Development of Wide Range MI Element

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MI sensors are magnetic sensor based on the Magneto Impedance (MI) effect discovered by Mori et al. in 1993. Magnetic sensors with a measurement range of 3 ~ 12 G are mainly used as electromagnetic compasses. The demand for magnetic sensors with wider measurement ranges has increased recently due to the rapid popularization of smart phones and tablets. We investigated the effect of the length of wires on the sensor characteristics to expand the measurement range more than that of the AMI306 electronic compass (measurement range: 12 G). We developed an MI element with a wire length of 0.35 mm that had a 1.5 times wider measurement range than that of the AMI306, while retaining almost the same sensitivity by narrowing the coil pitch and using a demagnetizing field. In addition we clarified the measurement range would be predicted from the anisotropy field of wire in the static magnetization.

Key words: magnetic sensor, magneto impedance element, demagnetizing field, wider measurement range

1. Introduction

The magnetic sensor is used in various fields such as industry, automobile, IT and biomagnetism. MI sensors are magnetic sensor based on the Magneto Impedance (MI) effect discovered by Mori et al. in 1993. After that, there were three remarkable progresses towards commercialization of the MI sensor. First was the increase of the sensitivity and lower power consumption by the change of the excitation system of amorphous magnetic wire from high frequency sine wave drive to the pulse drive. Second was the ability to identify the magnetic pole by transforming the impedance into voltage with a pick up coil or the off-diagonal method. Third was the miniaturization of the MI element by photolithography and plating processes. Through the above developments, the highly sensitive, low power consumption and small MI sensor was commercialized as an electromagnetic compass and entered the market. Since its small MI sensor shows high sensitivity and low power consumption, it is expected to be used for the wearable market which is expected to expand rapidly in the near future.

Magnetic sensors with a measurement range of 3 ~ 12 G are mainly used as electromagnetic compasses. Recently, due to the rapid popularization of smart phones and tablets, further advancement (for example, smaller size, lower power consumption, higher sensitivity, lower noise and wider measurement range) is required. Especially, from the viewpoint that the position where an electromagnetic compass is arranged within smart phone is limited, the expansion of measurement range is strongly required.

We previously reported the anisotropy field of the amorphous magnetic wire in the static magnetization is proportional to the measurement range of MI sensor. However, around 2.4 kA/m for AMI306 was the limit until now. Another way to expand the measurement range is the increase of the demagnetizing field and it theoretically increases inversely with the square of the length of the amorphous magnetic wire. Therefore, we investigated the effect of the length of wires on the sensor characteristics to expand the measurement range more than that of the AMI306. And also we clarified the relationship between the demagnetizing field and the measurement range caused by circumferential magnetization based on MI effect.

2. Experimental procedures

2.1 Amorphous magnetic wire

A nearly non-magnetostrictive amorphous magnetic wire (hereinafter referred to as wire) with a diameter of 15 μm and composition Co-Fe-Si-B system produced by an in-water-rotating quenching process was purchased from UNITIKA LTD. It is known that above wire has circumferential magnetic domain and the longitudinal direction of the wire is hard axis of magnetization. Therefore the hysteresis loop in the longitudinal direction 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. Here, in this paper, the 90 % saturation magnetic field in the hysteresis loop was defined as \( H_k \), where \( H_k \) corresponds to the anisotropy field.

2.2 Fabrication of MI element and evaluation method

The MI element using above wire was fabricated as follows. Under pattern of pick up coil by photolithography and plating processes was prepared preliminarily, then the wire was mechanically put on the pattern, and finally upper pattern of pickup coil was connected to the under pattern. The sensor characteristics of the MI element were evaluated with an electric circuit. Here, in this paper, the slope of sensor output between ± 0.8 kA/m was defined as the...
sensitivity, the external magnetic field at maximum sensor output voltage was defined as $H_p$, where approximately $H_p$ corresponds to the measurement range, and the difference of maximum and minimum sensor output voltage was defined as the peak to peak voltage.

2.3 Designs of fabricated MI element

The designs of fabricated MI element are shown in Table 1 and the appearances of the fabricated MI elements are shown in Fig.2. The lengths of wire were $0.22 - 0.52$ mm (0.52 mm at AMI306). The output voltage of MI element was predicted to decrease, due to the coil turns decrease owing to the wire length decrease. Therefore in order to compensate the output voltage loss, coil pitch was narrowed from 30 μm (for AMI306) to 17 μm. Using these MI elements, the effect of the wire length on sensor characteristics was investigated.

| Sample No. | a | b | c | d | AMI306 |
|------------|---|---|---|---|--------|
| Wire length (mm) | 0.22 | 0.32 | 0.42 | 0.52 | 0.52 |
| Element length (mm) | 0.3 | 0.4 | 0.5 | 0.6 | 0.6 |
| Coils pitch (μm) | | 17 | | | 30 |
| Coil turns (turn) | 7 | 13 | 19 | 25 | 15 |
| Wire R (Ω) | 2.6 | 3.6 | 4.8 | 5.7 | 6.4 |
| Coil R (Ω) | 0.7 | 1.1 | 1.4 | 1.8 | 1.2 |

2.2

3. Result and Discussion

3.1 The effect of the wire length on the sensor characteristics

In order to expand the measurement range, the effect of the wire length on the sensor characteristics was investigated. Each sensor output is shown in Fig.3, as compared to AMI306. From Fig.3, its dependence on wire length was evaluated and shown in Fig.4. As shown in Fig.4, $H_p$ increased dramatically as wire length decrease. On the other hand the sensitivity and
the peak to peak voltage decreased. It is expected that MI element with 0.35 mm of wire would have a 1.5 times wider measurement range than that of the AMI306, while retaining almost the same sensitivity.

Fig.6, $H_p$ is approximately proportional to $H_k$ including the demagnetizing field, therefore $H_p$ caused by circumferential magnetization based on MI effect, would be predicted from $H_k$ of wire in the static magnetization.

3.2 The relationship between $H_p$ and $H_k$

As for the increase of $H_p$ as wire length decreases, in order to investigate the relationship between $H_p$ and $H_k$, the hysteresis loops in the longitudinal direction of the wire in with several lengths were measured. Then the effect of the wire length on $H_k$ as compared to the theoretical value from the aspect ratio of each wires, and the relationship between $H_p$ and $H_k$, were respectively summarized in Fig.5 and Fig.6. As shown in Fig.5, $H_p$ increased dramatically as the wire length decrease as well as the case of $H_k$. This increase of $H_k$ as the wire length decreased results from the increase of the demagnetizing field and it was approximately in agreement with the theoretical value. And as shown in

4. Summary

In this paper, we investigated the effect of the length of wires on the sensor characteristics to expand the measurement range more than that of the AMI306. In the result, we developed an MI element with a wire length of 0.35 mm that had a 1.5 times wider measurement range than that of the AMI306, while retaining almost the same sensitivity by narrowing the coil pitch and using a demagnetizing field. In addition we clarified $H_p$ caused by circumferential magnetization based on MI effect, would be predicted from $H_k$ of wire in the static magnetization.

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