Abstract

This article describes the design and testing of a planar current fluxgate sensor prototype. The prototype is composed of a fluxgate current sensor totally embedded in printed circuit board combined with signal processing electronics. The fluxgate sensor excitation and pickup coils are implemented as racetrack shaped copper windings in the printed circuit board internal layers and they are surrounded by an electroplated magnetic core consisting of a thin film of nickel–iron alloy. The electronics provides excitation (including saturable inductor) of the fluxgate and signal processing (filtering and synchronous detection) of the pick-up signal. The prototype has been tested over a 2 A current range with sensitivity 28 V/A at 60 kHz. Excitation using a saturable inductor at 60 kHz has been used and 2 A peak–peak value of the excitation current was reached. We decreased consumption in the sensor from 2.6 W for sine-wave excitation to 0.7 W for excitation for saturable inductor.

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1. Introduction

There are several types of contactless current sensors. Typically the Hall sensor is used for large currents [1], and magnetoresistive sensors (AMR, GMR) [2] are used for higher resolution applications. Fluxgate sensors [3] and current transformers [4] are used in applications, where resolution and stability is critical.

The traditional construction of the fluxgate sensor tends to be complicated and expensive [3]. In this paper we present our experience with low cost fluxgate current sensors built within printed circuit board. The basic sensor construction and characteristics were presented in a previous paper [5]. This paper describes the sensor characteristics when driven by an excitation using a saturable inductor and presents the electronics used to achieve the excitation and the detection of the signal from the pickup coils.

2. Sensor construction

The basic construction of the sensor consists of racetrack shaped copper coils embedded in the internal layers of the PCB, which are surrounded by a magnetic core.

The magnet core is formed by electrodeposition of magnetic material on the external layers of the PCB. The top and bottom layers of magnetic material are connected by magnetic material on the sidewall of a hole cut in the PCB, thus forming a closed core.

The excitation coil encircles the two centre legs of the core. The pickup coils encircle the outer legs of the magnetic core. The PCB trace carrying the current to be measured passes through the centre of each core half (see Fig. 1). A wide track has to be used for this dc current winding in order to carry a strong current to be measured (app. 10 A) (Figs. 2 and 3).

The operation of the current sensor is similar to the operation of the conventional fluxgate using second harmonic detection, except that the magnetic field to be detected is provided by the dc current rather than by an external field. The sensor design is described in greater detail in our previous paper [5].

Fig. 4 shows the corresponding BH loop for the sensor core. It can be seen that the core with all used excitation turns is with the 1.5 A current saturated. The coercivity and saturation
Fig. 1. Sensor layers description.

Fig. 2. Image of a fabricated sensor [5].

Fig. 3. Image of a cross-section through one half of the sensor [5], the copper track layers are from the top: magnetic core, first half of pickup winding, second half of pickup winding, dc current winding, drive winding.

Fig. 4. BH loop for the sensor core at 50 kHz [5].

Fig. 5. Principle scheme of the excitation circuit and signal processing electronics.

The flux density of the core material is approximately 370 A/m and 1.3 T, respectively.

3. Sensor electronic

The excitation frequency is 60 kHz and is generated by a PIC microcontroller (Microchip). The amplified driving signal from the PIC is used to switch a HEXFET IRF 7105. The HEXFET transistor is connected in series with a capacitor and the driving coil of the sensor. There is an add inductor in the series connection of capacitor and driving coil of the sensor. The add inductor provides the resonance between the capacitor. Current caused by this resonance brings the core to the saturation.

The signal from the pick-up coil is filtered with two, second order, band pass filters. The filtered signal is detected using a switch-synchronous detector. The control signal for the detector is also driven from the PIC controller. It is possible to set the phase between the excitation and detector driving signals in the PIC firmware.

The output signal from the detector is then filtered using a low pass filter. The basic principle of the scheme is shown in Fig. 5.

Fig. 6 shows a picture of the planar fluxgate sensor embedded in PCB on left side and signal processing electronics on the right side. The core on the signal electronic board is the saturable inductor.

Fig. 6. PCB fluxgate current sensor (left) and signal process electronic (right).
4. Excitation circuits

The main limitation of the devices based on fluxgate sensors is the consumption caused mainly by the excitation circuits—the circuit providing periodically saturating of the core. There are several typical excitation methods. The simplest with highest consumption is the sine-wave excitation. Fig. 7 shows recorded drive current and pickup voltage for discussed current sensor. The consumption in the sensor is 2.6 W.

