VOL. 10, NO. 18, OCTOBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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ANALYSIS OF GEOMETRICAL FEATURES OF E-SHAPED CORE M-COIL FLUXGATE MAGNETOMETER

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ABSTRACT

This paper presents the variation analysis of micro-coil fluxgate magnetometer. The design and analysis have been carried out using COMSOL multiphysics. The performance of the μ-coil have been analyzed by taking three different combinations of one parameter into account such as number of turns in order to find the optimized design. The optimized design of the micro coil can be used as a reference for the future fabrication of μ-scale fluxgate magnetometer. According to the results we found that the optimized design which has more number of turns. Therefore the number of turns has been adjusted to finalize the sensitive device. Hence, the coil with more number of turns has more sensitivity than the other with 0.053 mV.

Keywords: micro-fluxgate, fluxgate magnetometer.

INTRODUCTION

The fluxgate magnetometer (or saturable-core magnetometer) was developed during World War II as an airborne detector of submarines. It has a sensing element of permalloy or similar material that becomes magnetically saturated in very low magnetic fields.

A coil surrounding the core excites it to near saturation at a frequency of about 1 kHz. If there is no external applied magnetic field, the alternating magnetic flux induced in the core is symmetrical in the two directions, but an external steady magnetic field along the axis of the core causes it to approach saturation more quickly during half of the cycle, and the resulting flux is asymmetric (Matthews, Gauld, & Stinner, 2005). Fluxgate magnetometers are used to find the low magnetic fields at the room temperature because of its sensitivity. Fluxgate is a device which consists of one or more soft iron cores each surrounded by primary and secondary windings. In addition, This sensor is act as same like d.c. transformers, d.c. current transformers and magnetic amplifiers. Moreover, it is a device used for determining the characteristics of an external magnetic field from the signals produced in the secondary windings. Due to its compatibility, affordability and very low power making capacity fluxgates were used in variety of sensing applications.

Thereupon, over past decade MEMS devices are most popular and reliable in the field of sensors. Geometrical features of fluxgate coils such as width of the coil, distance between successive coil, and gap between top and bottom coils have an effect towards device miniaturization and performance. This paper presents the recent improvement in the sensitivity of the fluxgate magnetometer by considering the E-core structure. In addition, we will vary the space between the coil and core in order to measure the sensitivity of the sensor which would be possible by calculating the induced voltages in the secondary or pickup coil. We can divide the applications of magnetic sensors into two main categories which are Direct and indirect measurements. In direct measurements the desired information are the magnetic field strength and its direction. In indirect application, non-magnetic signals are detected by using the magnetic field as intermediary carrier. In this case the non-magnetic information is transferred into the magnetic domain and then measured using a magnetic sensor(Marchesi, 2006). This paper begins with overview of fluxgate magnetometer, followed by simulation results and conclusion.

Fluxgate magnetometer

According to the principle the core is periodically saturated by the excitation field which is produced by the excitation current Iexc. The core and coil design of basic sensor configuration is shown in Figure-1 (Ripka, 1992). A fluxgate magnetometer, which consists of a small, magnetically susceptible, core wrapped by two coils of wire. An alternating electrical current is passed through one coil, driving the core through an alternating cycle of magnetic saturation (i.e. magnetized - unmagnetised - inversely magnetized - unmagnetised - magnetized). This constantly changing field induces an electrical current in the second coil, and this output current is measured by a detector. In a magnetically neutral background, the input and output currents will match. However, when the core is exposed to a background field (the earth's magnetic field), it will be more easily magnetized in alignment with that field and less easily magnetized in the direction opposite to it. Hence the alternating magnetic field, and the induced output current, will be out of step with the input current. The extent to which this is the case will depend on the strength of the background magnetic field. It was reported (Hwang *et al*., 2003) that fluxgate magnetometer has the features of small size, high sensitivity, high temperature stability and so on.

