Novel Eddy Current Testing Sensor for the Inspection of Printed Circuit Boards

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Abstract—This paper presents a novel eddy-current testing (ECT) sensor for the inspection of printed circuit board (PCB), which detects trace damages on PCB conductors. The sensor is composed of a meander-exciting coil and three solenoid pick-up coils. Application of three pick-up coils increases the speed of the inspection process. Information about defects can be extracted either from an amplitude or a phase of a signal obtained during the inspection. A visualization process was provided using the amplitude data. In this paper the structure of the ECT sensor and principles of detection as well as experimental results are presented.

Index Terms—Defect, meander coil, PCB, sensor, solenoid coil, testing.

I. INTRODUCTION

QUALITY control is a very important factor during fabrication of printed circuit board (PCB). Although etching processes are precisely prepared and controlled, some defects on PCB can appear. In order to avoid further problems upon power-up, an inspection of the PCB circuit must be provided before all elements are installed. Existing methods of PCB inspection are either time consuming or not efficient. Optical methods, based on visual recognition processes, are limited to the inspection of outer surfaces (visible defects). Other testers—flying probes, do not deliver information about partial defects on conductors. Moreover, different kind of flying probe is required for each type of PCB. This is labor-intensive. Furthermore, flying probes require frequent cleaning using the ultrasound technique to keep their small resistance [1].

A new method of PCB inspection by an ECT sensor allows detection both, visible and invisible defects. The eddy current testing technique has a long history and many applications such as: the investigation of large metal structures, planes wings or weld connections [2]. The new approach is unique, and requires construction of a special sensor. The sensor consisting of an exciting meander coil and a solenoid pick-up coil has been already reported [3], [4]. The sensor has high sensitivity, and its application allows efficient scanning. The construction of a new sensor, presented in this paper, is similar to the sensor presented before. There is also the meander exciting coil used to produce magnetic field which causes uniform eddy currents in tested material. But the output signal is obtained from three solenoid pick-up coils installed on a one collective glass core. The output signal is composed of the three subsignals. Correlation functions are set to
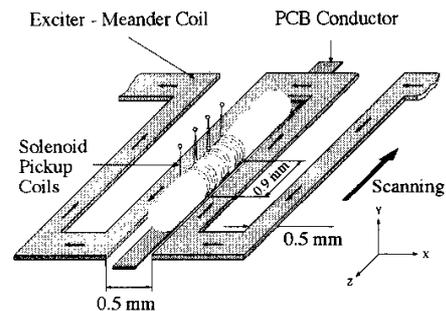
Fig. 1. ECT sensor for the inspection of printed circuit board.

equalize these subsignals. The information about possible defects can be extracted from an amplitude or a phase of the summary output signal.

II. STRUCTURE OF ECT SENSOR—PRINCIPLES OF DETECTION

Fig. 1 shows an ECT sensor used for the inspection of PCB. The meander coil, used to inspect printed circuit boards, has a remarkable shape. Long conductors with an exciting current produce a magnetic field B, which generates eddy currents in the PCB conductors. Any defects on the tested conductors appear as obstacles for the eddy currents and cause changes in their distributions [4]. There are three pick-up coils installed on the collective glass core. The pick-up coils are inserted in the same position, therefore signals delivered by these coils possess very similar value of an offset voltage. Solenoid pick-up coils allow the inspection of a tangential component of B (in z-axis direction). An inspection of the tangential component B_z is more difficult than an inspection of the normal component B_y, because B_z appears in a very small distance from the test conductor, and its value is not as high as the value of the normal component. However, the tangential component appears only in specific cases—together with defects or at conductors' boundaries. In the case of a defectless conductor, there is no tangential component generated by the tested conductor. The output signal does not have to be extracted from others signals as it is in the case of the inspection of the normal component. This is a big advantage of this sensor and the main reason for its high sensitivity.

