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Time-Coded GMI Magnetic Field Sensor

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A time-coded giant magnetoimpedance (GMI) magnetic field sensor was investigated and designed. The successfully constructed and tested laboratory model demonstrated a sensitivity of 5 μs/μT in the field range of ±200 μT. The sensing element in the form of an amorphous thin wire, 100 mm in diameter ×50 mm long, was fit into a small field modulation coil of 60 mm length. At a magnetic field modulation in the range of hundreds of Hz, the change in time interval of two adjacent GMI voltage peaks was linearly related to the external magnetic field to be measured. This mechanism improved the sensor linearity to better than 0.3% in the measuring range of ±200 μT.

Keywords : magnetic field sensor, GMI, amorphous wire, time-coded

1. Introduction

Since Panina and Mohri reported the giant magneto-impedance (GMI) phenomenon in soft magnetic amorphous wires in 1994 [1, 2], the GMI effect has provided a novel method for detecting a low magnetic field with very high sensitivity. Recent studies on the GMI effect have suggested the possibility of fabricating magnetic field sensors with high performance [3-5]. Due to their high sensitivity, fast response, good stability, low power consumption and easy miniaturization, GMI sensors show great potential as the next generation of magnetic sensors for low magnetic field detection [6-8].

In general, when the GMI ratio curve of the amorphous wire is measured in a magnetic field, the GMI profile has a typical form of the solid curve shown in Fig. 1. Despite the presence of a small hysteresis [9] between the forward (solid line) and backward (dotted line) curves of the GMI profiles, this hysteresis has been neglected. To determine the relation between the GMI ratio and field, several previous works have presented methods for directly measuring the magnetic field using the linear region of the GMI curve.

In order to obtain high linearity, some studies presented a method for using a bias field and feedback coil for the chosen working point [3, 6]. Other studies conducted a compensating item by utilizing another identical sensing element, consisting of a pair of GMI elements, for differentiating the symmetric configuration [10]. In most cases, these conventional methods were unable to overcome the GMI-effect drawbacks of hysteresis and the non-linearity of the operating points. In contrast to the DC magnetic field, however, the GMI effect of an amorphous wire reveals an even function in an AC modulation field, presenting a large hysteresis area, as shown in the solid curve in Fig. 2. In the presence of an external magnetic field, the whole set of GMI curves are shifted from the original location to a new position, as shown by the dotted curve. Based on this finding, the present work proposes another idea, which combines the advantages of time-coded progress in [11] with the advantageous features of the sensing element's GMI effect. On the basis of this novel idea, we constructed a laboratory model of the proposed sensor to demonstrate the accuracy of the idea.

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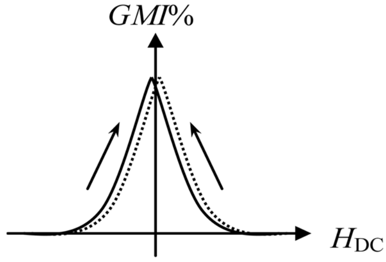

Fig. 1. GMI curves measured in a DC magnetic field.

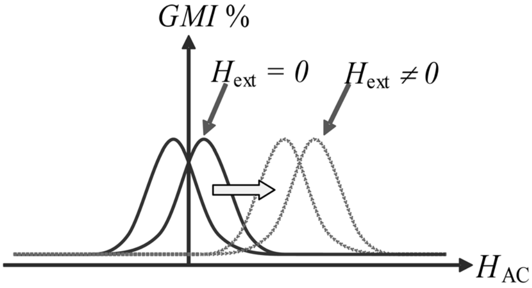

Fig. 2. GMI curve shifts corresponding in the presence of an external DC magnetic field.

2. Operation Principle of the Designed Sensor

An amorphous micro-wire was used as the active magnetic element due to the circumferential magnetic anisotropy which induces an extremely high GMI ratio [1, 2]. A schematic diagram of the constructed sensor is shown in Fig. 3. The amorphous wire was inserted into a magnetic field modulation solenoid coil, which was long enough to cover the whole of its length, and subjected to an AC current at a frequency of a few hundreds of kHz. The GMI ratio of the amorphous wire was obtained after a series of the signal condition stages.

Fundamentally, the mode of the operation principle of the sensor is shown in Fig. 4, where the time-based progresses of V_m, V_C, and V_D are presented with respect to those in Fig. 3. According to the flux-gate principle, if the modulation field is strong enough to induce saturation of the GMI curve, the shifts of the GMI peaks express the presence of the external field to be measured (as pointed out in Fig. 2). Fig. 4-a) presents the time-based progress of the voltage drop $V_m(t)$, which is determined from the GMI(H) curve shown in Fig. 2. Because the GMI curves are shifted with the external magnetic field, the $V_m(t)$ signal

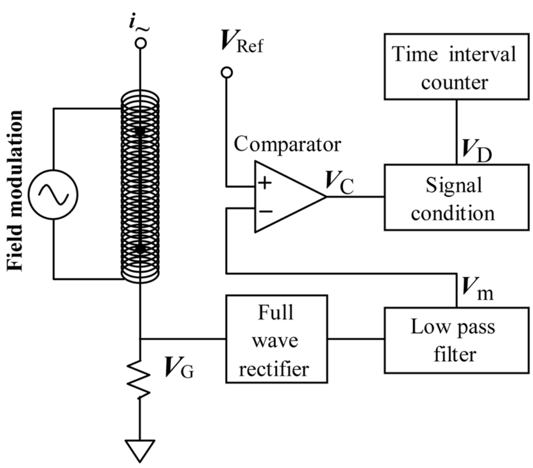

Fig. 3. Block diagram of the designed sensor.