VOL. 10, NO. 18, OCTOBER 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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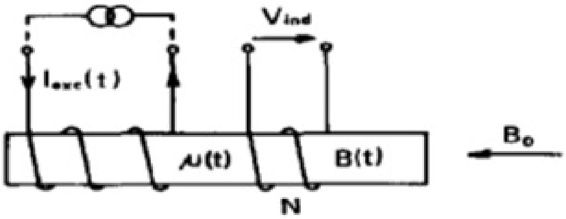
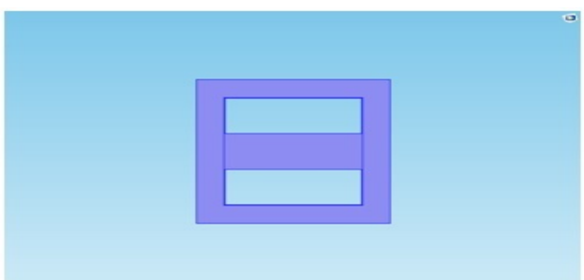


Figure-1. (Ripka, 1992) Basic arrangement of Fluxgate Magnetometer.

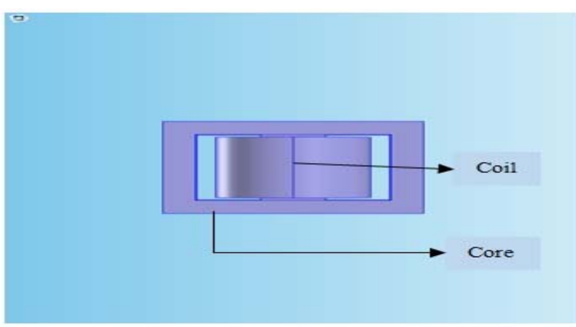
RESULTS AND DISCUSSION

Design procedure of E-core Fluxgate Magnetometer

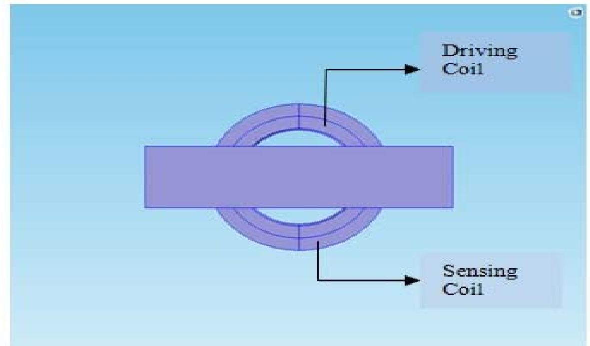
Figure-2 illustrates the fluxgate magnetometer structure both in front and top view. The sensor consists of ferromagnetic core (soft iron material) and coil such us primary coil (Driving Coil) and Secondary Coil (Sensing Coil) which are by copper material. Chang-Hung (Chang-Hung *et al*., 2013) analyzed the different structure of fluxgate magnetometer such as triangular, square, rectangular core and also the core loss, noise of those structures using FEA (finite element analysis) in millimeter scale where as in this paper, we have considered only E-core structure of fluxgate magnetometer in micro scale by varying its coil turns which in turn produce magnetic flux variation. The width and height of the core are $(80 \times 70)\mu m$ respectively. Firstly, the coil turns has been set for 30 (number of turns in driving coil) and 50 (number of turns in secondary coil) then the magnetic flux density would be measured. The same procedure has been continued for different coil dimensions that will be discussed in the following section along with the above explained model.



(a)



(b)



(c)

Figure-2. (a) E-shaped core without coil, (b) Front view of Fluxgate Magnetometer, and (c) Top view of Fluxgate Magnetometer.

SIMULATION RESULTS

It is evident from the principle of fluxgate stated by (Razmkhah, Eshraghi, Forooghi, Sarreshtedari, & Fardmanesh, 2011) that fluxgate core (ferromagnetic core) would be drive into the saturation mode which is observed from the (B-H) curve of core material. In order to get the saturation point of the core material (ferromagnetic material), the B-H cure has been analyzed which is shown in Figure-3. The graph depicts the saturation period of core over the length. Here, for the ferrite P2500 material it would magnetize until 0.35s after that it remains stable which is our saturation period during this period no more magnetization means it attains its maximum state of magnetization.

