Development of Low Noise MI Sensor and Its Applications

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Abstract— The MI sensor is a magnetic sensor based on the MI (Magneto Impedance) effect discovered by K. Mohri et al. in 1993. A specialized low noise analog output magnetic sensor (nT sensor: MI-CB-1DK) has also been commercialized by AICHI MICRO INTELLIGENT for use in detecting AC magnetic fields. According to theoretical analysis, although the MI sensor is foreseen to show the $\mathrm{fT}/\sqrt{\mathrm{Hz}}$ level of noise density, MI-CB-1DK shows 20–30 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ at 10 Hz. In this paper, in order to develop an MI element showing lower noise, the effect of the aspect ratio of the amorphous magnetic wire, the number of wires and the effect of electric contact on multiple wires on noise density were investigated. Then an MI element which shows 1/10 the noise density of MI-CB-1DK was developed.

1. INTRODUCTION

The MI sensor is a magnetic sensor based on the MI (Magneto Impedance) effect discovered by K. Mohri et al. in 1993 [1]. A small and highly sensitive magnetic sensor (AMI 306) based on the MI effect and used as an electromagnetic compass mainly in mobile phones and smart phones has been developed and commercialized by AICHI MICRO INTELLIGENT [2]. On the other hand, a specialized low noise analog output magnetic sensor (current nT sensor: MI-CB-1DK) has also been commercialized for use in detecting AC magnetic fields [2]. And also a research of biomagnetic measurement using MI element has been reported [3]. According to the theoretical analysis, the MI sensor is foreseen to show the $\mathrm{fT}/\sqrt{\mathrm{Hz}}$ level of noise density [4]. However, AMI306 shows around 7 $\mathrm{nT}/\sqrt{\mathrm{Hz}}$ level of noise density at 10 Hz and the current nT sensor (MI-CB-1DK) shows 20–30 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ at 10 Hz.

In this paper, in order to develop an MI element showing higher sensitivity and lower noise as compared to MI-CB-1DK, the effect of the aspect ratio of the amorphous magnetic wire, the number of wires and the effect of electric contact on multiple wires on noise density was investigated.

2. EXPERIMENT

A nearly non-magnetostrictive amorphous magnetic wire (hereafter called wire) with a diameter of 30 µm and composition Co-Fe-Si-B system produced by in-water-rotating quenching process was purchased from UNITIKA LTD. The hysteresis loop of the wire with a length of 5 mm was measured by Vibrating Sample Magnetometer (Toei Scientific Industrial Co., Ltd, type: PV-M10-5) and is shown in Fig. 1. The vertical axis shows the normalized magnetization by saturated magnetization.

The MI element using above wire was produced with photolithography and a pickup coil made of 30 µm copper wire was wound, and then the sensor characteristics were evaluated with an electric circuit which excites the wire by 80 mA as used in MI-CB-1DK [5]. The noise density of the MI element was measured by FFT analyzer (ONOSOKKI, type: CF-5220Z) at zero magnetic fields in the threefold magnetic shield box.

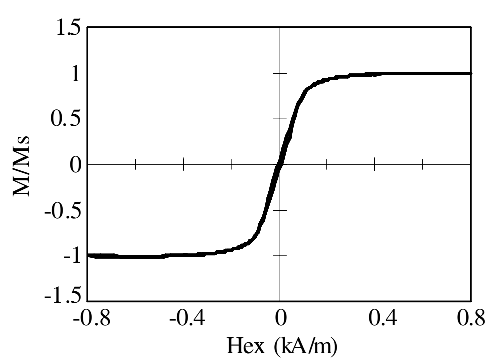

Figure 1: The hysteresis loop of wire.

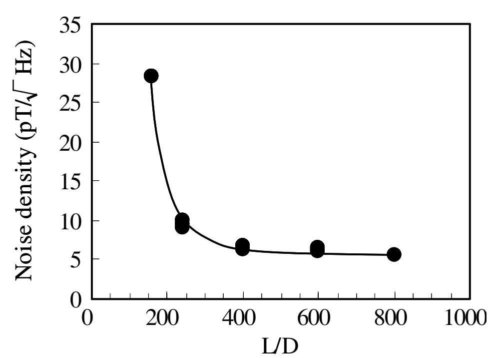

Figure 2: The effect of L/D on noise density at 10 Hz.

3. DEVELOPMENT OF LOW NOISE MI SENSOR

3.1. The Effect of Aspect Ratio, Number of Wires and Electric Contacts on Sensor Characteristics

In order to determine wire length, the effect of aspect ratio (L/D) on noise density was investigated and a sample at 10 Hz is shown in Fig. 2. Here L is defined as wire length and D is defined as diameter of wire. As shown in Fig. 2, noise density decreases as L/D increases and is saturated when L/D exceeds 400. This is because the sensitivity increases with the decrease in demagnetizing fields.

Next, in order to further reduce noise density, the effect of the number of wires on noise density was investigated. The MI element was produced with a number of wires connected in parallel and a pickup coil was wound around it. The noise density at 10 Hz is shown in Fig. 3. As shown in Fig. 3, noise density decreases as the number of wires increases. Although it was expected that the noise density decreased in inverse proportion to the square root of the number of wires, the noise density decreased almost linearly as the number of wires increased.

Thirdly, in order to further reduce noise density, the effect of electric contact with 4 wires (type A and B, shown in Fig. 4) on noise density was investigated and is shown in Fig. 5. As shown, the MI element of type B shows lower noise density compared to type A.