III. FORMATION OF THE SUBSIGNAL

A signal delivered from a solenoid pick-up coil is composed of two components. First component is generated by an exciting current and second component is generated directly by eddy currents. These two components have the same frequency but
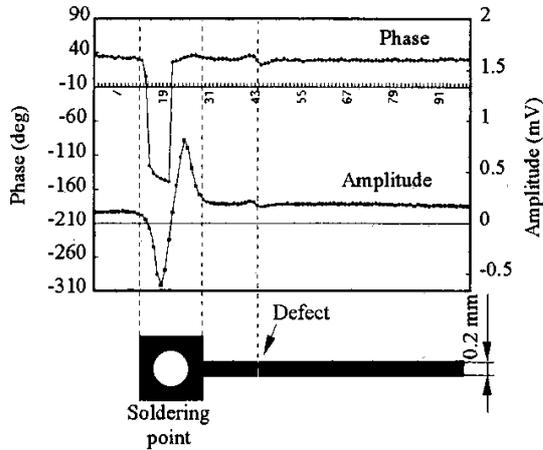
Fig. 2. Amplitude and phase obtained from the inspection of one conductor and soldering point.

Fig. 3. Subsignals obtained from each pick-up coil (amplitude data).

different phases. According to experimental results, there is 70° difference between their phases. Location of a defect can be determine from an amplitude or/and a phase characteristics. The amplitude characteristic shows that defects are always located between two peaks (high and low). The analysis of the phase characteristics can be extended by an interpretation of the signal shape. Fig. 2 shows the amplitude and the phase characteristics obtained from the inspection of one PCB conductor with a soldering point. In case of the soldering point the shape of the phase characteristic is different than the shape obtained from the defect. Indeed, the shape depends on proportion of the two components. The second component generated by the eddy-currents, is much higher in case of the soldering point, where it "switches" the phase of the output signal causing a characteristic "rectangular" shape. In the area of the defect, where the second component is relatively small due to the width of the conductor, the phase characteristic possesses an aberration.

IV. CALIBRATION OF SUBSIGNALS

During the inspection, a measurement system based on three lock-in amplifiers, has been used. Amplitudes or phases of subsignals, obtained from the lock-in amplifiers, were used for the calculation of the output signal. The output signal combines the three subsignals together. In order to provide successful combination of subsignals coming from three pick-up coils, calibration of the subsignals has to be done. During calibration, all pick-up coils inspect the same PCB model, then a pattern signal U is calculated. Next differences between the subsignals and the pattern signal, are estimated. The calibration process includes following steps. Each subsignal is transferred into numerical gradients, then reconstructed again with a settled value of the offset. During next step, these three components are added together and filtered by a moving average filter. The output (pattern) signal U is calculated according to the formula

$$U_i = \frac{1}{3} \sum_{i=1}^{n-2} \left[\left(V_{i+1}^{(1)} - V_i^{(1)} \right) + \left(V_{i+2}^{(2)} - V_{i+1}^{(2)} \right) \right.$$
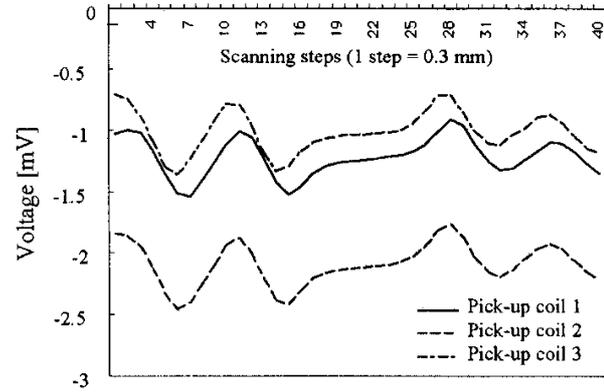$$\left. + \left(V_{i+3}^{(3)} - V_{i+2}^{(3)} \right) \right] \quad (1)$$
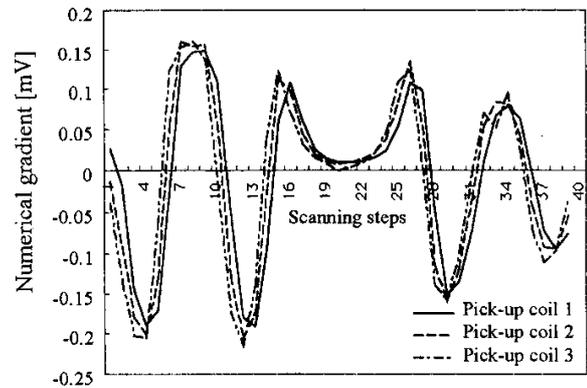
Fig. 4. Numerical gradients of the subsignals.

