitation coil and two sensing coils moved stepwise above a wide steel plate with an artificial defect. All material parameters are known.

The dimensions of the cross section of the artificial defect in the plate are 2×2 mm. The plate was placed on a large iron desk to avoid influence of the surrounding environment.

The probe was placed above the plate in the height of 1.4 mm, in parallel to the defect (see Fig. 1, bottom part) and moved in short steps of length 5 mm along the plate. In every step we measured and stored the time-dependent voltage that was averaged always over 15 periods to eliminate a random noise. The plate starting in the centre of the probe could not be used as a reference defect, because the voltage difference was too large and the instrumentation amplifier was saturated. Thus, the probe was placed as close as possible to the edge of the examined plate where the difference was still small enough to avoid saturation of the amplifier and this waveform was used as a reference pulse for seeking for its replicas in the measurement signal.

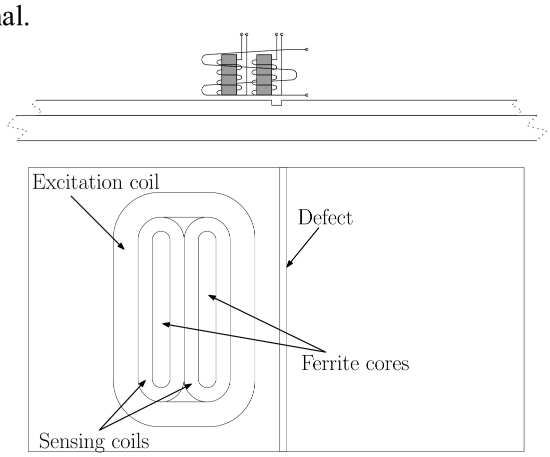

Fig. 1. Measuring arrangement: top – front view, bottom – top view

The experimental setup consisted of a differential reflection eddy current probe powered by MOSFET power switch driven by a laboratory pulse generator through an optocoupler with a MOSFET driver (see Fig. 2, upper part). The signals picked up by the sensing coils were attenuated by a resistor voltage divider and one from another subtracted in an integrated instrumentation amplifier. The voltage difference was measured by a digital storage oscilloscope (see Fig. 2, bottom part).

4. POSTPROCESSING OF RESULTS AND THEIR EVALUATION

4.1. Cross-correlation

The cross-correlation of the measurement signal with the reference pulse is used to reveal a defect. The cross-correlation is an operation returning a function whose values depend on the similarity between two input functions. The idea is to use this operation to seek for parts of the measured signal similar to the response of the probe placed over a large defect (in [8], the edge of a metal plate was used), i.e., the reference pulse. The cross-correlation then should give high peaks (negative or positive) in the place of pulses in the measurement signal corresponding to the parts similar to the reference signal. In the place of the centre of the defect, these peaks change their signs.

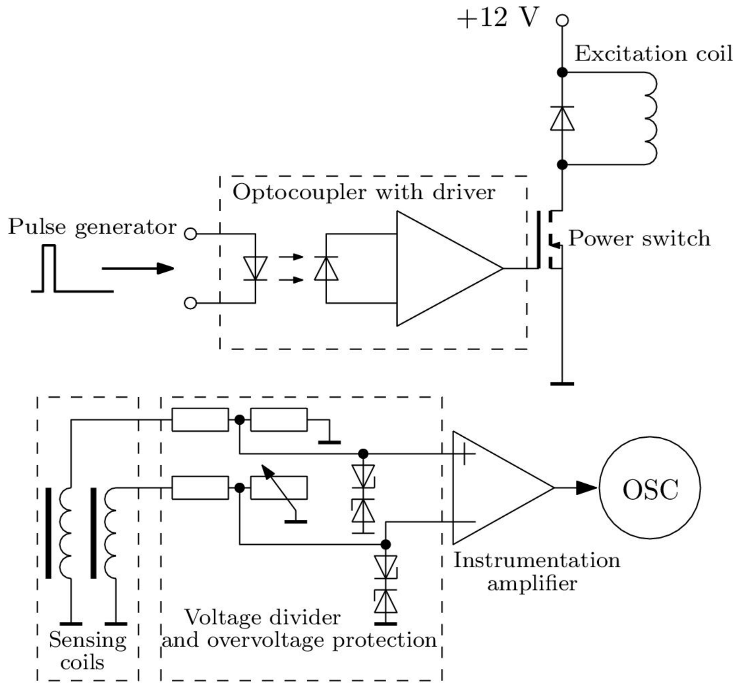

Fig. 2. Scheme of measurements: upper part – source circuit, lower part – measuring circuit

