Application of Phase for Image Processing during Inspection of Printed Circuit Board by Eddy-Current Testing Probe

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This paper introduces an innovative image processing technique for the inspection of Printed Circuit Board (PCB) by an Eddy-Current Testing (ECT) probe. The visualization of an inspected model is obtained from a phase of an output signal measured by a lock-in amplifier. Although the lock-in amplifier delivers also information about an amplitude of the output signal, the visualization process can be performed without the amplitude. Information about size of a defect can be extracted from the shape of phase characteristic. Introduction of the phase into image processing allows farther combination of the amplitude with the phase and developing a confirmation process, where information about defects obtained from the amplitude characteristic can be confirmed by information obtained from the phase characteristic.

Key words: phase, image processing, eddy-current testing, printed circuit board, meander coil, solenoid coil

1. INTRODUCTION

There are many methods of image processing during inspections by eddy-current testing (ECT) probes based on the analysis of the amplitude or/and the phase of the output signal, or solutions of inverse problems. Although the phase of the output signal carries a lot of information about the structure of the inspected materials, image processing based only on the phase is very difficult and in some cases even impossible¹⁾.

In the new application of ECT technique for the inspection of printed circuit board (PCB), information about defects can be also obtained from the amplitude or the phase²⁾. The structure of the probe and its features have been already reported^{3) 4)}. Analysis of the amplitude characteristic is mainly focused on the removal of the offset signal and noise, measurement of the signal's peaks and interpretation of the final signal^{5) 6)}. The analysis of the phase characteristic can also concern the analysis of its shape, which can be used in future for removal of soldering points from a final image⁷⁾.

In this paper a fast method of image processing involving a phase, is presented. Characteristic changes of the phase during the inspection of soldering points are explained. A sample of image processing is also shown.

2. STRUCTURE OF THE ECT PROBE

Fig. 1 shows a high sensitive ECT probe 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, which generates eddy currents in the PCB conductors. Any defects on the tested conductors appear as an obstacle for the eddy currents and cause changes in their distributions. The key point of the ECT probe is its pick-up coil, which has a solenoid shape. This kind of pick-up coil allows the inspection of a tangential component of B . The analysis of this tangential component is more difficult than the normal component, because it appears a very small distance from the test conductor, and it's 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 tested conductor. The output signal doesn't have to be extracted from others signals as in the case of the inspection of the normal component. This is a big advantage of this probe and the main reason for its high sensitivity.

Fig. 1 ECT probe with solenoid pickup coil.

Fig. 2 shows the amplitude and the phase of the output signal obtained from an experiment scanning of one conductor 1 mm wide with a disconnection of length 0.2 mm. The signal includes two large peaks. The position of the defect is between them. Other signals are treated as noise and for this model they are relatively small. There is also some offset voltage coming from inaccuracy in the

pick-up coil's setting. The output signal is clear and information about defect existence - very distinct, therefore the output signal does not include much noise.

Fig. 2 The amplitude and the phase obtained from a disconnection defect.

3. CHANGES OF PHASE

According to the Fig. 3, changes in the phase characteristic appear as a result of the addition of two signal components: the $U_{offset-1}$ component caused by an exciting current, and the $U_{offset-2}$ component caused by eddy currents. These two components have the same frequency but different phase. In case of the inspection of a non-defect structure $U_{offset-1}$ and $U_{offset-2}$, added together, cause an offset signal U_{offset} . During the inspection of a homogeneous material the resultant data obtained from the lock-in amplifier (U_{o-max} and $\varphi_o - \varphi_i$) remain constant. Fig. 4 shows the formation of the signal obtained as a sum of two components $U_{offset-1}$ and $U_{offset-2}$. The components have sinusoidal character and there is 70° difference between their phases. The resultant signal possesses different phase than the first component $U_{offset-1}$.

In case of the inspection of a Printed Circuit Board conductor with a defect, the amplitude U_{2-max} of the component $U_{offset-2}$ increases by the amplitude U_{d-max} of signal caused by the defect - U_{defect} .

Fig. 3 Formation of the output signal during inspection of PCB conductor by the ECT probe.

Fig. 4 Formation of the output signal from two sinusoidal components $U_{offset-1}$ and $U_{offset-2}$.

Changes of the phase of the output signal are caused by the changes of proportion

$$P = \frac{U_{1-max}}{U_{2-max} + U_{d-max}} \quad (1)$$

The amplitude U_{d-max} obtained during the inspection of a narrow (0.2 mm) conductor is much smaller than the amplitude U_{d-max} from the inspection of wide conductor (0.8 mm) or a soldering point. Therefore the proportion P also strongly depends on the width of the inspected conductor. Characteristic "rectangular" changes of the phase, shown in Fig. 5, exist only during the inspection of wide conductors or soldering points where $P \approx 0.2$. These changes do not appear during the inspection of narrow conductors ($P \approx 5$), where the amplitude U_{defect} is too small to switch the phase of the total signal and produce the characteristic "rectangular" shape, and only generates a small "wave" form as it shown in Fig 6.

