Application of Giant Magnetoresistance Sensor for Micro Material Detection

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This paper presents the application of giant magnetoresistance (GMR) sensor for micro material detection. The proposed ECT probe was fabricated for detection of conductive microbead by spin-valve type magnetoresistance (SV-GMR). The four exciter coils (Helmholtz, ferrite core, flux concentrator and double spiral) were used to compare the conductive microbead detection of signals that were obtained from GMR sensor. Both of eddy-current testing (ECT) technique and static magnetic methods were applied to detect the ferromagnetic material. In addition, the two GMRs were used to detect the underground water velocity. The results enabled us to determine the position and achieve a good level of signals.

Key Words: giant magnetoresistance, eddy-current testing, ferromagnetic, underground water velocity

1. Introduction

Since being discovered giant magnetoresistance (GMR) effect, has influenced the data storage technology [1]. In the recent years, GMR has been successful for the detection of flaw and crack on printed circuit board [2]. In this paper we present the application of giant magnetoresistance for detection micro material. The four exciter coils were used to compare the conductive microbead detection of signals that were obtained from GMR sensor. Both of eddy-current testing (ECT) technique and static magnetic methods were applied to detect the ferromagnetic material. In addition, the two GMRs were used to detect the underground water velocity.

2. SV-GMR Characteristic

The SV-GMR configuration that had a thickness of 50 μm and an effective area of 25 μm x 200 μm. It consists of 4 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 100 μm thickness. The normal resistance is 1900 Ω

The SV-GMR characteristics were verified for capability of detecting magnetic field of the specimen. The direct current (DC) and small signal of SV-GMR characteristics are discussed as follows.

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2.1 DC Characteristic

DC exciting current was fed to the Helmholtz coil within a range of -4 to 4 mT. The DC characteristics of the SV-GMR has maximum magnetic ratio approximately of 6 % of normal resistance or it has resistance variation between 1890 to 2010 Ω. The linear region sensitivity of the proposed SV-GMR is around 1.5 % / mT or 120 Ω / mT. There is also a low hysteretic loop. Moreover, the proposed SV-GMR sensor has high sensitivity with the applied magnetic fields ranging from -1 to 1 mT.

2.2 Small signal 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 100 kHz and with strength of ± 200 μT.

3. Conductive Microbead Detection

The probe consists of SV-GMR and an exciter. Each of the ECT probe was used with the similar SV-GMR but the exciter was changed to improve the magnetic flux distribution on conductive microbead. Four exciter coils were designed and developed for generating the magnetic field inside the conductive microbead; Helmholtz, ferrite core, flux concentrator and double spiral.

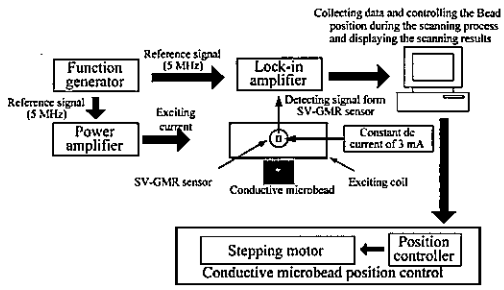


Fig. 1 System control and data acquisition

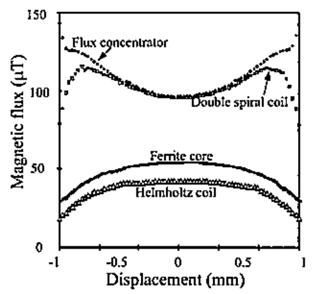


Fig. 2 Magnetic flux distribution by FEM

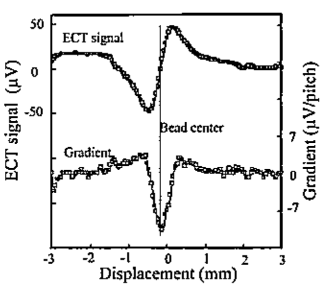


Fig. 3 Recognition of bead position

3.1 System control and data acquisition based on ECT technique

Figure 1 shows the system control and data acquisition diagram. The guide user interface base on MatLab programe was applied to collect data and control the bead position during the scanning process. The position control is controlled by the computer for scanning inspecting the conductive microbead. High-frequency excitation at 5 MHz is generated by function generator and is fed to the power amplifier before feeding to the exciting coil. High-frequency measurement and data acquisition system is applied to measure ECT signal achieved from the SV-GMR sensor. However, the signal is very weak and composes of many unwanted signals, the harmonics and high frequency noise. Therefore, the measurement system must have ability of improving the signal-to-noise ratio. The phase sensitive detector or Lock-in amplifier was used to measure very small signals although the signal contains a lot of noise. This is because phase-sensitive detection can improve the signal-to-noise ratio of noise signal.

3.2 Investigation of the magnetic field distribution by using FEM

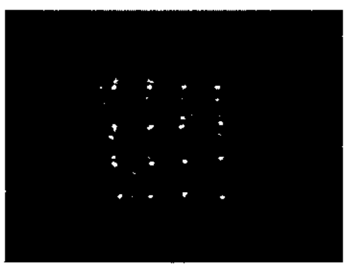
Finite element method, FEM, model was used to check that this was achieved. The model parameters included exciting current 200 mA at 5 MHz. Maxwell 3D software version 10 from Ansoft Corporation, was used.

