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Development of Micro-size Search Coil Magnetometer for Magnetic Field Distribution Measurement

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For the measurement of the magnetic field distribution with high spatial resolution and high accuracy, the magnetic field sensing probe must be non-magnetic, but the MFM probe and sub-millimeter-meter size Hall probe use a ferromagnetic tip and block, respectively, to increase the sensitivity. To overcome this drawback, we developed a micro-size search coil magnetometer which consists of a single turn search coil, Terfenol-D actuator, scanning system, and control software. To reduce the noise generated by the stray ac magnetic field of the actuator driving coil, we employed an even function λ-H magnetostriction curve and lock-in technique. Using the developed magnetometer, we were able to measure the magnetic field distribution with a magnetic field resolution of 1 mT and spatial resolution of 0.1 mm × 0.2 mm at a coil vibration frequency of 1.8 kHz.

Keywords : search coil magnetometer, magnetic field measurement, magnetic field distribution, Terfenol-D actuator

1. Introduction

For the measurement of the magnetic field distribution, a Hall probe and MFM probe have generally been used. In the case of an MFM probe, its size is very small but the probe material is ferromagnetic. Using an MFM probe, it is possible to measure the magnetic field distribution with high spatial resolution, but not accurately, due the non-linear and hysteresis properties of the ferromagnetic tip. In the case of a Hall probe, the area of the sensing element is normally in the range of a few mm×mm. To reduce the area of the sensing element and to increase the sensitivity, a ferrite block was employed. In this case, the magnetic field still cannot be measured accurately, due the non-linear and hysteresis properties of the ferrite material [1].

In this work, we studied a search coil type magnetometer whose sensing area is in the range from 0.1 mm× 0.2 mm and which allowed us to measure the magnetic field accurately. The vibration frequency of the search coil was increased using a Terfenol-D actuator to increase its sensitivity.

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2. Construction of Search Coil Magnetometer

A search coil magnetometer makes use of Faraday's induction law. If we construct a single turn search coil, as shown in Fig. 1, and the coil vibrates in the longitudinal direction with an amplitude Δl_o, the induced voltage from the coil is as follows:

$$V(t) = BL\Delta l_o \omega \cos \omega t \tag{1}$$

where L is the width of the search coil, ω is the angular frequency of the search coil's vibration, and B is the magnetic flux density to be measured.

For the measurement of the magnetic field with a spatial resolution in the micro-meter range, Δl and L must be in the sub-mm range. For example, if we let Δl and L both be 0.1 mm, and B=10^{-2} T, we need $\omega \approx 10^4$ rad/s to obtain an induced voltage of 1 μV.

The search coil was constructed by means of a PCB pattern, which was 100 mm long, 0.2 mm wide and had a

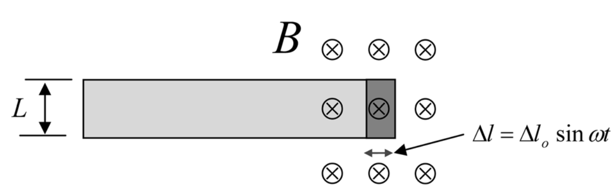

Fig. 1. Principle of the single turn search coil magnetometer.

copper line width of 0.1 mm. For the vibrator with an angular frequency of $\omega \approx 10^4$ rad/s, we constructed a Terfenol-D actuator without a bias magnetic field. When we apply a magnetizing frequency of f_o, the vibration frequency of the search coil becomes $2f_o$ due to the even function of the λ–H magnetostriction curve. In this case, we can eliminate the noise induced by the stray ac magnetic field of the actuator coil using the lock-in amplifier technique.

Fig. 2 shows the search coil constructed using the PCB pattern with a width of 0.2 mm and length of 100 mm. Fig. 3 shows a photograph of the Terfenol-D actuator and assembled search coil. The actuator employed a Terfenol-D rod 6 mm in diameter and 50 mm long produced by ETREMA Co. [2]. The actuator driving frequency was set to the resonance frequency of 1.8 kHz.