Fig. 5 Phase and amplitude in case of $P=0.2$ and $\varphi_1-\varphi_2=70^\circ$ obtained from numerical calculations .

Fig. 6 Phase and amplitude in case of $P=5$, $\varphi_1-\varphi_2=70^\circ$ obtained from numerical calculations.

The rectangular shape on the phase characteristic reflects a switching process between two values of phase. The phenomenon of switching phase may be used for extraction of signals coming from soldering points from all signals obtained during the inspection. The signals representing soldering points are unwanted signals. Their elimination from a final image will improve the image legibility. Fig. 7 shows a PCB model consisting of a soldering point and a conductor 0.2 mm wide. The component U_{defect} is generated by the tangential component of magnetic flux density B_z . In the area of defect, where the value of B_z is relatively small due to small width of the conductor, the phase characteristic possess small wave form, as shown in Fig. 8. The area of the soldering point, where value of B_z is much higher, can be seen as the rectangular shape on the phase characteristic.

Fig. 7 PCB model consisting of a soldering point and narrow conductor.

Fig. 8 Phase and amplitude characteristics obtained from the above model - experimental result.

4. IMAGE PROCESSING

Signals representing a soldering point and defects are much more "steep" than signals obtained on the amplitude characteristic as shown in Fig. 9, therefore the selectivity of the phase characteristic is much higher, than the selectivity of the amplitude characteristic.

Fig. 9 Amplitude and phase characteristic obtained during the inspection of the PCB model with 2 defects.

This advantage has inspired an image processing using only the phase data. Introducing an image processing method, based on the phase characteristic, a good quality image can be obtained. Fig. 10 shows a diagram of the image processing. The process consists of 3 steps. First the phase data, obtained during scanning from the lock-in amplifier, are transferred into numerical gradients. The second step is the removal of low numerical gradients and the last step is the process of setting thresholds. Fig. 11 presents a sample from the inspection and image obtained using the phase data.

Fig. 10 Diagram of the image processing.

Fig. 11 PCB model and its image obtained using the phase data.

The quality of image obtained from the inspected model is good. All obstacles laying perpendicular to the direction of scanning (conductors, soldering points and the defect) are well visible.

5. CONCLUSIONS

Image processing, based on the analysis of the output signal's phase, allows good and fast visualization of an inspected printed circuit board. Due to good selectivity of the phase characteristics, the quality of the image is very good. Characteristic rectangular shapes existing on the phase characteristic during the inspection of soldering points can be used for full elimination of signals representing soldering points from the final image.

REFERENCES

- 1) V. Coccorese and F. C. Morabito, Performance Improvement in Eddy Current Testing via Phase Information, *Studies in Applied Electromagnetics and Mechanics* 14, Electromagnetic Nondestructive Evaluation (II), pp. 66-73.
- 2) D. Kacprzak, S. Yamada and M. Iwahara, Analysis of the structure of printed circuit boards by means of the eddy current technique, *INSIGHT Non-Destructive testing and Condition Monitoring (The Journal of The British Institute of Non-Destructive Testing)*, Vol. 42 No 5 May 2000.
- 3) D. Kacprzak, T. Miyagoshi, T. Tanigushi, S. Yamada, M. Iwahara, „Comparison of two types of pick-up coil for meander excitation”, *Non-linear Electromagnetic Systems*, P.Di Barba and A. Savini (Eds.), IOS Press, 2000, p.229-232.
- 4) D. Kacprzak, T. Miyagoshi, S. Yamada and M. Iwahara, „Inspection of Printed Circuit Board by ECT Probe with Solenoid Pickup Coil”, *Journal of J. Magn. Soc. Japan* Vol. 24, No. 4-2, 2000, p. 839-842.
- 5) T. Taniguchi, D. Kacprzak, S. Yamada, M. Iwahara, T. Miyagoshi, „Defect Detection of Printed Circuit Board by Using Eddy Current Testing Technique and Image Processing”, *Electromagnetic Nondestructive Evaluation (IV)* S.S. Udpa et al. (Eds.) IOS Press, 2000, p.111-119
- 6) T. Miyagoshi, D. Kacprzak, S. Yamada and M. Iwahara, „Feasibility of Inspecting Defects inn Printed Circuit Boards by Using Eddy-Current Testing Technique”, *Journal of Magnetic Society of Japan*, Vol. 23 No. 4-2, 1999 p. 1613-1616.
- 7) D. Kacprzak, T. Taniguchi, S. Yamada, M. Iwahara, T. Miyagoshi „Interpretation of Printed Circuit Boards “Structure via Amplitude and Signal” Phase Obtained from ECT Testing”, 6th Int. Workshop on Electromagnetic Non-destructive Evaluation, 2000.6.