High-speed PCB Inspection System Based on ECT Technique With Multi SV-GMR Sensor

High-Speed PCB Inspection System Based on ECT Technique With Multi SV-GMR Sensor

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This paper describes high-speed printed circuit board (PCB) inspection based on eddy-current testing (ECT) technique. The proposed ECT probe consists only of meander exciter coil and multi spin-valve giant magnetoresistance (SV-GMR) sensor that it was designed for detection of microcrack on PCB surface. To conduct high-speed scanning, harmonic analysis based on Fourier analysis is applied to acquire ECT signal at fundamental frequency. Signal variation at defect point is enhanced by applied averaging of multisignal obtained from the multi SV-GMR sensor.

Key Words: Eddy-current, Spin-valve giant magnetoresistance (SV-GMR), Multisensor, Harmonic analysis, Printed circuit board (PCB), Signal averaging.

1. Introduction

Eddy-current testing (ECT) technique is successfully applied in detecting microdefect on microconductor of printed circuit board (PCB) [1], [2]. The proposed technique is able to inspect not only conductor disconnections and short circuits but also partial defects on PCB conductor track width and thickness. Moreover, the probe, consisting of meander coil (exciting coil) and spin-valve giant magnetoresistance (SV-GMR) sensor, has very simple structure. Therefore the fabricated cost is inexpensive. Because of low-level ECT signal obtained from SV-GMR sensor, high-performance measurement technique is required. Lock-in amplifier is usually used to measure the ECT signal from SV-GMR sensor; however, scanning speed is restricted because of low-pass filter.

In this paper, Fourier analysis is applied to calculate the amplitude of ECT signal to decreasing of measuring time, thus, scanning speed can be increased. Multi SV-GMR sensor is applied to improve the signal to noise ratio (SNR) based on multisignal averaging technique.

2. Proposed ECT System Structure

2.1 ECT probe with multi SV-GMR Sensor

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As shown in Fig. 1, the proposed high-frequency ECT probe, which consisted of a long meander coil and SV-GMR serving as an exciting coil and a magnetic sensor respectively, was fabricated for the high-speed PCB inspection system. SV-GMR sensor was mounted on the long meander coil and its sensing axis was set to detect the magnetic field, B_z, only in scanning direction that usually occurs at the defect point or at PCB conductor boundary. The use of the long meander coil provides the advantages of easily developing of the multisensor to decrease the scanning time and of providing short distance between sensor and tested PCB.

The SV-GMR sensor had the structure, as shown in Fig. 2, with a sensing area of 93 μm×100 μm. Normal resistance of the SV-GMR sensor was approximately 400 Ω, while its sensitivity was approximately 150 μV/μT. The use of multi SV-GMR sensor further provided the possibility of decreasing the inspection time [3].

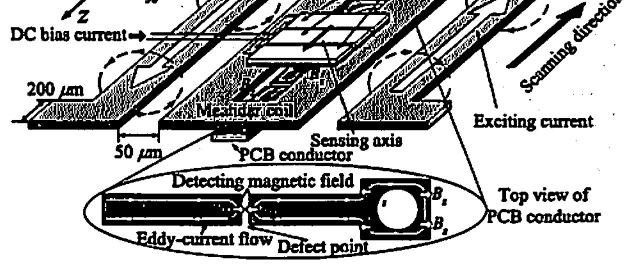

Fig. 1. Proposed ECT probe model with multi SV-GMR sensor

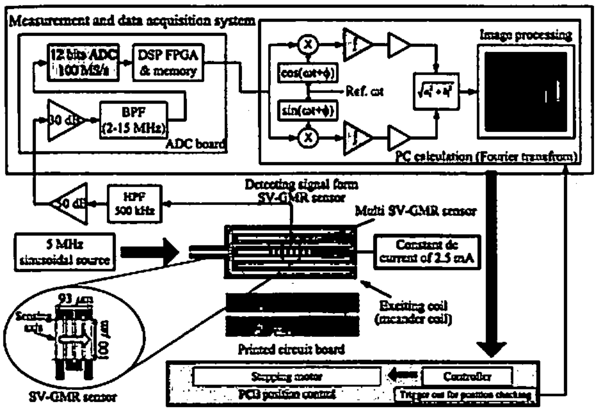

Fig. 2. Proposed system configuration

2.2 System configuration

The proposed system structure consisted of 4 parts as shown in Fig. 2. The first was the PCB position control system for moving the tested PCB in 2 dimensions. The second was the aforementioned high-frequency ECT probe. The third was the exciting system 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. Finally, the forth was the data acquisition system that, normally, used the Lock-in amplifier for measuring the ECT signal from the SV-GMR sensor. For decreasing inspection time, a high-speed analog-to-digital converter (12 bits at 100 MS/s) was used to capture the ECT signal from each SV-GMR sensor and transfer it to the computer for applying Fourier transform to the captured signal. Then, the PCB inspection with high-speed scanning produced the inspection resulting in less distortion.

