Conductive Microbead Array Detection Based on Eddy-Current Testing Using SV-GMR Sensor and Helmholtz Coil Exciter

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journal or publication title	IEEE Transactions on Maggetics
volume	42
number	10
page range	3572-3574
year	2006-10-01
URL	http://hdl.handle.net/2297/48327

doi: 10.1109/TMAG.2006.879966

Conductive Microbead Array Detection Based on Eddy-Current Testing Using SV-GMR Sensor and Helmholtz Coil Exciter

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This paper describes the detection of both single and array conductive microbead (PbSn) by using a spin-valve giant magnetoresistance (SV-GMR) as a sensor and the Helmholtz coil as an exciter based on eddy-current testing (ECT). Experiments were performed to detect a single and array conductive microbead, with three models. Each model consists of 4 × 4 microbeads but the microbead diameter and pitch were slightly different for each array. The microbead radius was 125 μm and the pitch was 500 μm. The ECT method was used to estimate the position of the centers of the microbeads and the error in the measurement was plotted on a plane. A good level of position resolution has been achieved and the signals were quite clear.

***Index Terms*—Conductive microbead, eddy-current testing, Helmholtz coil, spin-value giant magnetoresistance.**

I. INTRODUCTION

EDDY-CURRENT TESTING (ECT) is a well-known method of nondestructive evaluation technique that is usually applied to evaluate the material flaw without changing or altering the tested material. In addition, ECT technique is sensitive to material conductivity which depends on many variables such as material thickness, crack, etc. It is widely used in the aviation, nuclear power plant, and automotive industries, and in electronic assembly [1], [2].

In recent years, a new application of ECT with spin-valve giant magnetoresistance (SV-GMR) have been applied to detect conductive microbead and flaws on printed circuit board [3], [4].

This paper presents the Helmholtz coil as an exciter and SV-GMR as a sensor for detection of both single and array conductive microbead (PbSn). This technique was used for detecting the position of single and array conductive microbead and expressing the error of array position.

II. CONDUCTIVE MICROBEAD DETECTING BY ECT TECHNIQUE

A. ECT Probe Configuration

The ECT probe configuration is shown in Fig. 1. The probe consists of a pair of Helmholtz coil and a SV-GMR sensor. A copper wire of 0.2 mm diameter was used for making the coils where the coil diameter was 8 mm and the number of turns was four turns. The upper coil and lower coil were connected in series. An AC exciting current of 200 mA was fed to generate the magnetic field. In this work, two exciting frequencies were used; 5 MHz and 10 MHz.

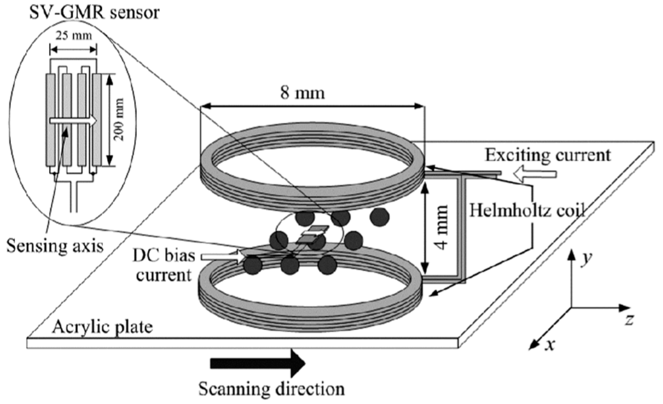

Fig. 1. ECT probe structure.

The SV-GMR sensor thickness was 50 nm and the effective area was 25 μm × 200 μm that consist of four strips, divided into two groups. Each group had two strips connected in series and the two groups were connected in parallel. The sensor had a protective polymer cover of 3 μm thickness.

B. SV-GMR Characteristic

The SV-GMR sensor was designed to have the most sensitive direction. However, some response was also expected for magnetic fields at the right angles to this direction. To determine the sensitive direction, the sensor was placed between the Helmholtz coils, but in three different orientations: with the sensitive direction aligned with the global x, y, and z directions. The magnetic field for these tests was driven at 10 kHz and with strength of 200 $\mu\mathrm{T}_{\mathrm{p-p}}$.

The SV-GMR sensor was biased with a constant current of 2.5 mA. A lock-in amplifier was used to measure the voltage difference across the terminals of the SV-GMR sensor. Fig. 2 shows the response of the sensor. It is confirmed that the sensitive direction responded at 72 μV/μT and this response was greater than the response of the other two directions (15 μV/μT).

Digital Object Identifier 10.1109/TMAG.2006.879966

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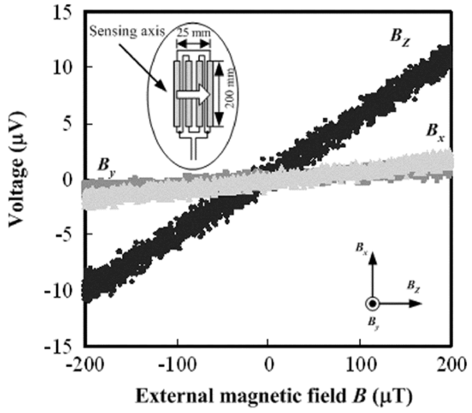


Fig. 2. SV-GMR characteristic.