The cross-correlation $R(k)$ (implemented in SciPy.signal Python library) is given by the expression

$$R(k)=\sum_{i=-\infty}^{\infty} f(i)\cdot g(k+i-n), \tag{1}$$

where f and g are arrays to be correlated. Here, the array f represents the measured signal and g is the reference pulse consisting of n elements. The cross-correlation was performed piecewise in each period of the signal. In this way, a continuous evaluation of the measurement signal during the assessment is possible.

4.2. Results of measurements and their discussion

An example of the response to the rectangular pulse is in Fig. 3 drawn by the dashed line. This response was used as a reference response for the cross-correlation described in paragraph 4.1. Concatenation of every stored waveform was used for simulation of the measurement signal, which can be seen in Fig. 4. The first pulse in this signal is the same as the dashed line in Fig. 3 and corresponds to the edge of the examined iron plate. The defect placement is about the beginning of the last third of the signal.

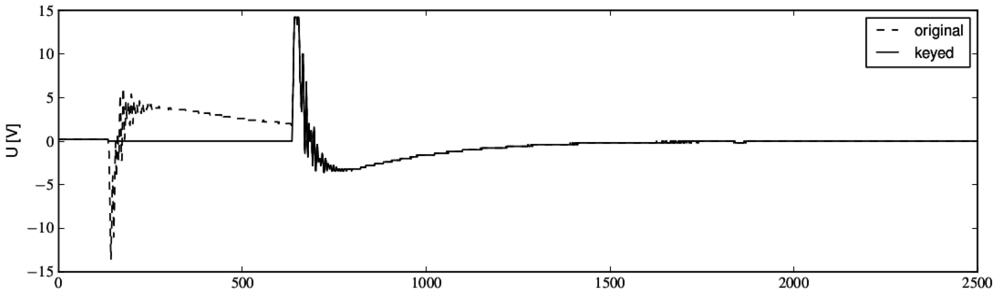

Fig. 3. Reference pulse

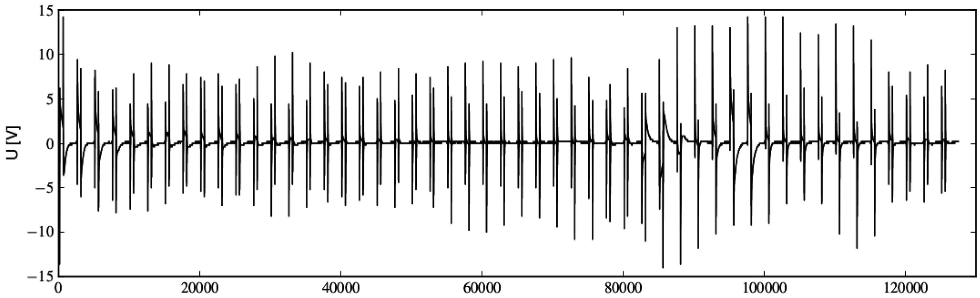

Fig. 4. Measurement signal

Fig. 5 depicts the cross-correlation of the measurement signal from Fig. 4 with the pulse in Fig. 3 (marked by the dashed line). The cross-correlation exhibits high peaks at the edge of the plate and around the place of the defect. In accordance with the assumption uttered in paragraph 4.1, the polarity of the peaks is changing at the place of the defect.

