Improvement on Defect Detection Performance of PCB Inspection Based on ECT Technique With Multi-SV-GMR Sensor

K. Chomsuwan[1,2], S. Yamada[1], and M. Iwahara[1]

[1]Institute of Nature and Environmental Technology, Kanazawa University, Kanazawa, Ishikawa 920-1192, Japan
[2]Department of Electrical Technology Education, King Mongkut's University of Technology, Thonburi, Bangkok 10140, Thailand

This paper describes the improvement on the defect detection performance of printed circuit board (PCB) inspection based on the eddy-current testing (ECT) technique with the multispin-valve giant magnetoresistance (SV-GMR) sensor. To obtain the ECT signal in the same scanning line, SV-GMR sensors are mounted on the exciting coil in the same column parallel with the scanning direction. Harmonic analysis based on the Fourier transform is used to analyze the signal from the SV-GMR sensor in order to increase scanning speed. Then signal averaging is applied to the ECT signal in order to improve the signal-to-noise ratio. Experimental results are performed to verify the inspection performance.

***Index Terms*—Eddy-current testing (ECT), multisensor, printed circuit board (PCB), scanning speed, signal averaging, signal-to-noise ratio (SNR), spin-valve giant magnetoresistance (SV-GMR).**

I. Introduction

The inspection of a printed circuit board (PCB) based on the eddy-current testing (ECT) technique has been developed and provides good inspection performance. The ECT probe structure has a very simple structure; therefore, the fabricated cost is inexpensive. Many kinds of magnetic sensors, such as solenoid coils, planar mesh types, and figure eight coils, have been applied to this purpose in order to improve the inspection performance. The spin-valve giant magnetoresistance (SV-GMR) sensor is also successfully applied in the detection of microdefects on high-density PCBs based on the ECT technique. Due to the SV-GMR sensor features, PCB inspection performance is increased [1]–[4].

The measurement of the ECT signal requires high-performance of noise reduction because the ECT signal has a low level and contains a lot of noise. The phase sensitive detector, known as the lock-in amplifier, is usually used to measure the ECT signal because this technique can improve the signal-to-noise ratio (SNR) up to 60 dB. Although high inspection performance can be obtained, scanning speed is restricted because of low-pass filter utilization based on the phase sensitive detector technique [5], [6].

This paper describes the improvement of inspection performance consisting of scanning speed and SNR. Instead of a lock-in amplifier, harmonic analysis based on the Fourier transform is applied to analyze the measured signal captured from the SV-GMR sensor, in order to improve scanning speed. However, the ECT signal, after applying Fourier transform, still contains a high level of noise. Then, the noise reduction technique based on the averaging of the ECT signal obtained from the multi-SV-GMR sensor is used in order to improve the SNR.

II. Proposed ECT Probe Structure

As shown in Fig. 1, the proposed ECT probe, which consisted of a long meander coil and the SV-GMR sensor, was fabricated for the purpose of PCB inspection. The use of a long meander coil provides the feasibility of easy extension of a number of sensors as an array sensor for the improvement of scanning time and of having a short distance between the magnetic sensor and the PCB conductor. Therefore, high SNR can be achieved. SV-GMR sensors were mounted over the long meander coil between two conductors, and the sensors were aligned in the same column to obtain the ECT signal in the same scanning line. The sensing direction of the sensors was set to detect the magnetic field B_z parallel to scanning direction. These magnetic fields usually occur at the defect point or at the PCB conductor boundary.

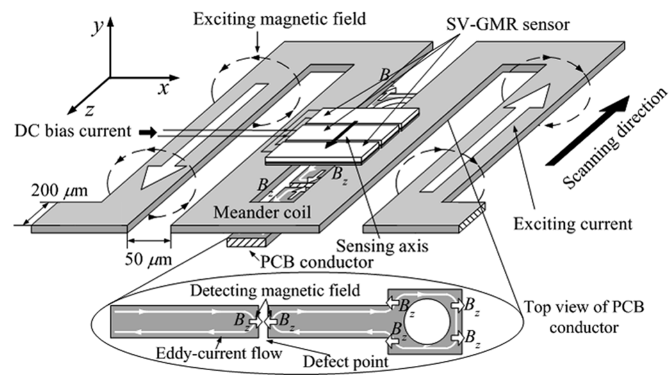

Fig. 1. Proposed ECT probe with multi-SV-GMR sensor.

The SV-GMR sensor has the meander structure, as shown in Fig. 2, with a sensing area of 93 $\times$ 100 μm. On one chip, it is equipped with four SV-GMR sensors, and the gap between the sensors is 200 μm. Normal resistance of the SV-GMR sensors is approximately 400 Ω, whereas the average of its sensitivity in the sensing direction is in the magnitude of 150 μV/μT.