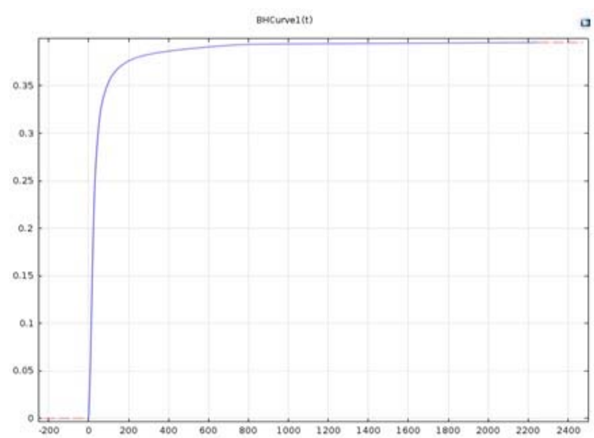


Figure-3. B-H cure for ferromagnetic material (Ferrite P2500).

According to the above result we know that the exact period of saturation of the core. It is proved (Marchesi, 2006) that when we increase the number of turns in the coil then it would increase the induced voltage in the coil. So, from the below relation it is clear that induced voltage is directly proportional to the magnetic flux density that directly impacts the sensitivity of the coil.

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$$V_{ind} = -\frac{d\phi}{dt} \quad (1)$$

$$V_{ind} = -N_{sens} * S * \frac{d}{dt} * \left(\frac{\mu_0 N_{exc} * I_0 \sin(2\pi f_{exc} t)}{l}\right) \quad (2)$$

N_{sens}	= number of turns in Sensing Coil
N_{exc}	= number of turns in Driving Coil
S	= cross section of sensing Coil
l	= length of the Excitation Coil
μ	= magnetic Permeability of the material
$I_o sin(2\pi f_{exc} t)$	= sinusoidal excitation current at frequency f_{exc}

Having stated the above relation it is proved from the simulation results shown in Figure-4(a) that when we increase the driving voltage it would increase the induced voltage in the sense coil. Figure-4(b) depicts the induced voltage in the sense coil over the period of time since the excitation is alternating it gives alternating output/induced voltage. The main objective of this paper is to prove the fact that has been shown in above relations (1) and (2). Consequently from the relation it is clear that the sensitivity of the sensor would increase by increasing the number of turns in the excitation and sensing coils.

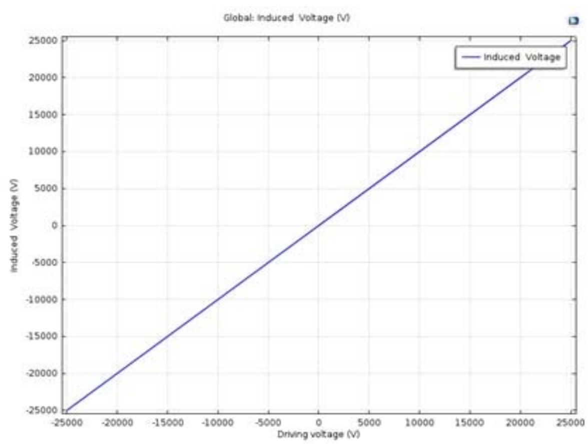

Figure-4(a). Increase Induced voltage by increasing driving voltage.

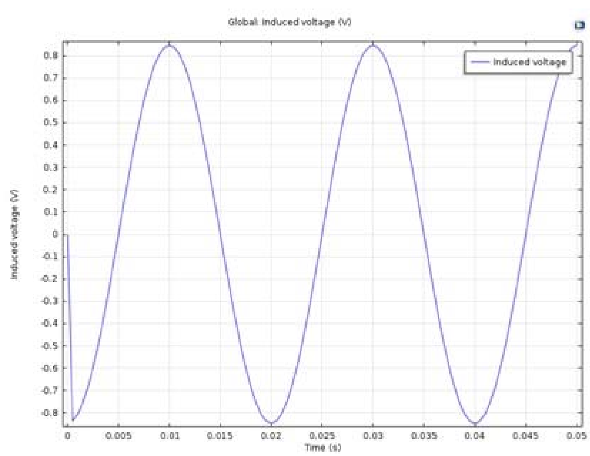

Figure-4(b). Induced voltage over the time period.