A schematic diagram of the magnetometer is shown in Fig. 4. The f_o output of a wave-form generator was connected to the power amplifier for the purpose of driving the Terfenol-D actuator and the $2f_o$ output of the wave-form generator was connected to the reference input of the lock-in amplifier.

For the measurement of the magnetic field distribution, we constructed a scanning system which is controlled by a computer and the output voltage of the lock-in amplifier was input to the computer via a DVM (Digital Volt Meter). A LabView based software program was used for the control of the scanner and for the data acquisition.

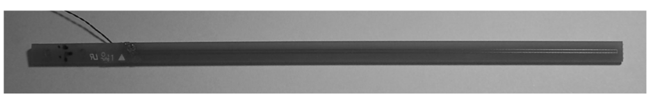

Fig. 2. Photograph of constructed micro-size search coil 0.2 mm in width and 100 mm long.

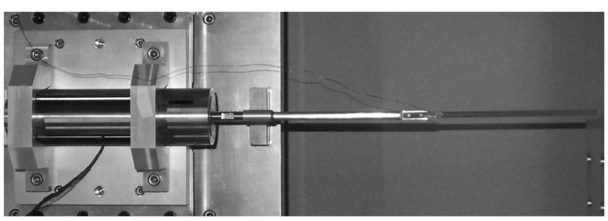

Fig. 3. Photograph of the assembled Terfenol-D actuator and micro-size search coil.

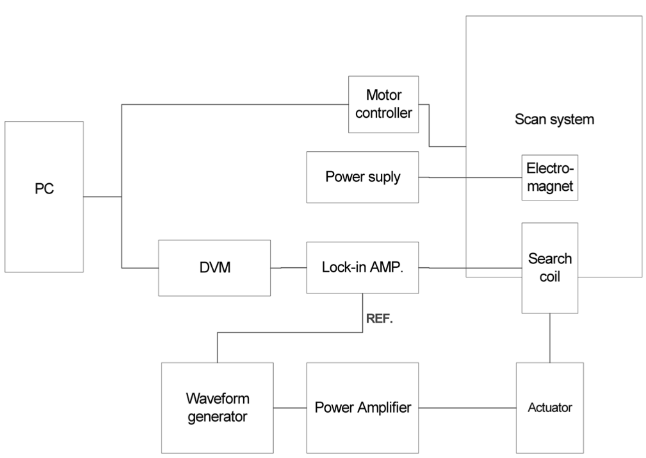

Fig. 4. Schematic diagram of the micro-size search coil magnetometer and scanning system.

3. Experimental Results and Discussion

To calibrate the developed micro-size search coil magnetometer, a reference magnet of 0.1 T was used. The output voltage of the search coil was about 50 μV for a magnetic field of 0.1 T and the noise level of the lock-in amplifier including the pre-amplifier was about 0.5 μV, which corresponds to about 1 mT. To demonstrate the constructed magnetometer, we designed two small magnets for the measurement of the magnetic field distribution; one is an electromagnet with an air gap of 2 mm and the other is a permanent magnet type with an air gap of 5 mm, as shown in Fig. 5. The magnetic field distribution of the two magnets was calculated numerically using Magnet 6.2 FEM software. Fig. 6 shows the measurement results of the magnetic field distribution at 1 mm above the surface of the magnet and the magnetic field component perpendicular to the magnet surface. The computer simulation results are shown in Fig. 6-(a) and the experimental results in Fig. 6-(b). Based on these results, the developed micro-size search coil magnetometer should allow the measurement of the magnetic field distribution with a spatial resolution in the range of 0.1 mm×0.2 mm and magnetic field resolution of 1 mT.