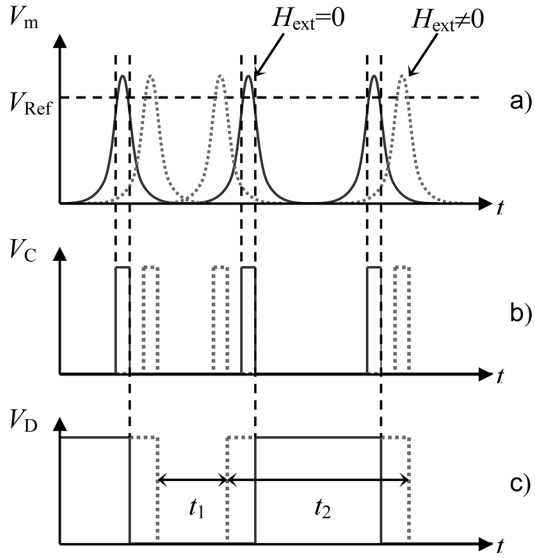

Fig. 4. Operational principle of the sensor: a) GMI voltage signals under modulation field, b) comparator output, and c) final output for time counting.

also acts in the same way in the presence of the external field. When H_{ext}=0, the V_m signal occurs in the time symmetry position (solid line curve). Once $H_{ext}\neq 0$ acts along the amorphous wire axis, it shifts the peaks corresponding to the change of the external field (dotted line curve). Consequently, the shifts of the separated peaks due to the change in the external magnetic field express the change in the time interval, Δt ($=t_2-t_1$), which is proportional to the external field, as shown in Figs. 4-b) and 4-c). Therefore, the problem of non-linearity is eliminated by applying this time-based progress to measure the external magnetic field. To measure Δt, a rectangular voltage signal (V_D) was created in output through the signal condition by means of flip-flop counting from the previous pulse stage output of the comparator, and then transferred to the final stage of time encoding for counting the time interval (Fig. 3). This time-coded method, in combination with the advantages of the GMI effect, facilitated the following improvements to important application in terms of the sensor: high linearity, no hysteresis, and no memory effect. In addition, without the need for related electronics of the compensation items, as required in other methods. The present sensor can be advanced to a more compactable form for the later manufactured stage.

3. Experiment

An actual experiment was conducted following the schematic diagram shown in Fig. 3. An amorphous wire, DC-20, supplied by Unitika Co., with a diameter of 100 μm and a length of 50 mm, was fitted into a modulation

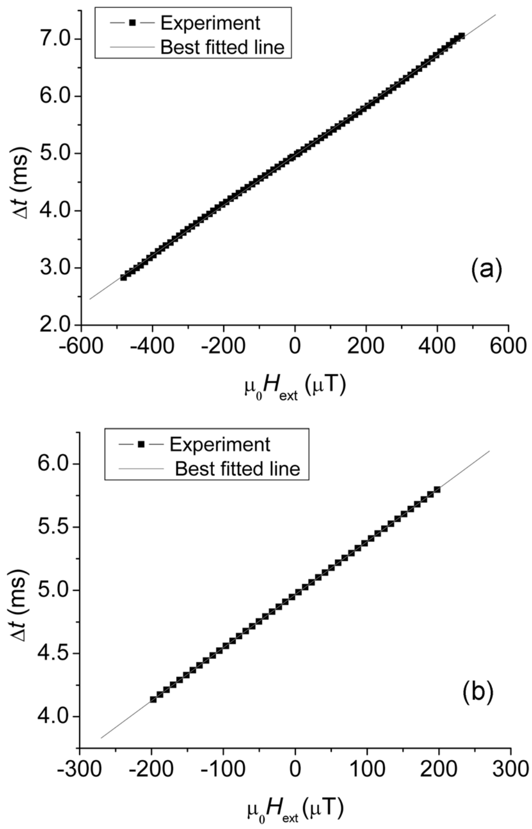

Fig. 5. Characteristic of designed sensor in ranges of ±500 μT (a), and of ±200 μT (b).

coil wound from enameled copper wire. The excitation AC current fed to the amorphous wire was set at a frequency of 300 kHz. The sinusoidal field modulation frequency was set at 100 Hz, which was sufficient to be imposed on the external DC magnetic field, thereby producing the corresponding sinusoidal variation of the output. The time intervals were measured by a Universal Counter HP 53131A with a resolution of 0.5 ns.

4. Measurements of Sensor Characteristics

Figs. 5-a) and 5-b) present the linearity of the sensor operated in the measured ranges of ±500 μT and ±200 μT, respectively. The sensitivity of the magnetic field measurement of the sensor was in the order of 5 μs/μT, and was strongly dependent on the interval between the two GMI-induced voltage peaks of the amorphous wire, and hence on the properties of the chosen amorphous wire. The linearity calculated by means of the standard derivation method was 0.3% for the range of ±200 μT.

5. Conclusions

A newly proposed, magnetic field GMI-sensor was designed, constructed and tested successfully. The functional principle of the sensor operation was based on the time-coded measurement of the changes in time interval of the voltage drop peaks in the presence of an external DC magnetic field. The linearity of the designed sensor was 0.3% for the range of ±200 μT. The main study purpose was to demonstrate the accuracy of the proposed idea to complement the operational principle of the present sensor, rather than as a completely new device design. The obtained study results, although only preliminary, are acceptable for progress to the next advanced stage of further micro-miniaturization and size optimization. The sensitivity and resolution of the model may be significantly increased by careful choice of the sensing element and working conditions, along with the optimized electronics.

Acknowledgements

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