Journal of ELECTRICAL ENGINEERING, VOL 57. NO 8/S, 2006, 77-79

Co-RICH AMORPHOUS MATERIAL IN FLUXGATE AND GMI REGIME

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A comparison between fluxgate and GMI sensor has been made using universal sensor structure for both regimes of operation. Temperature stability and perming effect were investigated. The results show that competitiveness of GMI sensors over the fluxgates is lower mainly due to huge temperature sensitivity of the offset. Nevertheless, the easy miniaturisation of GMI sensors allows them to be used in vast of low cost applications, which do not demand high accuracy.

Keywords: orthogonal fluxgate, giant magnetoimpedance, temperature stability, perming, amorphous ribbon

1 INTRODUCTION

An enormous increase of amorphous materials production, which occurred in last few decades, launched deployment of these materials for novel sensing techniques. Especially soft magnetic materials rich on iron or cobalt have found vast range of usability for sensors such as fluxgates [1] and also, the recently re-invented, magnetoimpedance sensors [2].

Giant magnetoimpedance (GMI) has experienced huge increase of interest since the late 80's. The easy manufacturing of GMI sensors, possible miniaturisation and large sensitivity to magnetic field resulted in the development of many applications intended mainly for commercial use [3], [4]. Nevertheless, the GMI sensors have significant drawbacks, which handicap them against the other sensors. The crucial one is a large temperature sensitivity [5], [6]. In comparison with commercially available fluxgate sensors [7], the temperature stability of the offset is two or three orders worse [8]. On the other side, the GMI sensors compete with significantly longer period of the development of fluxgates. Therefore we decided to construct a sensor structure, which can be operated both in the fluxgate and the GMI regimes. The observed properties allow the proper comparison of the two regimes.

2 SENSOR STRUCTURE

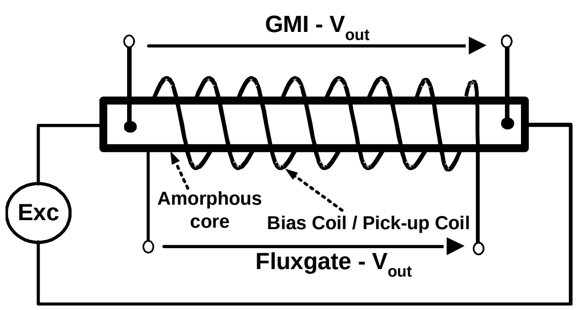

Fig. 1. A scheme of the universal sensor structure

The universal sensor structure is very simple. It consists of a ferromagnetic amorphous core and a solenoid coil of 270 turns wound on the core. The core is made of 10 cm long, 1 mm wide and 20 μm thick CoFeSiBCr amorphous ribbon, which was annealed for 10 min in the air atmosphere at 390°C. A magnetic field of 2.4 kA/m aligned with longitudinal axis of the ribbon was acting on the ribbon during annealing treatment in order to induce axial magnetic anisotropy and hence improve GMI properties of the ribbon. No additional treatment, required specially for fluxgates, has been made.

2.1 Orthoghonal fluxgate sensor

Orthogonal fluxgate sensors use AC current flowing through the ferromagnetic core for the saturation of the core. For the fluxgate regime, two conditions have to be complied: (a) Excitation current must be high enough to saturate the core. (b) The frequency of excitation should be low enough to avoid the skin effect.

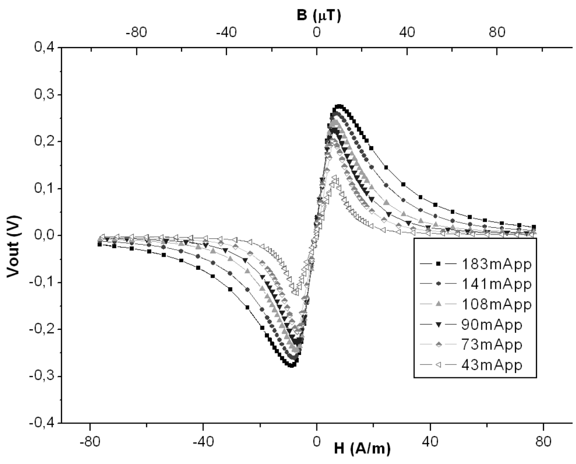

Fig. 2. Response of the orthogonal fluxgate sensor

The amplitude of the excitation current higher than 45 mA partly meets the first criterion: the near-surface field intensity in the core then reaches 22.7 A/m, which is larger than 15.9 A/m required to provide saturation field $B_s = 0.5$ T (supposing that the relative circular AC permeability at working frequency of 50 kHz is not lower than

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ISSN 1335-3632 © 2006 FEI STU

25 000). This means that at least one half of the core volume is saturated. These estimates have been proven by experimental measurements. The sensor in fluxgate regime was excited by a sinewave current of six different amplitudes. The responses are shown in the Fig. 2, where one can see that the current amplitude of 36.5 mA (73 mA_{pp}) is sufficient to saturate the core as much as necessary. With growing amplitudes of the excitation, the sensitivity also increases. The response with lower slope (for 43 mA_{pp}) shows the case, when the core does not reach the saturation.