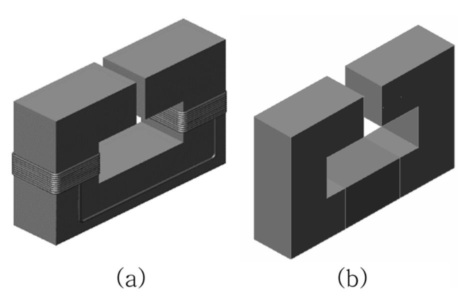

Fig. 5. Schematic diagram of two small magnets used for the measurement of the magnetic field distribution; (a) electromagnet with air gap of 2 mm, (b) permanent magnet with air gap of 5 mm.

4. Conclusions

In this work, we developed a micro-size search coil

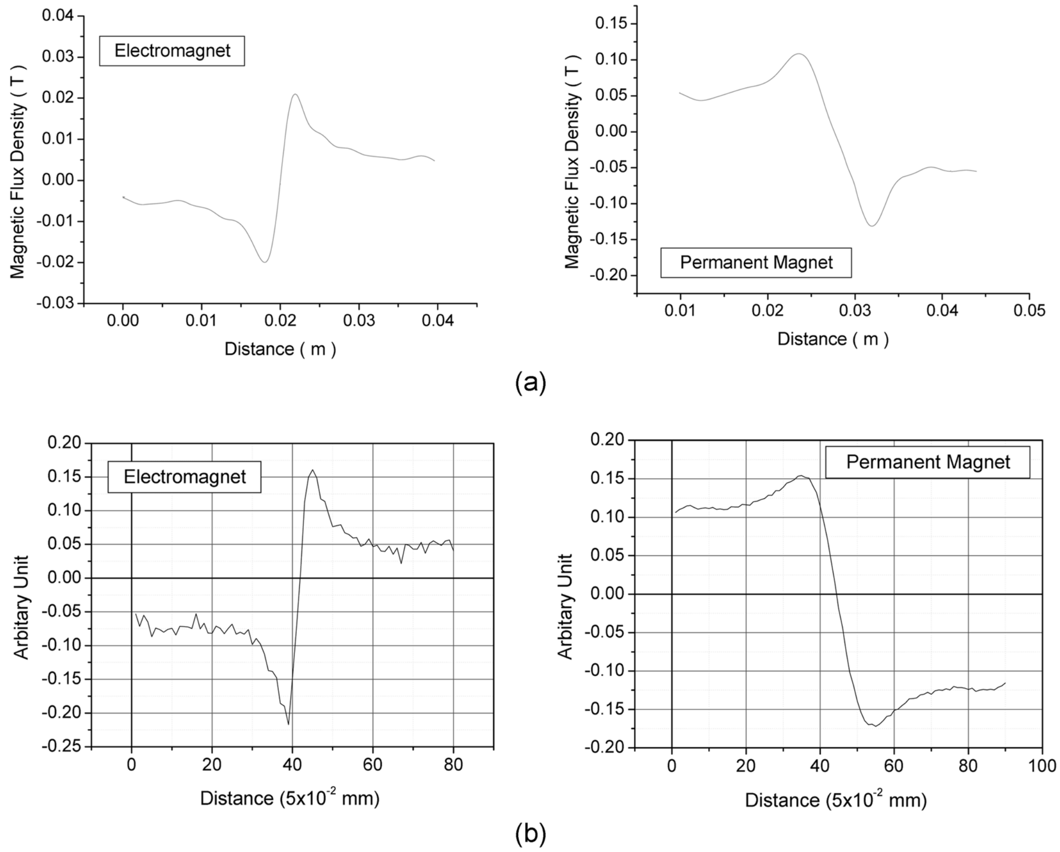

Fig. 6. The magnetic field distribution at 1 mm above the magnet surface and the magnetic field component perpendicular to the magnet surface were (a) computer simulation results, (b) measured using magnetometer.

magnetometer which consists of a search coil with a single turn, a Terfenol-D actuator, a scanning system, and control software. To reduce the noise generated by the stray ac magnetic field of the actuator driving coil, we employed a magnetostriction curve which is an even function of λ–H and a lock-in technique. Using the developed magnetometer, we were able to measure the magnetic field with a resolution of 1 mT and spatial resolution of 0.1 mm×0.2 mm.

References

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