Introduction of a Base-Model for Eddy Current Testing of Printed Circuit Boards

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In this paper we propose a model to reproduce printed circuit board (PCB) pattern eddy current testing signals based on 3D finite-element method (FEM) package and scanning simulation. In this method we consider some common PCB elements as test pieces while a simple Meander-type coil is utilized as excitation coil above the elements. Numerical solution to the above problem with the help of a 3D FEM provides the magnetic flux density in the region above the PCB test elements. Shifting the test element's position step by step and repeating the numerical calculation for each of the test elements new positions, the scanning process of a PCB test piece is simulated. Analysing and smoothing the magnetic field data from all of the aforementioned steps provide the final PCB pattern signal. Image processing technique was applied to obtain the PCB part image.

Index Terms—**Eddy current testing (ECT), finite-element method (FEM), Meander coil, printed circuit board (PCB) inspection.**

I. Introduction

EDDY CURRENT TESTING (ECT) is an important non-destructive method used for inspection and locating defects on conducting materials such as metallic pipes, wings of airplanes or even the conductive strips of a printed circuit board (PCB) [1], [2].

The advantages of this method are fastness and low mechanical stress resulting from its non-contact nature, which are suitable for the inspection of delicate objects. Another feature of this method is that we can get the information in the direction of thickness by choosing an adequate excitation frequency considering surface effect. Therefore when it is used in the inspection of PCB, it can find not only disconnection of the printed pattern, but also chipping defect and imperfection of thickness which are hard-to-find by conventional image processing methods [3], [4].

For the realization of the PCB inspection by ECT method, however, there are two difficulties to be solved. First, eddy-currents should be induced efficiently in thin and narrow printed circuit. For this purpose a Meander-type excitation coil is used [1]. The Meander structure is preferable to the induction of the eddy-currents along the line conductor like printed circuit as shown in Fig. 1.

Second, the pattern of the conductor on PCB is not uniform, different from conventional testing material for ECT. In other words eddy currents in a PCB strip are constrained to a specific path. Hence, the output of the ECT probe includes many kinds of signal originated from not only defects but also PCB pattern. Consequently, introducing a technique which it selects only the defect signal is indispensable for this application.

Data processing technique which is already developed [5] could be used to extract the defect signal from the ECT probe output; however the difficulty of distinguishing some defects where they are close to each other still limits the application of this method. Hence, we introduce a method which we call the base-model method to reproduce the PCB pattern from a PCB pattern sheet. Having the pattern and comparing it with the pattern resulted from experiment, one could locate any probable defects. In other words, If one subtracts the base-model signal from the ECT output signal of a defected PCB, the defect signal is obtained.

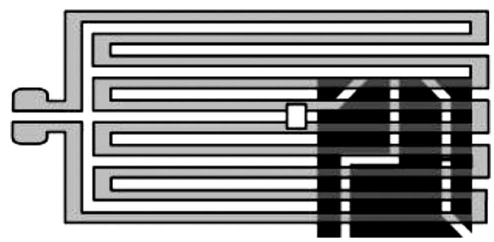

Fig. 1. A Meander-type coil is shown above a PCB while a GMR sensor is set at the midpoint of the coil.

The first step in this method is simplifying a complicated PCB pattern geometry to many simple basic parts; however there is just a few numbers of such simple parts geometry. The next step includes the simulation of scanning process of simple parts individually. This simulation is based on a numerical calculation using a 3-D COMSOL package. Finally by assembling the individual results from each basic part one can obtain the final signal from the whole PCB pattern sheet. On the other hand a series of experiments were conducted to get the pattern of each simple part.

The two results from base-model method and experiment for some of the basic parts have been compared in this research. The process of assembling the whole PCB basic parts and subtracting the two results are in progress.

II. Method

As the aim of our model is to reproduce the pattern of a non-defected PCB in a theoretical way by simulating the scanning process, the following issues should be worked on carefully.

A. Disassembling the PCB Pattern

It is possible to consider a PCB pattern geometry as an assembling of some basic parts as seen in Fig. 2. In this way a complicated pattern could be separated into basic parts. The pattern

Digital Object Identifier 10.1109/TMAG.2008.2002864

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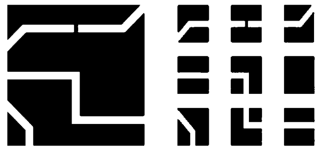


Fig. 2. (a) A typical PCB pattern sheet. (b) The pattern is disassembled to nine basic parts.