3. Measurement Technique

3.1 ECT signal acquisition method

The noisy input signal measured from the SV-GMR sensor can be written with the signal and noise terms as follows:

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

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

To measure the signal at fundamental frequency by applied Harmonic analysis based on Fourier transform, the signal $v_{in}(t)$ in Eq. (1) is multiplied by cosine and sine function at the fundamental frequency. Therefore, the noisy signal can be

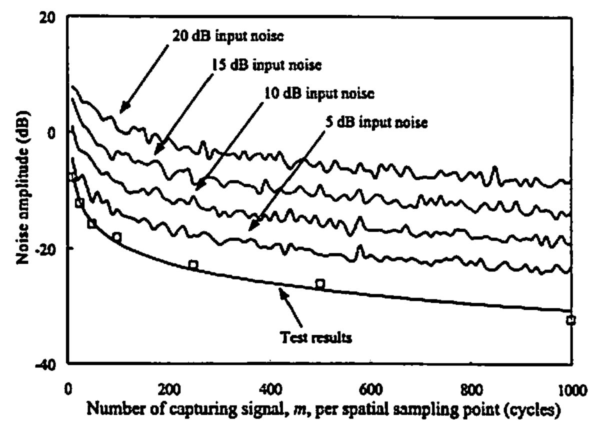

Fig. 3. Signal to noise ratio rejection performance by applied Fourier transform

obtained as follows:

$$\begin{aligned} V_x = {} & (V_s/2)\sin(\theta_s - \theta_r) + (V_s/2)\sin(2\omega t + \theta_s + \theta_r) \\ & + \sum_{noise=1}^{\infty} (V_{noise}/2)\sin((\omega_{noise} - \omega)t + \theta_{noise} - \theta_r) \\ & + \sum_{noise=1}^{\infty} (V_{noise}/2)\sin((\omega_{noise} + \omega)t + \theta_{noise} + \theta_r) \end{aligned} \quad (2)$$

$$\begin{aligned} V_y = {} & (V_s/2)\cos(\theta_s - \theta_r) - (V_s/2)\cos(2\omega t + \theta_s + \theta_r) \\ & + \sum_{noise=1}^{\infty} (V_{noise}/2)\cos((\omega_{noise} - \omega)t + \theta_{noise} - \theta_r) \\ & + \sum_{noise=1}^{\infty} (V_{noise}/2)\cos((\omega_{noise} + \omega)t + \theta_{noise} + \theta_r) \cdot \end{aligned} \quad (3)$$

where θ_r is phase shift of the multiplying function.

Integration within interval time was applied to the Eqs. (2) and (3). The gain (2 per interval time) was multiplied to the integration results to obtain a_l and b_l, respectively. Signal amplitude was achieved by applied a_l and b_l to equation, $\sqrt{a_1^2 + b_1^2}$. This technique is well known in the name of "Harmonic analysis base on Fourier transform". Because of the noisy signal, the suitable numbers of capturing signal, m, (in unit of cycles) was required for obtaining the less noise signal after applying the Fourier transform. Fig. 3 shows calculation output obtained from the simulation and test results when the noise in dB per one unit of fundamental amplitude was added to the fundamental signal. The test results also agree with the simulation results. To obtain less noise, large numbers of capturing signal, m, was required for the calculation.

The use of harmonic analysis increased the data acquisition for a speed up to 10 kS/s depending on the number of capturing signal, m. The probe was able to scan while the signal was acquired. As a result, the scanning speed can be increased with less distortion and with higher scanning resolution.

3.2 Signal - to - noise ratio improvement

Multisignal averaging technique is applied to reduce noise containing in the calculated signal. Because defect signal contains in all calculated signal although it has low-level whereas noise is not same to each other signal. Therefore, taking an average of the signals, measured from multi SV-GMR sensor, can reduce noise containing in the signal. It means that SNR can be improved.