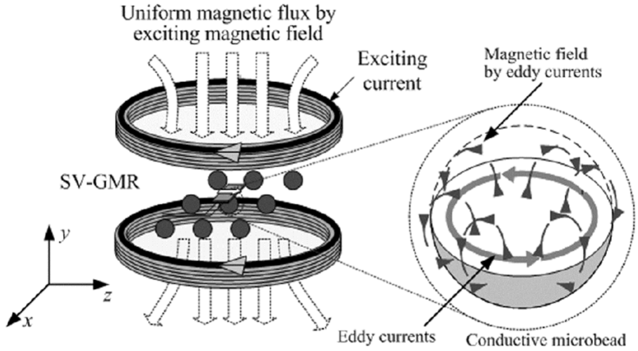


Fig. 3. Magnetic field distribution on ECT probe and conductive microbead.

TABLE I
PbSn ARRAY MODEL

Model (4x4)	I	II	III
PbSn radius (μm)	150	125	125
Pitch (μm)	500	500	450

C. Detecting Principle

Fig. 3 shows the principle of conductive microbead detection. An AC current was applied to the Helmholtz coil. The Helmholtz coil was chosen because it produces a reasonable homogenous and straight magnetic field which is normal to the planes of the coil. Fig. 3 shows the magnetic field generated by Helmholtz coil. This magnetic field induces eddy currents in the conductive microbead. It is observed that the direction of eddy currents in the conductive microbead opposes the current flow in the exciting coil. The eddy currents in the conductive microbead generated a magnetic field. SV-GMR sensor detected the signal that was generated by eddy currents inside the conductive microbead.

Several specimen arrangements were studied. In all experiments, the microbead material was PbSn. For the first experiments, a single microbead was used. In the single-microbead experiment, six beads were tested in the range from 125 to 380 μm (125, 150, 200, 250, 300, and 380 μm). The model information in the other test is listed in Table I.

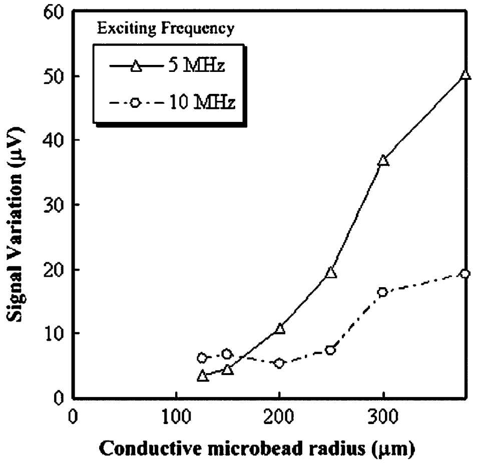


Fig. 4. Signal variation as a function of conductive microbead.

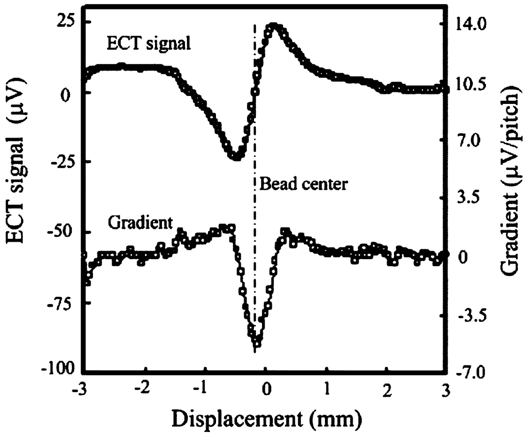


Fig. 5. ECT signal and gradient obtained from the detection of a PbSn with 250 μm radius at the exciting frequency 5 MHz.

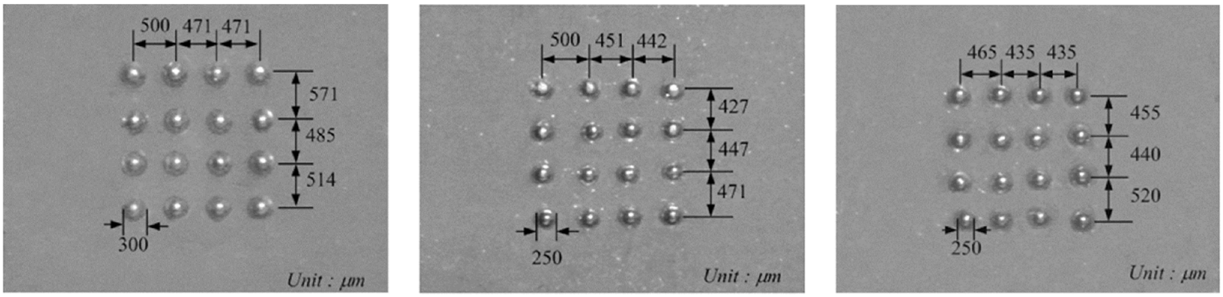
III. RESULTS

A. Investigation of the Single Conductive Microbead

Fig. 4 shows the effect of the microbead diameter on the strength of the measured signal. It is clear that the signal changes rapidly to a low level as the microbead diameter decreases. In case of the conductive microbeads of radius greater than 150 μm, the lower frequency (5 MHz) excitation caught a higher measured signal because these differences may be attributed to nonideal behavior of various parts of the experiment apparatus, which included the power amplifier, coils, mounting frame, and the SV-GMR sensor. Stray capacitance and other parameters that increase with frequency are likely to be significant. Fig. 5 shows the ECT signal and its gradient without offset that was obtained from the detection of conductive microbead with 250 μm radius at exciting frequency of 5 MHz. We can define the position by considering the peak to peak of ECT signal and its gradient.