3.2. Development of MI Element and Its Noise Density

Based on the above investigations, an MI element with 4 wires of 10 mm with type B connections and a wound coil of 300 turns was designed. Its appearance and output property are shown in Fig. 6 and Fig. 7, respectively. The noise density of the developed MI element is shown in Fig. 8, as compared to commercialized MI-CB-1DK and AMI306. As shown in Fig. 8, the noise density of the developed MI element is about 1/10 of MI-CB-1DK. Next, with practical use in mind, sensor output of the developed MI element with ± 1 nT at 1 Hz is shown in Fig. 9, as compared to FG sensor [6] of the almost same size and MI-CB-1DK. As shown in Fig. 9, the developed MI element

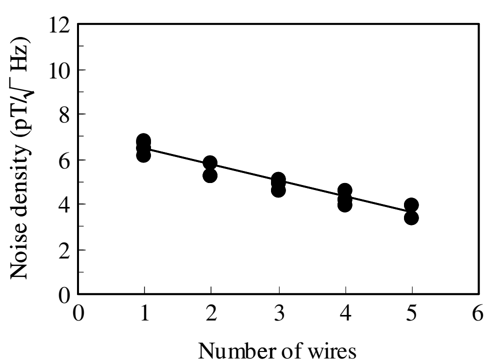

Figure 3: The effect of number of wires on noise density at 10 Hz.

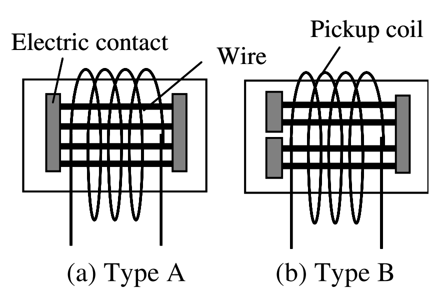

Figure 4: Electric contact type with 4 wires.

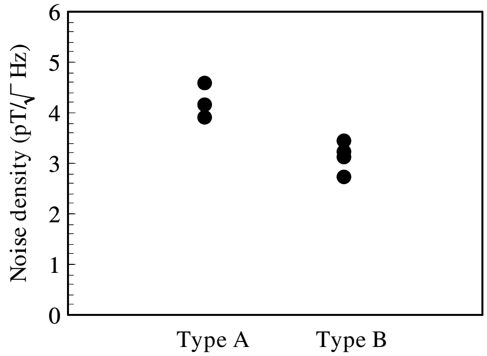

Figure 5: Comparison of the noise density at 10 Hz between type A and type B.

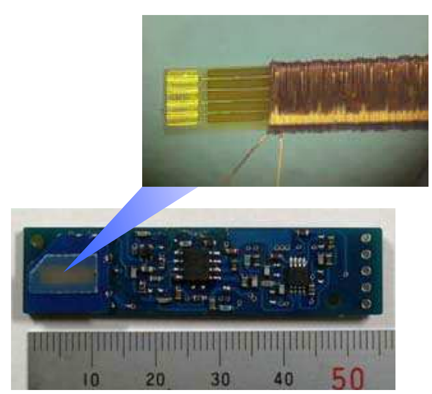

Figure 6: The appearance of developed MI sensor.

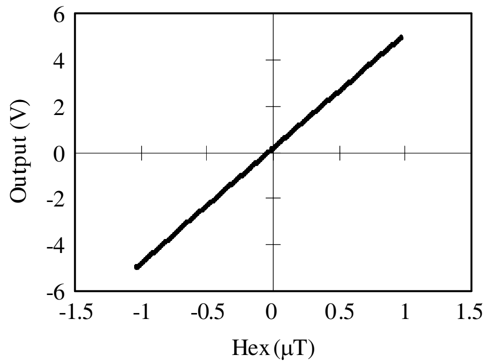

Figure 7: Output property of developed MI element.

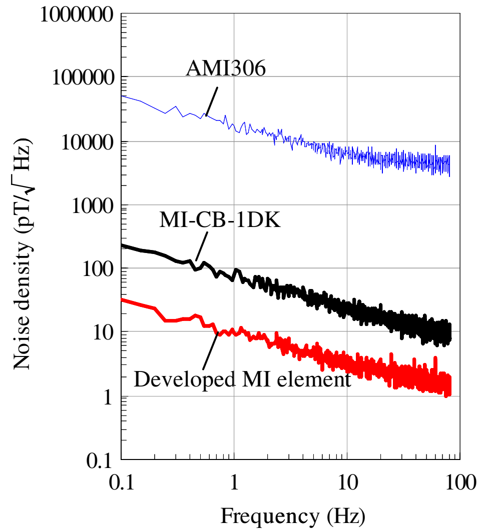

Figure 8: Noise density of developed MI sensor.

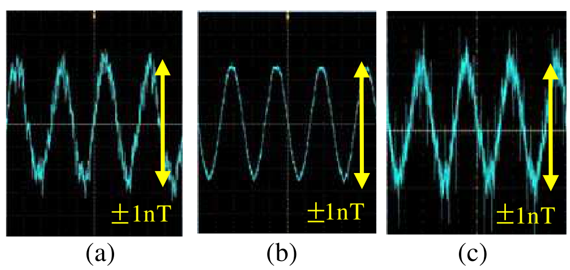

Figure 9: Sensor outputs of developed MI element. (a) MI-CB-1DK. (b) Developed MI element. (c) FG sensor.

shows sufficient magnetic resolution for detecting week magnetic fields of 1 nT order.

4. SUMMARY

In this paper, in order to develop an MI element showing lower noise density, the effect of aspect ratio of amorphous wire, number of wires and electric contact on multiple wires on noise density was investigated. Then, an MI element showing 1/10 of the noise density of MI-CB-1DK was developed.

This developed MI element is expected to be used in various fields (foreign body detection and biomagnetic measurement etc.), due to its sub-nano-T level of noise.

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