The penetration depth calculated for the 50 kHz excitation is 13 µm even for higher relative permeability of 50 000. Thus the second criterion is also satisfied. The solenoid coil serves as the pick-up coil and is connected directly to lock-in amplifier locked to the 2nd harmonics of the excitation current.

2.2 GMI sensor

In case of GMI sensors, however, the skin effect is the necessary contributor to the change of RF impedance, which is the measure of external magnetic field. Due to the skin effect, the excitation current of constant amplitude flows only in a thin near-surface shell. When the field acts on the core, its permeability changes thus the skin depth changes as well. This correlation results in the change of RF impedance of the core. The sinewave excitation current is set to 5 mA / 1 MHz. The penetration depth is then 4 µm.

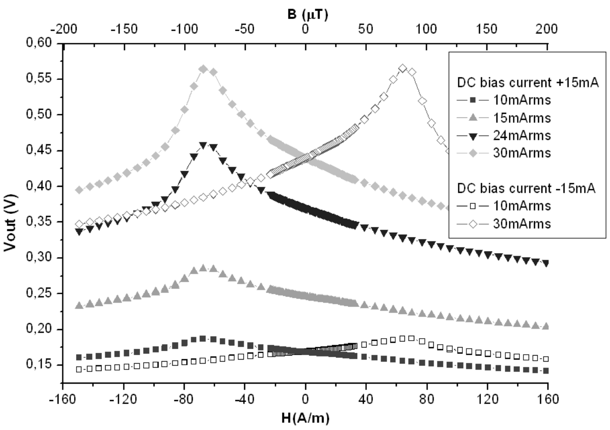

Fig. 3. Responses of DC biased GMI sensor

Because of Y-axis symmetry of the magnetoimpedance response, the solenoid coil is used to induce the constant bias field, which shifts the working point of the sensor to the linear part of the magnetoimpedance response. The bias current (DC current flowing through the solenoid) is experimentally set to 15 mA. The voltage drop along the magnetic core is detected by RF lock-in amplifier, which is locked to the first harmonics of the excitation signal. The responses of the sensor are shown in the Fig. 3. The curves with filled and empty marks represent the responses of the sensor biased with the solenoid current of +15 mA and –15 mA, respectively.

2.2.1 GMI with AC Bias

The GMI structure was also tested in so-called AC bias mode. The squarewave current of 15 mA/100 Hz in the solenoid results in periodical horizontal flips of the GMI response of the amorphous core. A subtraction of flipped and non-flipped response brings several advantages over the "classical" DC bias mode: (a) zero offset at zero magnetic field, (b) higher sensitivity and (c) reduction of the temperature offset drift. In this mode of operation the sensor behaves as a double-core structure [6], [8], [9]. The detail description of the AC biased GMI sensor was made in ref. [10]. Responses of the AC biased GMI sensor are shown in Fig. 4 (after [10]).

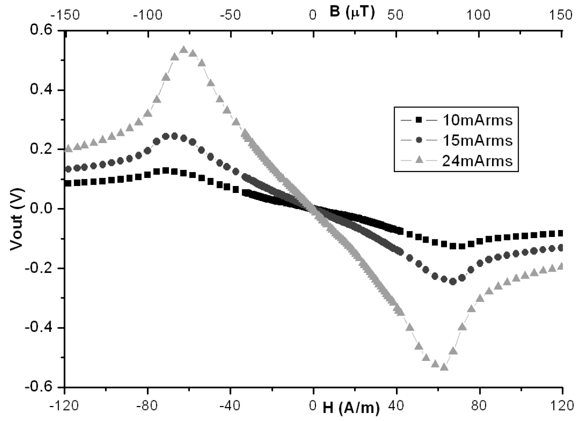

Fig. 4. AC biased Single core GMI sensor from [10]

3 PERFORMANCE TESTS

Tests were focused mainly on temperature stability (temperature offset drift and temperature sensitivity drift) and perming effect (permanent output change after exposition to large magnetic field shocks). All the measurements have been accomplished for sensor in open loop connection.