III. Measurement Technique

A. ECT Signal Acquisition Method

The ECT signal measured by magnetic sensors contains a lot of noise, although high-performance magnetic sensors, such as the SV-GMR sensor, are used. The noisy signal measured from the sensor can be written in signal and noise terms as follows:

$$v_{\text{in}}(t) = V_s \sin(\omega t + \theta_s) + \sum_{\text{noise}=1}^{\infty} V_{\text{noise}} \sin(\omega_{\text{noise}} t + \theta_{\text{noise}}) \quad (1)$$

Digital Object Identifier 10.1109/TMAG.2007.893480

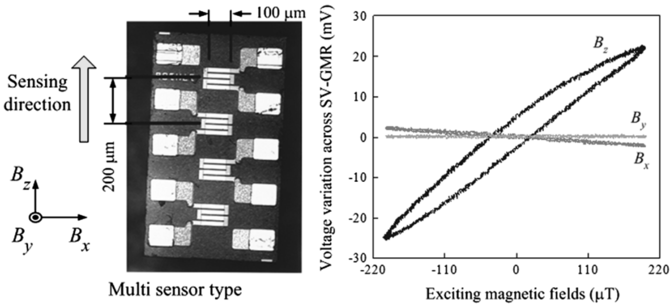

Fig. 2. Proposed multi-SV-GMR sensor and its characteristics.

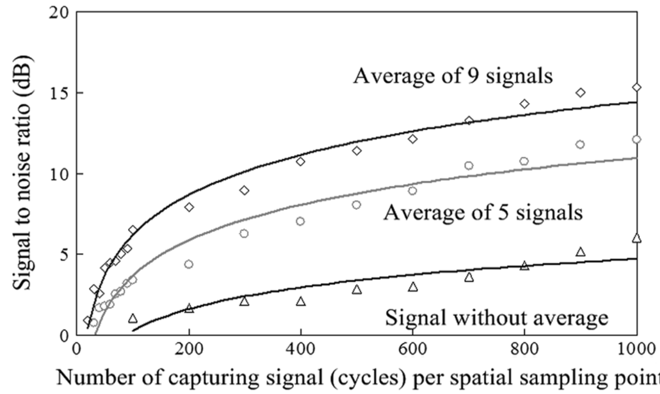

Fig. 3. Simulation results of SNR improvement with the proposed technique (defect signal: −20 dB; noise: 10 dB).

where V_s, ω, and θ_s are the amplitude, fundamental frequency, and phase shift of the signal, respectively, and $V_{\text{noise}}, \omega_{\text{noise}}$, and θ_{noise} are the amplitude, fundamental frequency, and phase shift of the noise, respectively.

To measure the signal amplitude V_s at the fundamental frequency, harmonic analysis based on the Fourier transform is applied to the measured signal $v_{\text{in}}(t)$ in (1). However, the calculation output still contains a lot of noise because of high-level noise in the measured signal $v_{\text{in}}(t)$. In order to accurately obtain signal amplitude, the array of the captured signal m (in the unit of cycles) is applied by the Fourier transform in the same time. To obtain less noise contained in the calculation output, a large number of captured signals m is required.

Although the use of harmonic analysis can increase the data acquisition speed, the overall acquisition speed depends on the number of captured signals m. The probe is able to continuously scan while the ECT signal is acquired. As a result, the scanning speed can be increased with less distortion and with higher spatial scanning resolution.

B. SNR Improvement Based on Signal Averaging

In order to improve SNR, the multisignal averaging technique is applied to the ECT signal after applying the Fourier transform. Since the SV-GMR sensors are aligned on the same scanning line, multisignal averaging can be obtained in order to reduce noise. The defect signal is contained in all ECT signals, although it is has a low level, whereas noise is not same to each other's signal. Therefore, by taking an average of the ECT signal from multi-SV-GMR sensors, noise contained in the ECT signal can be reduced. This means that the SNR can be improved [7].

Simulation results are shown in Fig. 3. The defect point signal with an amplitude of −20 dB was added to the measured signal. Random noise of 10 dB was included in the measured signal. Two average values, 5 and 9 signals, were simulated. The results show that the proposed technique can improve the SNR at the defect point. For the captured signal m of larger than 100 cycles, SNRs averaging of 5 and 9 signals are higher than that without applied signals averaging approximately 6 and 8 dB, respectively.