where:

V	is the value (amplitude or phase) obtained from subsignals,
$i = 1, 2, \ldots, n$	is the number of scanning steps, and
$(1), (2), (3)$	are the pick-up coils respectively.

Fig. 3 presents the exemplary subsignals obtained from the pick-up coils. Each of the subsignals possess different values of the offset voltage. However all subsignals have very similar shape. Fig. 4 shows the numerical gradients calculated from the subsignals. And Fig. 5 shows the resultant pattern signal. It is easy to estimate the differences between the pattern signal and subsignals. These differences have to be added to the subsignals, to equalize their offsets.

V. IMAGE PROCESSING

An image processing used for the visualization of data obtained, consists of three steps: removal of a noise and an offset component coming from nonuniformity of geometrical conditions, calculation of thresholds and visualization of data obtained as a surface chart.

There are three ways to realize the removal of the noise and the offset component:
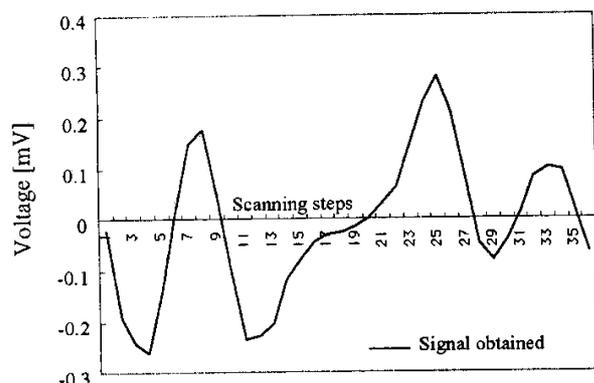
Fig. 5. Resultant pattern signal.

Fig. 6. Inspection results (a) PCB model, (b) image using amplitude data.

• removal of the noise by a linear phase finite impulse response (FIR) digital filter and removal of the offset signal,
• removal of undesirable components by Wavelet transform,
• removal of the noise and the offset using setting thresholds for numerical gradients (the fastest method).

In a final image defects are visible as spots not corresponding to soldering points, as shown in Fig. 6. The detection process relies on the estimation of numbers of spots and their locations. The visualization process can be improved if elimination of spots representing soldering point, was possible. The extraction of signals caused by soldering points can be realized using phase characteristics. A new filter, which can analyze the shape of signals should be developed. Thus all "rectangular" signals (coming from soldering point) could be neglected, and the final image might be constructed of the signals representing defects.

VI. CONCLUSION

The reported ECT sensor, composed of three pick-up coils, allows obtaining subsignals. The subsignals can be combined into the output signal due to very small differences between
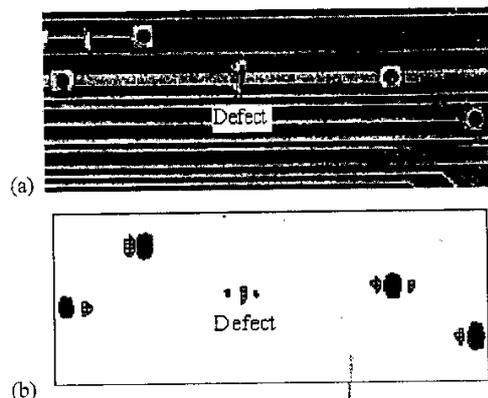
them. In order to increase testing speed, the number of pick-up coils should increase. Characteristic "rectangular" shapes, existing on the phase characteristic during the inspection of soldering points, can be used for an elimination of signals representing soldering points from the final image.

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