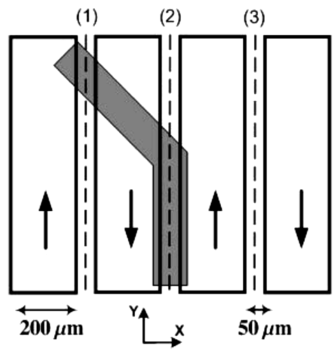


Fig. 3. Top view of 3D FEM simulation of the problem. An open-elbow PCB basic part, 100 um width, shown in gray is set 50 um under four legs of Meander coil.

reproducing process could be applied to the different basic parts individually to get the final image for each of the parts. These images are then assembled to get the whole PCB image.

Even though the pattern of a typical PCB is quite complex, the repeatability of the basic parts in the pattern can be taken as an advantage to limit the number of calculations. Here we investigate three different basic parts as shown in Fig. 1: open-elbow, straight, and half part. The width and thickness of each part are considered to be 100 and 10 um, respectively.

B. Probe Details and Physical Quantity Measurement

A long Meander-type coil is utilized as excitation coil. To simulate the coil, we use four straight long conductive strips located parallel to each other. The distance between each strip is considered to be 50 um. The width and thickness of each strip is also assumed to be 200 and 35 um, respectively, as seen in Fig. 3.

In a real experiment, a SV-GMR sensor [6], is located in the middle point of the Meander coil in such a way that it measures the magnetic flux density in the scanning direction. Because of that the physical quantity which we calculate here is the magnetic flux density due to interaction between the Meander coil and a PCB basic part. Unfortunately, there is no analytical solution to such a problem; hence, we use numerical solution to find the magnetic flux density. Using FEMLAB package, we simulated a Meander coil above a basic part in a 3D model as shown in Fig. 3 for a typical open-elbow basic part.

The element shape used in the 3-D finite-element method (FEM) calculation was second-order tetrahedron to obtain an acceptable smoothed result, while its type was nodal. We also used magnetic vector potential formulation. In this case the number of degrees of freedom for the FEM package solver was about 220 000. The frequency was considered to be 5 MHz.

Since the legs of the coil were supposed to be very long in y-direction and they had periodicity in x-direction the magnetic field has only tangential component at infinity. Hence, the Dirichlet boundary condition was applied to the problem which means we used magnetic insulation as the boundary condition.

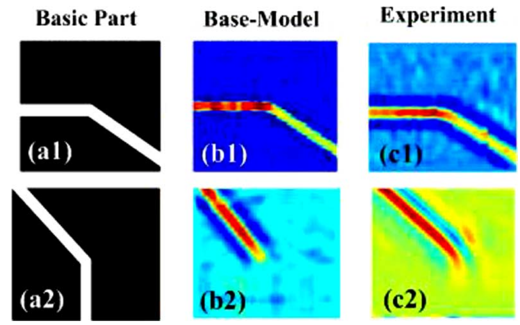


Fig. 4. (a1), (a2) Basic parts obtained after disassembling. (b1), (b2) Base-model results of scanning simulation based on 3D FEM analysis. (c1), (c2) Experimental results of the same pattern PCB, notice that the scanning direction is from left to right in the horizontal direction.

C. Simulation of Scanning Process and Image Processing

A 2-D scanning system includes scanning in two directions, i.e., x-direction and y-direction, which we should consider both of them in the scanning procedure simulation. To simulate the x-direction scanning process we repeated the FEM calculation for many different PCB part positions on the x-direction relative to the Meander coil. It means first we put the part in a reference position and run the package to obtain the magnetic flux density. Then we move the position of the PCB part one step on the x-direction. Here we considered each step to be 25 um as in the experiment. After running the program and getting result, the same procedure was repeated for a new position of the PCB part. We repeated the procedure 10 times or in other words for 10 steps.

For simulating the y-direction scanning process we measure the magnetic flux density on each central line between the strips of the Meander coil which are shown by dashed lines in Fig. 3.

As we moved the PCB part 10 steps and we also had 3 central lines, we got 30 columns of data. These data was gathered in a matrix to be used for image processing step. To obtain an image of the PCB part, the gradient of the aforementioned matrix was taken as an edge detection process [7]. A median filter was also applied to get a clearer image as in Fig. 4(b1) and (b2). Notice that the scanning direction was in an up-down direction, i.e., y-direction.

One of the most important points in the calculation is related to the width of the sensing area of magnetic sensor which we should take into account.

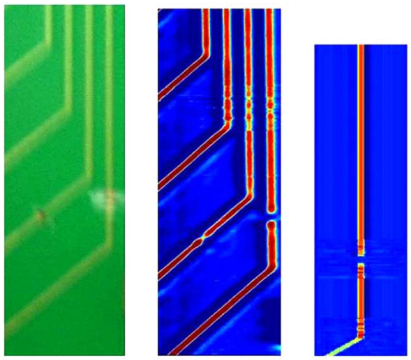
The GMR sensor used in the experiment has a sensing area about 100 um by 100 um; hence, we should consider the effective sensing area as a surface, not as a point, to obtain a more realistic result as close as possible to the experimental result. The wide-area sensing effect causes the final image to be a little blurred in comparison with the result of a point-sensor.