In the experimental result, as shown in Fig. 4, single ECT signal contains high-level noise, and it is still very difficult to identify the small defect point, although the simple filtering technique was applied to the signal. By applied signal averaging, the defect point is easier to detect, although the defect point has a small size.

IV. Experimental Results

A. Experimental Setup

A sinusoidal current of 200 mA at a frequency of 5 MHz was fed to a meander coil to generate the exciting magnetic field. A DC constant current of 5 mA was also fed to the SV-GMR sensors. A high-speed analog-to-digital converter (12 bits at 100 MS/s) was used to capture the ECT signal from the SV-GMR sensor. Before the signal from the SV-GMR sensor was fed to the analog-to-digital converter, the signal was amplified with a gain of 50 dB. Fourier analysis was applied to the captured signal based on digital calculation by a personal computer. Signal averaging was calculated after finishing the scanning process.

B. Inspection Performance

A simple PCB model made from Cu with a thickness of 9 μm coated by 0.05 μm Au was used in the experiment. The conductor disconnections ranging from 50 to 500 μm were made on the PCB conductor. By using the lock-in amplifier, the proposed ECT probe was capable of inspecting the 50-μm conductor disconnection located on the 70-μm PCB conductor width. However, scanning speed was restricted at around 0.001 m/s [3].

Fig. 5 shows the SNR against the PCB conductor disconnection when the proposed data acquisition technique with and without multisignal averaging was used. A scanning speed was 0.05 m/s and the number of captured signals was 200 cycles. The SNR of the single signal is lower than that of nine signals of approximately 7 to 10 dB. The applied signal averaging provides the capability of detection of the 50-μm conductor disconnection over the 70-μm PCB conductor width. In inspection performance comparison between the proposed technique and the use of the lock-in amplifier, inspection performance is still the same; however, in the proposed technique, the scanning speed is higher.

C. Sample PCB Inspection

The sample PCB model and its inspection results are shown in Fig. 6. The conductor disconnection and partial defects were made on the model. The probe scanned the PCB model along the y-direction, with the x-direction pitch of 20 μm and scanning speed of 0.05 m/s. The defect on the tested PCB can be identified based on a comparison of the inspection results between the reference and tested PCB. Spatial resolution of scanning was 12 μm, approximately, whereas the scanning process

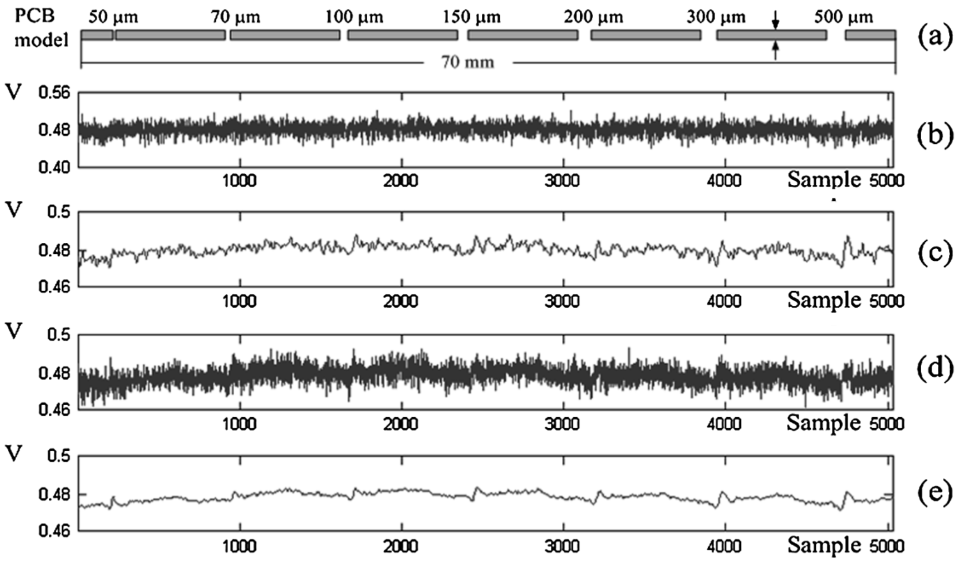

Fig. 4. The detected ECT signal with SV-GMR scanning over the PCB model with a scanning speed of 0.05 m/s and captured signal of 100 cycles, m. (a) PCB model; (b) detected signal from SV-GMR; (c) applied FIR filter to the signal (b); (d) nine averaging signals; (e) applied FIR filter to the signal (c).