Simulation results are shown in Fig. 4. Defect point signal with amplitude of -20 dB is added to the measured signal. Random noise of 10 dB is included in the measured signal. Two average values, 5 and 9 signals, are simulated. The results show that the proposed technique can improve the SNR at defect point whereas scanning speed is high. SNR, for larger than 100 cycles capturing signal, is higher than the signal without applied averaging technique approximately 6 dB and 8 dB for averaging of 5 and 9 signals, respectively.

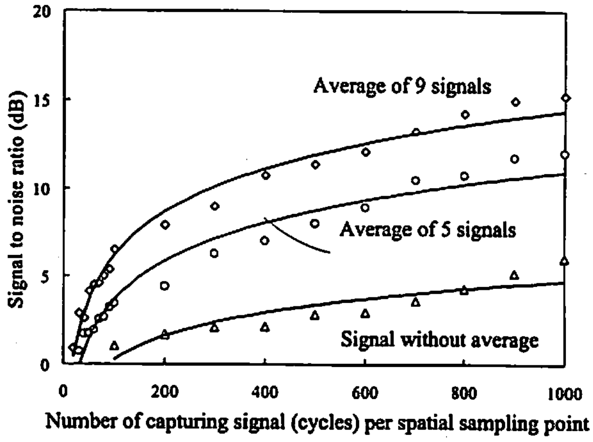

Fig. 4. Simulation results of SNR improvement with proposed technique (defect signal: -20 dB, noise: 10 dB)

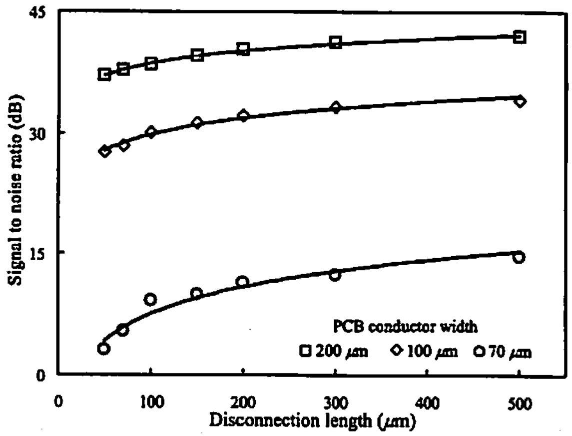

Fig. 5. Signal to noise ratio vs. conductor disconnection length acquired by Lock-in amplifier.

4. Experimental Results

4.1 Inspection performance

The performances of PCB inspection system based on ECT technique were tested. Simple PCB model made from Cu with a thickness of 9 μm coated by 0.05 μm Au was used in the experiment. Conductor disconnections ranging from 50 to 500 μm were allocated on the PCB conductor.

Fig. 5 shows SNR versus conductor disconnection when Lock-in amplifier was used to acquire the signal from the SV-GMR sensor. By using Lock-in amplifier, the proposed ECT probe was capable of inspection the PCB conductor disconnection on the 70-μm PCB conductor width. SNR depends on PCB conductor width and disconnection length. SNR increased gradually as a logarithm function when the PCB conductor width was wider. In contrast, scanning speed was restricted at around 0.001 m/s.

For applied harmonic analysis as shown in Figs. 6 and 7, high noises contain in the calculated signal depending on the scanning speed and the number of capturing signal, *m*, as a result, SNR was drop. However, applied multisignal averaging technique, acquired from multi SV-GMR senor, could improve SNR. In inspection of lager PCB, Fig. 6, high-speed scanning could be done and large number of capturing signal, *m*, was not required. Therefore, high-scanning speed and high-spatial resolution scanning up to 100 S/mm could be achieved while inspection accuracy was still high. For small PCB inspection, Fig. 7, scanning speed had to decrease and large number of capturing signal, *m*, was required to keep high accuracy of inspection. This is because the signal variation was low and the analog-to-digital converter could not acquire the ECT signal at a frequency of 5 MHz without loss, although a high speed analog-to-digital converter was used.

The probe could inspect the conductor disconnection on the 100-μm PCB conductor, although the disconnection length was about 50 μm. In addition, the scanning speed was faster than that of using the Lock-in amplifier and spatial sampling frequency was higher than 10 kS/s depending on the selected number of capturing signal, *m*. Although multisignal averaging provided a good signal enhancement performance, simple noise reduction method, for example FIR filter, should be applied to the calculated signal for improvement of inspection accuracy.