On the other hand, calculated results obtained by the base-model shows that the resolution of the final image of the basic part is inversely proportional to the scanning step size.

The whole above procedure could be applied to any of the other basic parts. In this way the image produced by each of the basic parts is obtained, and could be assembled to get the image of a complicated PCB pattern shown in Fig. 5(c).

III. Experimental Results

The probe used in the experiment consists of a long Meander coil as an exciter and a SV-GMR sensor to measure the magnetic flux density. The sensor was mounted on the long Meander coil



(a) (b) (c)

Fig. 5. (a) Photo of a real PCB. (b) Image of the PCB obtained by experiment after applying image processing technique. (c) Image obtained by base-model method for a small part of the PCB.

and its sensing axis was set to detect the magnetic flux density, only in the scanning direction. The use of the long Meander coil provides the advantage of easily developing a multisensor, which is another technique that can improve the scanning speed. In addition, it provides a short distance between the SV-GMR sensor and tested PCB. As a result, the sensor easily acquires the ECT signal at defect point with high SNR.

Magnetic field excitation was generated by feeding high-frequency exciting current to the long Meander coil. In this research, sinusoidal current of 200 mA at a frequency of 5 MHz was fed to the Meander coil. A lock-in amplifier was used as a data acquisition system for measuring the ECT signal from the sensor. Scanning a small part of a PCB in an experimental situation consist an open-elbow, a straight, and a half part, applying image processing technique [8]; we get the patterns which can be seen in Fig. 6(a), (c), and (e). Fig. 6(b), (d), and (f) show the base-model results.

The results show that our method could be a good candidate for producing a PCB pattern using a PCB pattern sheet. On the other hand, subtracting the pattern obtained by the method from the pattern by the experiment gives the defect pattern on a clear background without the complicated PCB conductor pattern.

It is a very important point to get an easy distinguishable image of a probable defect on a complicated PCB instead of a complicated maze of lines. The base-model method which we introduced is under development to get such a result.

IV. Conclusion

We introduced the base-model method to provide a PCB pattern image using a numerical method. Using the resultant image from the method and comparing it with the experimental result, probable defect on PCB conductor strips could be identified on a very clear background.

As the model is based on a FEM calculation, calculation time, smoothness and precision of the result depends on the PC and the number of degrees of freedom of the model. For example if one chooses a linear element the result will not be as smooth and precise as needed. Having the result for a few number of basic PCB parts as shown in Fig. 2 is enough to reproduce a complicated pattern. However if the dimensions of a real PCB parts changes, for example the width of a part in some area, the method should be applied to the new basic part to get a new image related to the part.

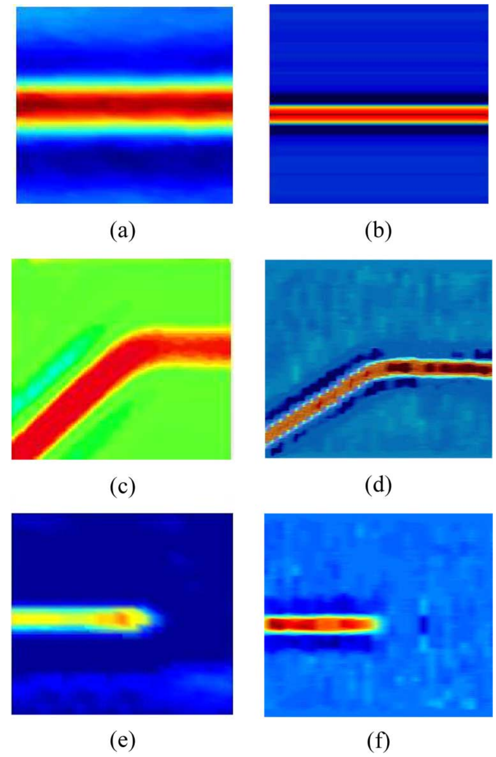


Fig. 6. (a), (c), and (e) are the images obtained from experiment and (b), (d), and (f) are the images produced by the base-model method. Scanning was done in an up-down direction.

The method shows a considerable development in PCB inspection and could be extended to other areas of ECT inspection where the test piece is made of a complicated pattern as well.

Acknowledgment

This work was supported in part by the Foundation for Technology Promotion of Electric Circuit Board.

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