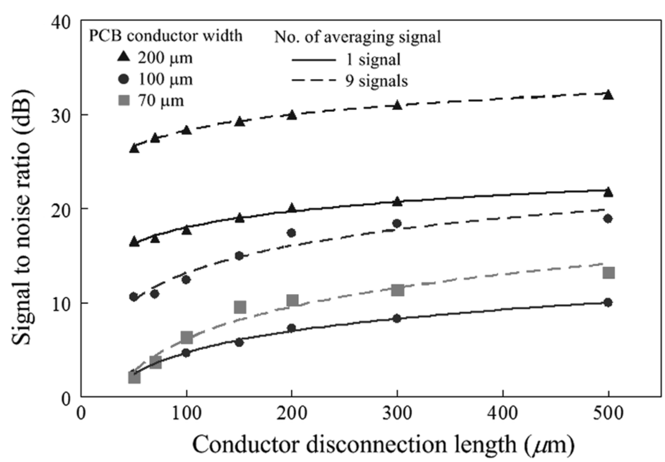

Fig. 5. SNR against conductor disconnection length.

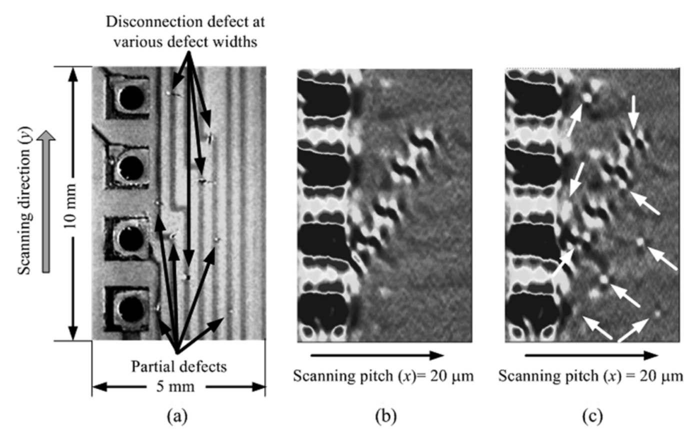

Fig. 6. Sample PCB model and its inspection results at scanning speed of 0.05 m/s represented in 2-D image. (a) Photograph of the PCB model, (b) inspection result of the reference PCB model, and (c) inspection result of the tested PCB model with nine averaging signals.

took 5 min. From inspection results, defects on the PCB model are clearly identified.

The applied multi-SV-GMR sensor technique based on multisignal averaging can improve inspection capability for both SNR and spatial resolution. Nevertheless, the number of signals used in averaging should have an enough value to enhance the defect signal.

V. Conclusion

The improvement on defect detection performance of the PCB inspection based on the ECT technique is explained. The scanning time is reduced by the use of harmonic analysis based on the Fourier transform, and the SNR is improved by using the multisignal averaging. By using the proposed method, the defect on the PCB conductor, with width and disconnection length of 70 and 50 μm, respectively, can be detected, and the scanning speed of 0.05 m/s and spatial resolution of scanning approximately 12 μm can be obtained.

References

[1] T. Taniguchi, D. Kacqrzak, S. Yamada, and M. Iwahara, "Wavelet-based processing of ECT images for inspection of printed circuit board," *IEEE Trans. Magn.*, vol. 37, no. 7, pp. 2790–2793, Jul. 2001.

[2] S. Yamada, K. Nakamura, M. Iwahara, T. Taniguchi, and H. Wakiwaka, "Application of ECT technique for inspection of bare PCB," *IEEE Trans. Magn.*, vol. 39, no. 5, pp. 3325–3327, Sep. 2003.

[3] K. Chomsuwan, S. Yamada, M. Iwahara, H. Wakiwaka, and S. Shoji, "Application of eddy current testing technique for high-density double-layer printed circuit board inspection," *IEEE Trans. Magn.*, vol. 41, no. 10, pp. 3619–3621, Oct. 2005.

[4] S. C. Mukhopadhyay, "A novel planar mesh-type microelectromagnetic sensor—Part I: Model formulation," *IEEE Sensors J.*, vol. 4, no. 3, pp. 301–307, Jun. 2004.

[5] User's Manual Model SR844 RF Lock-in Amplifier Rev. 2.5, vol. 2, 1997, pp. 68–73, Standford Res. Syst.

[6] N. V. Nair, "A GMR-based eddy current system for NDE of aircraft structures," *IEEE Trans. Magn.*, vol. 42, no. 10, pp. 3312–3314, Oct. 2006.

[7] S. A. Huettel and G. McCarthy, "The effects of single-trail averaging upon the spatial extent of fMRI activation," *Neuroreport*, vol. 12, no. 11, pp. 2411–2416, Aug. 2001.

Manuscript received October 30, 2006 (e-mail: komkrit.cho@kmutt.ac.th).