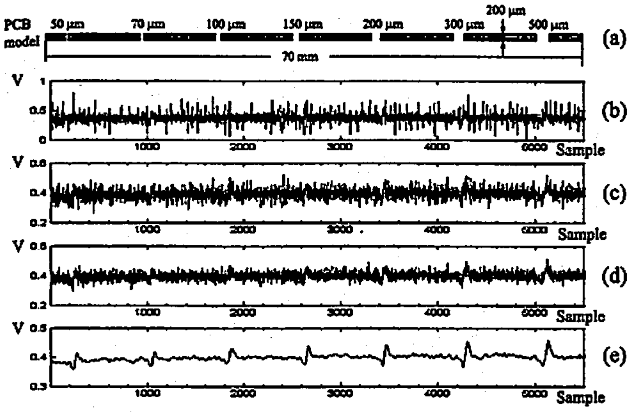

Fig. 6. Detected ECT signal with SV-GMR scanning over PCB model (a) with scanning speed of 0.10 m/s and 10-cycle capturing signal, *m*. (b) detected signal from SV-GMR, (c) applied 5 averaging signals, (d) applied 9-averaging signal, and (e) applied FIR filter to signal (c)

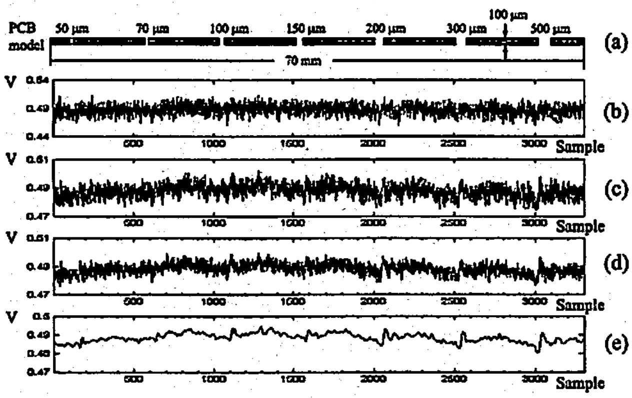

Fig. 7. Detected ECT signal with SV-GMR scanning over PCB model (a) with scanning speed of 0.05 m/s and 200-cycle capturing signal, *m*. (b) detected signal from SV-GMR, (c) applied 5-averaging signals, (d) applied 9-averaging signal, and (e) applied FIR filter to signal (d)

4.2 Sample PCB inspection

The sample PCB model and its inspection results are shown in Fig. 8. Numerical gradient image was applied to the calculated signal and represented in 2-dimension image. With scanning speed of 0.05 m/s and 200-cycle capturing signal, the spatial resolution in scanning direction were approximately 20 μm and y-direction pitch was fixed at 5 μm.

The defect points could not be easily identified although simple noise reduction method was applied before the image was generated. The use of 5-averaging and 9-averaging signal made the defect points clearer to specify. Applied multi SV-GMR sensor technique based on multisignal averaging could improve inspection capability. Nevertheless number of signal used in averaging should have enough value to enhance the defect signal.

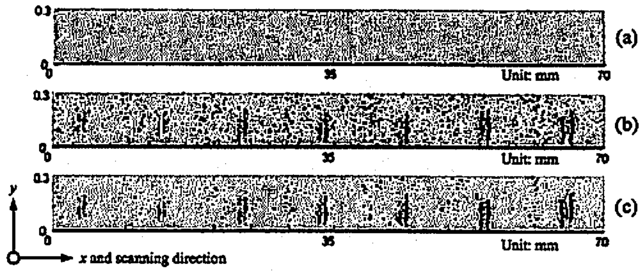

Fig. 8. Two-dimension gradient image obtained from scanning the PCB model in Fig. 6 (a) with scanning speed of 0.05 m/s and 200-cycle capturing signal, *m*. (a) the result without applied averaging technique, (b) 5-averaging signal result, and (c) 9-averaging signal results

5. Conclusion

The ECT probe with multi SV-GMR sensor is successfully applied to inspect a high-density bare PCB. Applied harmonic analysis based on Fourier transform was able to increase the scanning speed and spatial sample frequency, but the inspection performance was decreased. However, the use of multisignal averaging technique based on multi SV-GMR sensor could improve the inspection performance and increase spatial sample frequency.

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