3.1 Temperature tests

In order to obtain the temperature offset drifts, the structure was firstly placed into a magnetically shielded temperature chamber.

Table 1: Parameters of the orthogonal fluxgate and the GMI sensor with DC and AC bias.

	Temperature offset drift	Sensitivity temp. coeff.
Orthog. fluxgate (90mA_{PP})	-0.0016 A/m/K (-2nT/K)	-0.17 %/K
GMI with DC bias (10mArms)	-0.92 A/m/K (-1160nT/K)	0.19 %/K
GMI with AC bias (after [10])	-0.056 A/m/K (-70nT/K)	0.11 %/K

Afterwards, another temperature chamber placed in Helmholtz coils was used for investigation of the sensitivity temperature coefficients. Measurements in the temperature range from –20ºC to +80ºC and from –3ºC to +80ºC were made for the first and the second measurement set-up, respectively. The results obtained for the three different regimes are summarised in the Table 1.

3.2 Perming effect

Investigations regarding the influence of large magnetic shock fields were performed after the temperature tests. The sensor structure, placed in solenoid with large magnetisation constant (K = 6300 A/m/A), was subjected to successively growing strong magnetic field shocks of both polarities. Initial magnitude of the filed shocks was 1 mT and maximum was 4 mT (3.2 kA/m). Perming effects were investigated for the fluxgate regime and for both GMI regimes at different amplitudes of excitation current. The Fig. 5 shows maximal changes, by which the output of the sensor shifts from the former state, when the field shock is applied. (The voltage values are recalculated to corresponding magnetic fields).

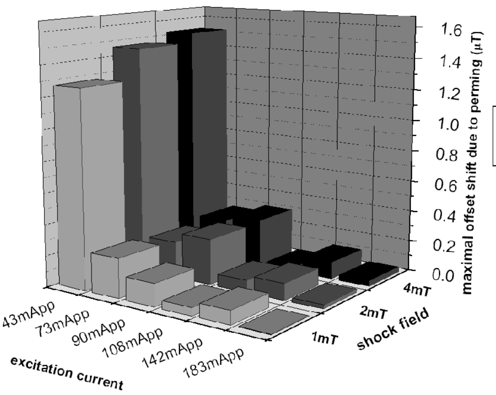

Fig. 5. Perming effect of the orthogonal fluxgate

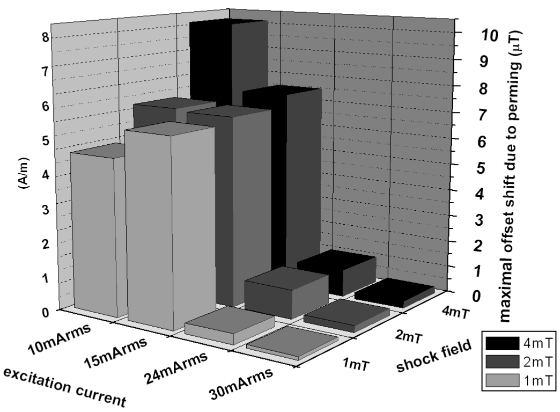

Fig. 6. Perming effect of the DC biased GMI sensor

The results shown in graph again prove that the core is not saturated for the excitation current of 43mA$_{pp}$. In this case the perming effect is as large as 1.5 μT and decreases to values lower than 40 nT for the excitation of 183 mA$_{pp}$ (4 mT shock field).

Fig. 6 shows the results of the same test made on the structure in GMI regime. As it can be seen, the offset changes are much higher than those for the fluxgate regime. It should be, however, noted that amplitudes of GMI excitation currents are lower than those for fluxgates. The best results are obtained for the excitation of 30 mA$_{RMS}$ (85 mA$_{pp}$). The offset changes by 250 nT, which are similar to the fluxgate excited with 90 mA$_{pp}$. The AC bias does not seem to improve the resistance of GMI sensor to shock fields, compared to DC bias.

4 CONCLUSIONS

Although the amorphous material used for the sensor has not been specially treated for fluxgates, the universal sensor structure operated in the fluxgate regime shows several times lower temperature offset drift, which is the crucial parameter when the sensors is intended for closed loop connection. The lower temperature stability of GMI sensors may be a restraint for their wider deployment in industry. Nevertheless, there is an enormous improvement in the temperature stability of GMI sensor when an AC bias is used instead of a DC one. The same classification can be taken for resistance to field shocks. The advantage of GMI sensors, the large sensitivity even for very small current amplitudes, is detracted by the huge perming effect.

Acknowledgement

The financial support from the from Czech Science Foundation project 102/05/H032 is appreciated

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Received 16 November 2006

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Michal Malátek (Ing.), biography not supplied.