The Analysis of GMR Sensor’s Angular Dependence

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Abstract. This paper presents the experimental results of GMR sensors’ angular dependence, which was tested by applying three different magnetic fields (5Oe, 10Oe, 15Oe) to GMR sensors with different sensitivity. It is found that the GMR sensor is sensitive to angular variation and can be characterized with a cosine function. By comparing the experimental curve with that simulated by the ideal model, we have established a modified model by introducing several new factors to make it fit with the test data.

1. Introduction
Since the giant magnetoresistance (GMR) effect was discovered in 1988 [1, 2], great attention has been paid on its applications, for example as rotation sensor in industry control area. Angular dependence of magnetic sensors, which include Hall-effect device, AMR sensor, and GMR materials have been previously reported [3-5].

However, characterization on angular dependence of GMR sensors is still lacking. In this work, the experiments in characterizing the angular behavior of GMR sensors were carried out in the lab of Center for Integrated Spintronic Devices (CISD) of Hangzhou Dianzi University. Two sensor chips with different sensitivity were chosen and have been measured by applying three discrete external magnetic fields.

The details of the experiment are presented in the section 2 and the experiment results are discussed in section 3. Furthermore, an improved model for angular characterization of GMR sensor is derived by introducing several correction factors in the last section.

2. Experiment procedure
The angular dependence of GMR sensor was measured by applying a fixed field at different direction. These fixed magnetic fields are chosen with three distinctive values of 5Oe, 10Oe and 15Oe. Since the applied fields are high enough so that the geomagnetic field (lower than 0.5Oe which is less than 10% of operation magnetic field) or some other background disturbances can be ignored in this experiment. Two GMR sensor chips with different sensitivity are employed to study the influence of sensor’s sensitivity to their angular behaviour. Table 1 shows SA GMR sensor series manufactured by SPINIC INC., in which SA02 and SA03 are chosen for this work. SA02 is with a sensitivity of ~3.5mV/V/Oe, and SA03 is with a sensitivity of ~2.5mV/V/Oe.
Table 1. SA series characteristics [6]

| Part Number | Saturation Field (Oe) | Linear Range (|Oe|) | Sensitivity (mV/V-Oe) | Resistance (Ohms) |
|-------------|-----------------------|----------------------|-----------------------|-------------------|
|             | Min       | Max       | Min       | Max       |                   |
| SA00        | 17.8      | 0.6       | 10.2      | 5.0       | 6.0               | 5.5K               |
| SA01        | 21        | 0.8       | 12        | 4.0       | 5.1               | 5.5K               |
| SA02        | 28        | 1.0       | 16        | 3.0       | 4.1               | 5.5K               |
| SA03        | 39        | 1.4       | 20        | 2.0       | 3.1               | 5.5K               |
| SA04        | 65        | 2.4       | 36        | 1.2       | 2.1               | 5.5K               |

Figure 2. (a) Wheatstone bridge structure of the sensor, R2 and R4 are covered by magnetic shields. (b) The static characteristics curve of SA02 [7].

Fig. 2 shows the sensor’s configuration as well as the transfer curve of SA02 sensor. Its performance is excellent with a good linearity and little hysteresis at near zero fields.

Figure 3. Brief structure of the sensor test system.

The brief structure of test system is displayed in figure 3 composing of GMR sensor chip and electromagnet: the chip is attached on the device-under-test (DUT) board, while the electromagnet used for applying fields can be rotated along the circle flame. The output data was acquired 20 times at each angle and then was averaged.
Because there is no any shield for background magnetic fields, the sensor’s sensitivity axis is adjusted to be perpendicular to the earth field, so that the geomagnetic influence could be reduced to the lowest.

3. Results and discussion
The experiment results are presented as following. The sensor SA02’s rotation response curves are shown as Figure 4(a), which are obtained respectively applied fields of 5Oe, 10Oe, 15Oe. Fig4 (b) displays the SA03’s response results. In these graphs, solid symbol and open symbol indicates the clockwise (CW) and the counter-clockwise (CCW) test results respectively.

![Results of SA02](image)

![Results of SA03](image)

**Figure 4.** The rotation response curve. (a) SA02; (b)SA03.

From these curves, we can see the sensor’s angular variation can be characterized with a cosine function. Some obvious output vibration appeared nearby the curve peak (shown as in the enlarged charts) at a relatively lower applying field (the 5Oe for SA02, the 5Oe and 10Oe for SA03,) at which magnetic field is roughly parallel to chip’s sensitivity-axis. This effect disappears at a higher field. The
factors such as the measurement accuracy and the magnetic field distribution generated by electromagnet could cause the error. Nevertheless, after we analyze the chip’s sensitivity, we find this fact would be eliminated if the product of chip’s sensitivity multiplied by operation field exceeds a certain value (around 250e). Therefore, it should be considered in the design for applications.

4. Model and conclusion

4.1. Ideal model

The simple sensing principle of the GMR material can be expressed as Fig. 5. Only the component of magnetic field along the direction of its sensitivity axis can be detected by the sensor.

\[ V_O = V_p \times S[H \cos \theta] \]  

Here \( V_p \) is the power voltage, \( S \) stands for the sensitivity of a certain chip, while \( H \) indicates the magnitude of operation magnetic field.

However, this simple expression is not so accurate if considering some non-ignorable effects in the applications.

4.2. Non-ideal effects

In real application, three non-ideal effects cannot be ignored: 1) the self-offset in chip; 2) the material’s sensitivity axis shift; 3) background magnetic noise.

First of all, as expressed in section 2, the sensor is with a configuration of Wheatstone bridge. Any difference among 4-resistor legs could cause the bridge unbalance, and output an offset voltage. Actually, the offset always exists because of process limitation. We use the symbol \( V_{\text{offset}} \) to indicate the offset voltage.

Secondly, the sensitivity axis shift should be considered. The symbol \( \omega \) is introduced into the function to express this effect and it is also a constant for a particular sensor.

The third, to the background magnetic noise, only the vector component along the sensitivity axis needs to be considered. It is an external magnetic field bias and variable as position changing, which is marked by \( H_E \).

To sum up these points above, a more practical model should be expressed like equation (2).

\[ V_O = V_p \times S[H \cos(\theta + \omega) + H_E] + V_{\text{offset}} \]  

Taking the SA02 at 150e as example, the-sensitivity is 3mV/V-Oe and is represented by \( S \) and \( \omega \) is calculated out by using experiment’s data, which equals to 0.0115 \( \pi \). The \( V_{\text{offset}} \) and \( H_E \) are both
taken by actual test, which are -8.74mV and 0.01Oe respectively. Then the model function can be
determined as equation (3).

\[ V_O = 5 \times 3 [5\cos(\theta + 0.0115\pi) + 0.01] - 8.74 \]  

(3)

Plot the curves of the equation (1) and (3). Fig. 6 displays the comparison result of model vs. data. Obviously, the modified model curve could fit the experimental data better than the ideal model.

4.3. Conclusion
By testing the sensor chip SA02 and SA03, and analyzing the experiment results, the angular
dependence of GMR sensor is characterized. The influence of sensor’s sensitivity on angular
behaviour is also analysed. Besides, a modified model is established to describe the characterization of
the angular dependence.

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