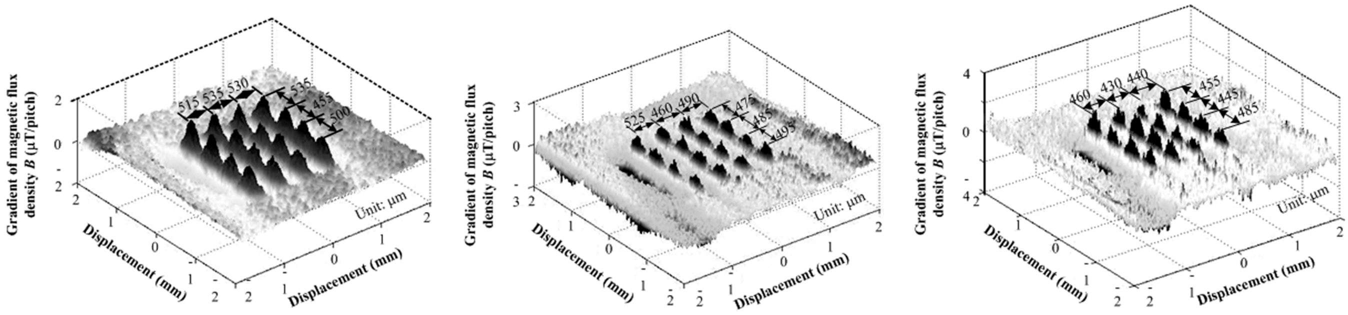
B. Detection of Conductive Microbead Array

Fig. 6 shows the three array models, which are detected by Helmholtz coil excitation and SV-GMR sensor. Fig. 7 shows the 3-D plot of measurement; we find that the positions of the



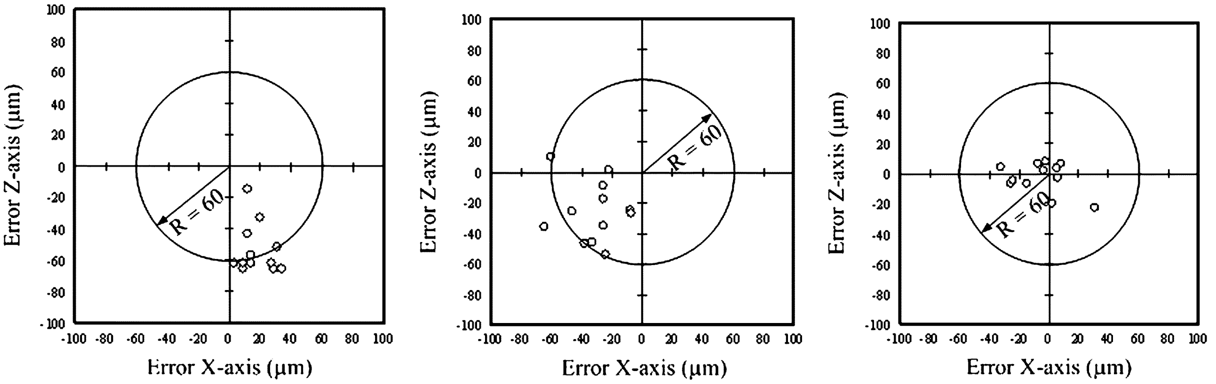
(a) Model I (b) Model II (c) Model III

Fig. 6. Array models of PbSn. (a) Model I, (b) Model II, (c) Model III.



(a) (b) (c)

Fig. 7. 3-D plot of measure signals. (a) Model I, (b) Model II, (c) Model III.



(a) Model I (b) Model II (c) Model III

Fig. 8. Error plots of position estimation. (a) Model I, (b) Model II, (c) Model III.

microbeads in each array within the gradient magnetic flux density maps is distinct and could be used to estimate the microbead positions. Fig. 8 shows the error of plot position estimation; the typical positional error of three arrays in the measurement was approximately 60 μm.

IV. CONCLUSION

An experimental method can be applied to detect single and array conductive microbead. The signal variation of conductive microbead has the information of the bead size. The positions of 150 and 125 μm radius conductive microbeads in an array arrangement of pitch 450 or 500 μm could be detected using the method described. The typical positional error in the measurement was approximately 60 μm. This technique enables us to detect smaller conductive bead when the GMR sensor was kept as close as possible to specimen. Moreover, it is possible to use this technique in physical measurement and biosensor application.

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Manuscript received March 13, 2006 (e-mail: teerasak@magstar.ec.t.kanazawa-u.ac.jp).