The FEM calculated the magnetic flux at the center in the middle of exciter coil. The four models (Helmholtz, ferrite core, flux concentrator and double spiral) were calculated to express the magnetic flux. Fig. 2 shows the result of magnetic flux at the middle of the four exciter coil models. The calculation shows the flux concentrator generated magnetic flux higher than double spiral and Helmholtz coil, around 1.22 % and 130 % respectively.

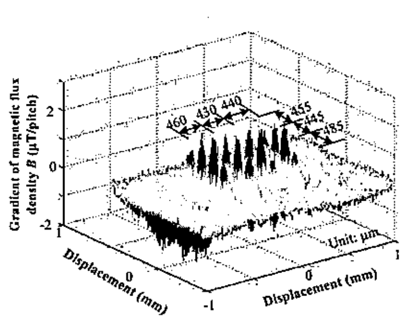
3.3 Recognition of conductive microbead and Comparison of signal result of proposed ECT probes

The identifications of the microbead are performed by considering the peak of ECT signal gradient. Fig.3 shows the maximum variation of the ECT signal versus the radius of the microbead.

The microbead array model with 125 μm radius and 410 to 460 μm microbead pitches as shown in Fig. 4 (a) and its detection results are shown in Fig. 4 (b). The microbeads are clearly recognized and the pitches of the microbead are also accurately



(a) Ball grid array model



(b) 3D plot of gradient of magnetic flux.

Fig. 4 Ball grid array detection

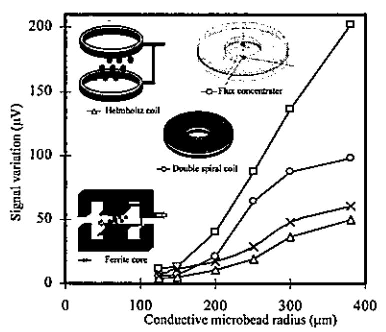


Fig. 5 Signal variation of detection microbead signal with various exciter coil

specified with error less than 70 μm.

The ECT probe scanned over the model with 20 μm scanning pitch and lock-in amplifier was used to measure the ECT signal obtained from SV-GMR sensor. The signal variation of ECT signal in Fig.5 is obtained from the detection of a microbead with range 125 to 380 μm radius at the frequency of 5 MHz. The Helmholtz, ferrite core, flux concentrator and double spiral were used as an exciter. The signal obtained from SV-GMR sensor with flux concentrator is higher than signal obtained form double spiral, Helmholtz coil and ferrite core. This agrees with the calculated results obtained from FEM calculation. The experimental results also show that signal variations at the microbead depend on the frequency of the exciting magnetic fields and the microbead radius.

4. Ferromagnetic Detection

Detection of ferromagnetic material, the high frequency method and static magnetic field were applied to recognize the magnetic particle.

The ECT probe for detecting the non-magnetic material was used for detection of the ferromagnetic material as shown in Fig. 6. The exciting frequency with 5 MHz was fed to the planar meander coil as an exciter for generating magnetic field. The ferromagnetic material was laid under the planar meander coil and SV-GMR sensor. We use the speed of ECT probe over the magnetic particle scanning with 0.5 mm/min.

Figure 8 shows the probe construction of static magnetic method. The static magnetic fields around 100 mT were applied to magnetic material to magnetize the magnetic material. The SV-GMR sensor is also set so the sensing axis will detect only the *z*-axis component of magnetic fields. The distance between the SV-GMR sensor and magnetic material was at least 50 μm. The SV-GMR sensor is scanned over the magnetic material with speed of 1 mm/min.

The magnetic particle model is made from Fe. The Fe is laid on an acrylic substrate and fixed with liquid glue. The magnetic particle sizes are 20, 40 and 60 μm.

Figure 7 shows the magnetic particle model and its results by using the ECT method. We found that the signal over the reference line can recognize the magnetic particle of only 40 and 60 μm size, because of the high lift-off height between SV-GMR to magnetic particle. The 2-D image plot shows the