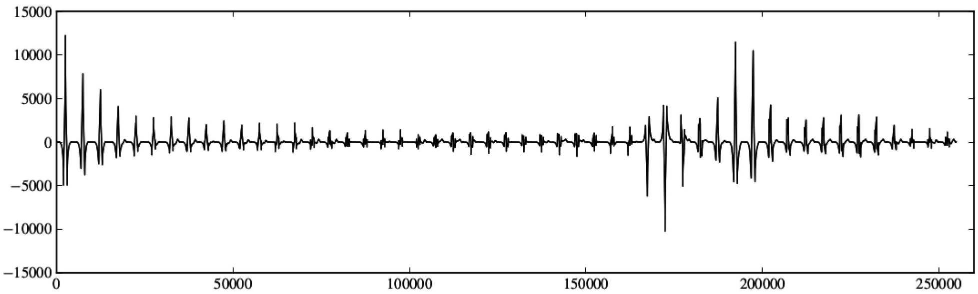

Fig. 5. Cross-correlation with the reference pulse

However, the response itself is its way periodic, so the main peaks are surrounded by other peaks corresponding to self-similar parts of the pulse and the whole cross-correlation product is too complicated. This problem can be solved by using only one part of the response while the other part is zeroed. The excitation pulse was used as a mask for keying the measurement signal. The keyed pulse is shown in Fig. 3 drawn by the solid line and the whole keyed measurement signal is in Fig. 6. The cross-correlation of these signals is drawn in Fig. 7. This waveform contains only simple peaks clearly indicating the position of the plate edge and also the defect.

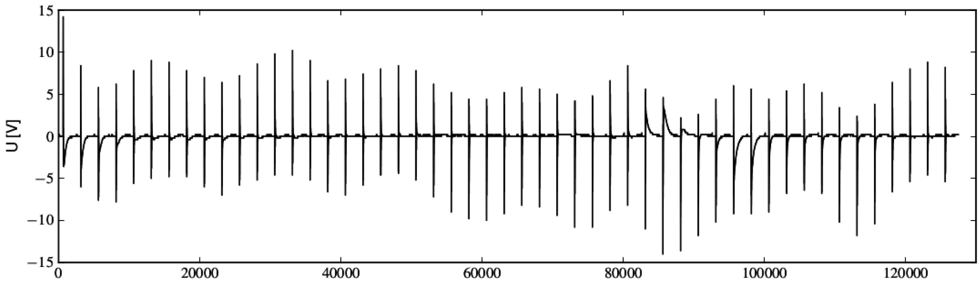

Fig. 6. Keyed measurement signal

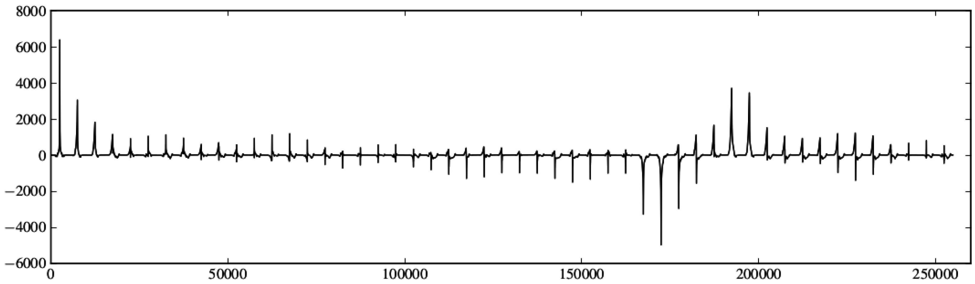

Fig. 7. Cross-correlation with keyed signal

5. CONCLUSION

In the present stage of research, the results are rather of the qualitative than quantitative significance. From the measured data (see Fig. 4) it is possible to detect the position of the defect (and also, the proximity of the margin of the examined plate) based on signal value in the non-transient parts of the pulses. But this signal is very jammed by high values from the transient parts, which makes the decision of the defect appearance difficult. By comparison with the known defect using the cross-correlation technique a new signal is made, which is not disturbed as much as the original signal (which can be seen in Fig. 5). This makes the decision of the defect appearance (based on high peaks of the cross-correlation product) easier. Even better improvement can be achieved by removing the self-similarities from the measured responses by time-domain keying. The cross-correlation of such signals exhibits high single polarity peaks (see Fig. 7), which makes very simple and distinct signal, where the position of the defect is very clear.

Thus, the technique can be declared beneficial. Nevertheless much work remains to be done in the domain of the arrangement and optimization of the measuring system (the sensing coils used, for example, were too large to provide good quantitative information about the defect).

Except for improving the measuring system, the following work will also be aimed at developing an algorithm able to decide automatically from the cross-correlation data the defect appearance and use them for the continuous detection.

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