Furthermore, we have chosen three combination of number of turns as stated in below table. Obviously, the flux density of the core wouldn't change because of no variation in the excitation current yet there would be possibility if we change the core structure. Since we have considered the coil change it's important to prove this in the form of results. According to the sharafi (Sharafi & Nekoui, 2008) it is proved that the grooved ring core structure has better sensitivity compared to normal ring core structure. Also it is reported that grooved structure consumes low power than the normal structure. Therefore, according to my design we have proved that the change in coil has results in good sensitivity and low power consumption without changing its core structure which may be complicate in practical whereas changing in turns would be less complicated. As a result, it is proved from my assumptions that coils with more turns have better sensitivity than the lower turns. Figure-5 depicts the output waveform of fluxgate magnetometer with different combination of number of turns.

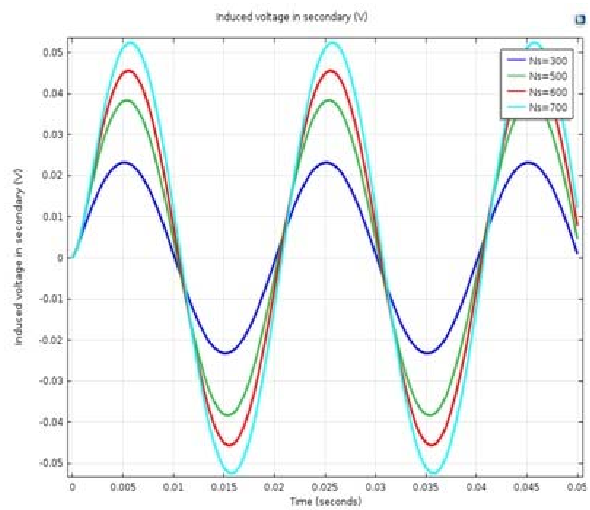

Figure-5. Sensor output voltage waveform with number of turns.

Table-1. Design parameters and their results.

Sensing Coil Turns (N_s)	Induced Voltage (mV)
300	0.025
500	0.039
600	0.045
700	0.053

Finally, the magnetic flux distribution which induces the voltage in secondary coil is shown in Figure-6. Although, it is proved using simulation tool yet still need to design the device to prove it practically. We hope that this work would be helpful to build the fluxgte sensor that consume low power and also with simple design.

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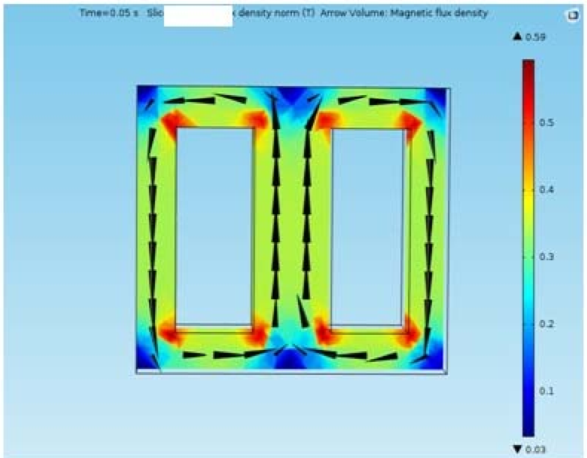

Figure-6. Flux distribution in E-shaped Core.

CONCLUSIONS

In this paper, geometrical features of fluxgate magnetometer analyzed by varying different coil width for the E-core structure using COMSOL multiphysics. The ferromagnetic material property and its characteristics suits for fluxgate core that has been discussed with the appropriate results. Moreover, the induced voltage in the sensing coil has been analyzed according to its combinations of number of turns. Simulation results are more helpful to find the optimum design suitable for the application purpose. Consequently, coil with different variations has taken in to account to prove the sensitivity of the sensor perhaps that has greater impact in the device. However, the fluxgate magnetometers are low power consumption and good sensitivity devices which makes the devices more suitable for portable compass application. Further research on the materials could lead to development of miniature fluxgate magnetometers suitable for high sensitivity and low noise DC and AC magnetic field measurements. Such a device will have great potential in positioning systems and low magnetic field measurements.

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