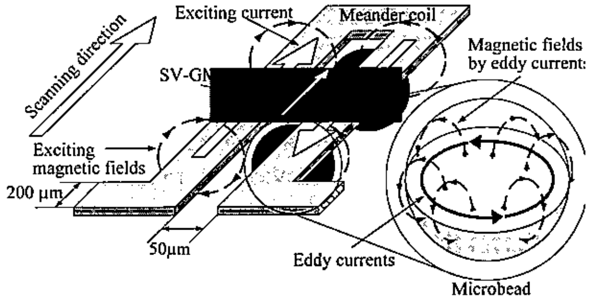


Fig. 6 ECT probe structure

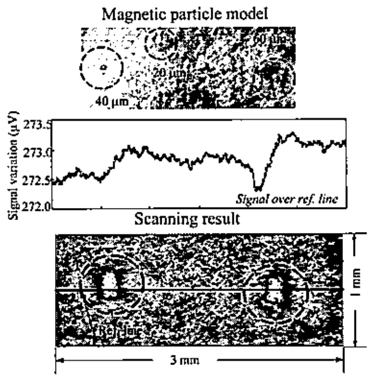


Fig. 7 Result of ECT method detection

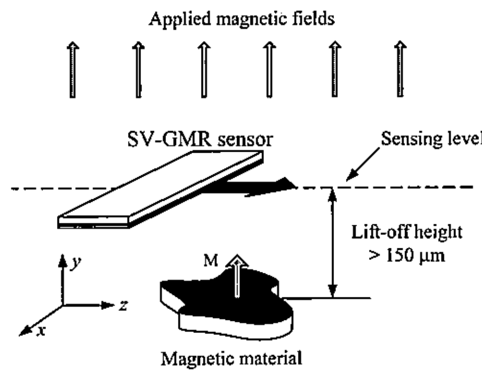


Fig. 8 Static magnetic method

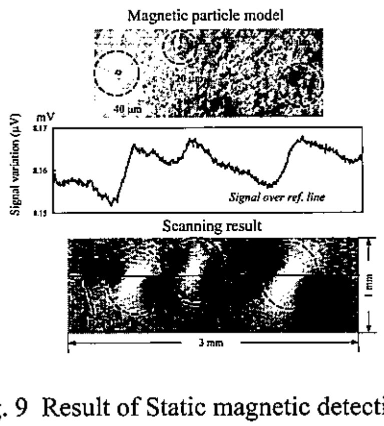


Fig. 9 Result of Static magnetic detection

signal of the SV-GMR sensor where is possible to detect the magnetic particles.

Figure 9 shows the magnetic particles model and its recognition results by using static magnetic method. The signal over the reference line shows the variation of signal wherever the magnetic particle exists. The 2-D image obtained from scanning result also shows the utilization of the SV-GMR sensor to detect the magnetic particle clearly.

According to the results of ferromagnetic material detection, we found that both of the high frequency method and static magnetic field method can recognize the specimen. In the case of high frequency method, this technique enables us to detect smaller ferromagnetic material if the GMR sensor is kept more close to specimen.

5. Underground Water Velocity Detection

The effect of underground water contaminated from the industrial area and nuclear power plant waste is considered as an environmental issue. The behavior of underground water is essential to monitor the potential of qualitative and quality. In the general, the velocity of underground water is very low around 10^{-6}–10^{-8} m/s.

The proposed model of underground water measurement consists of the two GMRs as a sensor and a magnetic particle reservoir as shown in Fig. 10. The fixed distance between GMR is 400 μm. The magnetic particle has a size of range 1-100 μm and has difference dipole moment direction. The concept is determining the one-dimension velocity by using the detect GMR signal from the magnetic particle over the GMR-I and II.

In fact the magnetic particles have a lot of environmental effect such as the pattern flow of underground water, conductivity of water, contamination, specific gravity of water and etc..

In this study only one-dimension is considered. We assume the density of magnetic particle as close as to the water source. In fact of particles sink effect, it is possible to find out the high range of weight distribution and particle density value close to water source.

5.1 Determination of underground water velocity

The one-dimension of velocity was calculated by using GMR signal. Because, the two GMRs have a fixed distance between them as described above, we can determine the one dimension of velocity. The one dimension velocity (m/s) equal distance difference (m) divided by time difference (s). Fig. 11(a) shows determination of underground water velocity by GMR.

5.2 GMR signal matching

The signal of GMR II range was selected to compute the correlation along GMR I signal to find out the matching position that make correlation equal I. Fig. 11(b) shows the position of start point of signal II that make the correlation coefficient equal to 1

6. Conclusion

The giant magnetoresistance (GMR) sensor with various exciter coils has clearly detected the micro material such as conductive microbead and ferromagnetic particle. The underground water velocity detection by GMR has been performed. It is possible to detect the physical position by this technique

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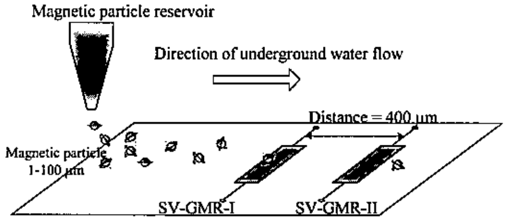
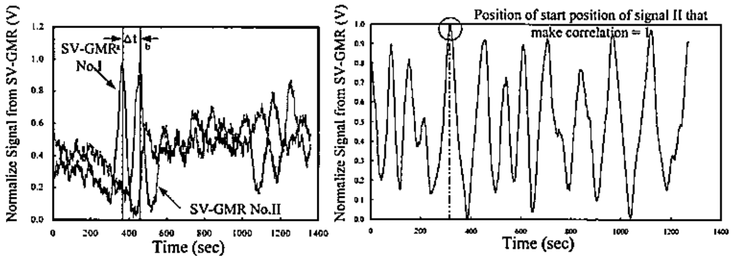


Fig. 10 Model of underground water velocity measurement by GMR sensor



(a) Signal of GMR I&II. (b) Correlation signal I&II

Fig. 11 Underground water velocity detection by GMR