Another method how to decrease RMS value of the excitation current is to use pulses. Ripka et al. [8] adapted this method in the excitation of micro-fluxgates and reduced the consumption radically. The disadvantage of this method is more complicated excitation circuit and reduction of the useful pick-up signal [8]. The excitation circuit is possible to adapt from the power electronic switching bridge. The lost of the useful signal is possible to compensate by increasing of the excitation frequency. The width of the pulses could be decrease to the short peaks.

The common used method how to excite fluxgates effectively is serial or parallel resonant with serial or parallel external capacitor. The needed energy for saturation is exchanging between the capacitor and inductance of the excitation coil. The consumption of the excitation circuit is then mainly caused by the losses in the resonant circuit. The resistance of the tracks forming the coils is quite high in the integrated fluxgates including PCB technology, therefore it is difficult to reach high level of the current.

Modified parallel resonant method with saturable inductor [6,7] is used for the excitation of discussed current sensor. Fig. 8 shows recorded drive current and pick-up coil voltage at 60 kHz. The consumption in the sensor was reduced to the value 0.7 W. The space distributions of the turns on the saturable inductor core has to be uniform due to its sensitivity to the external magnetic field (more details in [7]).

5. Characterisation

Fig. 9 shows basic characterization of the sensor using the saturable inductor excitation. The excitation frequency was 60 kHz, peak–peak value of the excitation current was 2 A, the phase of the synchronous detection was set at 1 A of measured current. All four turns of the sensor were used for measuring current (see Ref. [5]).

The power supply for the electronics was 9 V 400 mA and sensitivity 28 V/A at 60 kHz.

6. Conclusion

We have introduced a prototype sensor design [5] and supporting signal processing electronics for a planar fluxgate current sensor built in printed circuit technology.

We described in this paper the design of the signal processing electronics including saturable inductor in excitation circuit and basic characterization of the prototype. We decreased consumption in the sensor from 2.6 W for sinewave excitation to 0.7 W for excitation for saturable inductor. The sensitivity of the signal processing electronic with the sensor was 28 V/A at 60 kHz.

The PCB fluxgate current sensor with signal processing electronic shows technology feasibility for mass production and reduction of the cost. The temperature and time stability of the sensor has to be more investigated due to the different temperature coefficient of expansion in X-, Y- and Z-axis. This difference cause a stress in the ferromagnetic core and change of the parameters of the core.

References


Biographies

Alois Tipek received an engineering degree in 1999, a PhD in 2003 at the Czech Technical University, Prague, Czech Republic. He obtained his Masters degree and PhD in the area of fluxgate sensors, fluxgate magnetometers and their testing and calibration. He participated in several Czech research projects 1998 biomedical application of fluxgate magnetometers, 1999 satellite fluxgate magnetometer, 2001 micro-fluxgate sensors testing. His work and study was evaluated by Award “SIEMENS—2002” for PhD students. He was a postdoctoral fellow within the EMBARK initiative fellowship working in the NMRC in 2003–2005, Cork, Ireland. His fellowship was focused on the design, fabrication and characterization of electromagnetic based micro switches. He is currently working on two industrial grants concerning on novel fluxgates and AMR magnetic sensor development.

Terence O’Donnell received his BE in electrical engineering from University College, Dublin in 1991. In 1996 he received his PhD degree from University College Dublin for research in the area of finite element analysis of magnetic field problems. He is presently a senior research officer based in the Tyndall National Institute in Cork, where he is currently leading the team researching integrated magnetics. He has worked on numerous research projects relating to design, modelling and fabrication of planar magnetics for power conversion and data communications, integrated RF inductors, magnetic field sensors, and magnetics for remote inductive powering. Current research interests include the design, modelling and fabrication of integrated magnetic components.

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Seán Cian Ó Mathúna received the BE, MEngSc, and PhD degrees from the National University of Ireland, Cork, in 1981, 1984, and 1994, respectively. From 1982 to 1993, he was co-manager of the Interconnection and Packaging Group, National Microelectronics Research Centre (NMRC), University College Cork, Ireland, where he held the position of senior research scientist. In 1993, he joined PEI Technologies, NMRC, as technical/commercial director, where he was responsible for power packaging, planar/integrated magnetics, and product qualification. In 1997, he rejoined NMRC as group director with responsibility for Microsystems. In 1999, he was appointed as assistant director for NMRC with responsibility for microelectronics Integration with research themes in ambient electronics, biomedical microsystems, and energy processing for ICT. He is currently a Director of the newly formed Tyndall National Institute based in Cork, which incorporates NMRC and other research groups from UCC and CIT.