ISSN (Print) 1226-1750
ISSN (Online) 2233-6656
Journal of Magnetics 18(2), 159-162 (2013) http://dx.doi.org/10.4283/JMAG.2013.18.2.159

Optimization of Operation Frequency of Orthogonal Fluxgate Sensor Fabricated with Co Based Amorphous Wire

Young-Hak Kim[2], Yongmin Kim[1], Chang-Seob Yang[3], and Kwang-Ho Shin[1]*

[1]*Department of Information & Communication Engineering, Kyungsung University, Busan 608-736, Korea*
[2]*Department of Electrical Engineering, Pukyong National University, Busan 608-737, Korea*
[3]*6th R&D Institute, Agency for Defense Development, Changwon-shi 645-016, Korea*

(Received 1 June 2012, Received in final form 17 July 2012, Accepted 22 July 2012)

We present how to optimize the operation condition including frequency of the orthogonal fluxgate sensor in this paper. The orthogonal fluxgate sensor was fabricated with a Co-based amorphous wire with 10 mm long and 100 μm in the diameter and a 270-turn pickup coil wound on the amorphous wire. In order to investigate the frequency dependence of the sensitivity, output spectra of the sensor which was connected by using a coaxial cable with various lengths of 0.5-5 m were measured with a RF lock-in amplifier. The maximum sensitivities were obtained at different frequencies according to coaxial cable lengths. It was found that the optimal operation frequencies, at which maximum sensitivities were appeared, were almost identical to the frequencies of impedance resonance. The maximum sensitivity and optimal operation frequency were 1.1 V/Oe (≈ 11000 V/T) and 1.25 MHz respectively.

Keywords : orthogonal fluxgate, CoFeSiB amorphous wire, MHz operation, LC resonance, sensitivity

1. Introduction

Fluxgate (FG) sensors have been attracting great interests in magnetic engineering area for a long time as practical sensors in the magnetic field range of 10^{-7}-10 Oe [1-5], because they show low offset drift, high sensitivity, and excellent linearity in room temperature operation. Since an orthogonal fluxgate (OFG) sensor can be constructed without excitation coil, it has an additional advantage comparing with conventional fluxgate sensors in their simple structure [6-10]. Recently, A few research groups reported noticeable improvements in linearity and sensitivity of OFG sensors fabricated with amorphous wires [7-9], when they operated OFG in the fundamental mode. However, the operation frequencies were several tens kHz in their studies, although it is supposed that the higher sensitivity could be obtained at the higher operation frequency, because the sensitivity is proportional to the operation frequency [1, 2, 10]. As the FG sensor is operated in higher frequency, the higher output/sensitivity could be obtained according to Faraday's law. However, there are sensitivity reduction factors including LC resonance of the pickup coil and skin effect of the amorphous wire. Therefore, the operation frequency should be decided though systematic designing of equivalent circuit of the sensor pickup coil. The purpose of this study is to investigate how to decide the operation frequency of the OFG sensor fabricated with a cobalt base amorphous wire which is connected to instrument with 50 Ω-matched coaxial line. We report in this paper the relation between output property of the OFG sensor and impedance of its pickup coil, when the sensor connected to instrument with a coaxial line of which length is too long to be neglected.

2. Experimental Method

The OFG sensor was fabricated with a CoFeSiB amorphous wire with the length of 10 mm and the diameter of 100 μm (AC-2T made by Unitika Co. [11]) and a solenoid-shaped pickup coil with 270 turns of Cu wire with the diameter of 100 μm. The length of pickup coil solenoid was 3.2 mm. Fig. 1(a) shows a photograph of the fabricated orthogonal fluxgate sensor and schematic view

*Corresponding author: Tel: +82-51-663-5152
Fax: +82-51-625-1402, e-mail: khshin@ks.ac.kr

This paper was presented at the ICM2012, Busan, Korea, July 8-13, 2012.

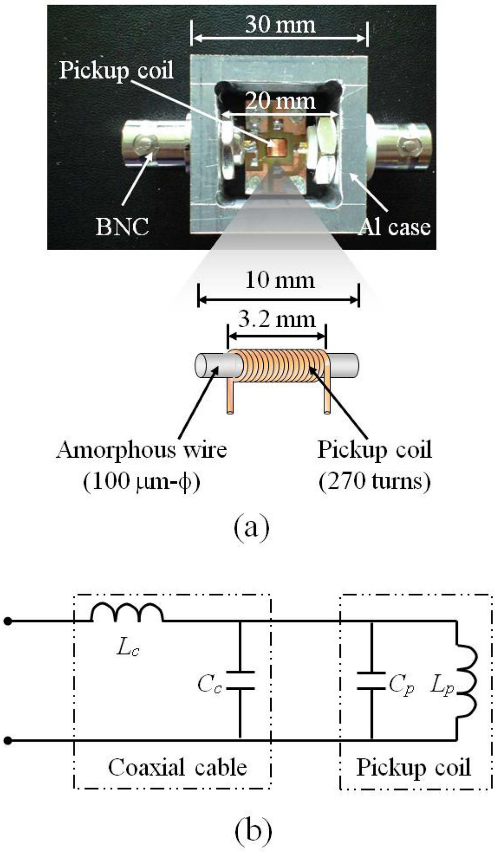

Fig. 1. (Color online) Photograph of the fabricated orthogonal fluxgate sensor and schematic view of the sensor element (a) and equivalent circuit representative of the pickup coil and coaxial cable (b).

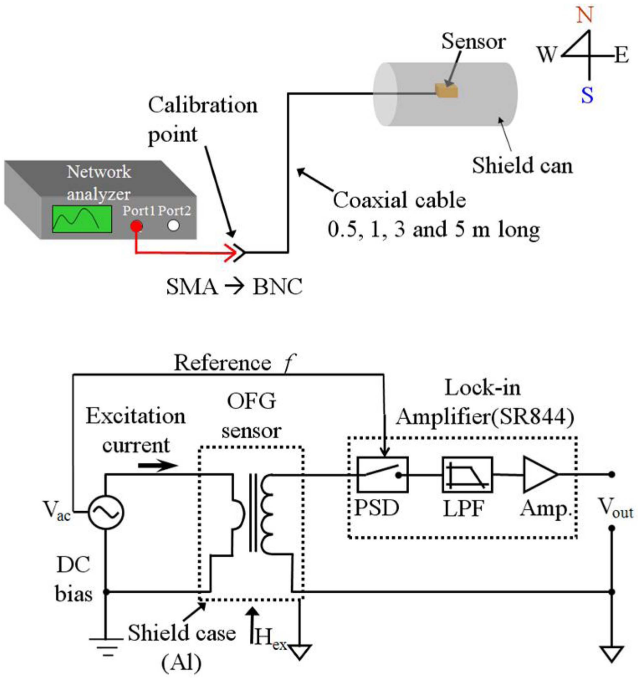

Fig. 2. (Color online) Measurement setups for impedance spectra of the pickup coil (a) and output voltage of the sensor (b).

of the sensor element, and Fig. 1(b) shows the equivalent circuit representative of the pickup coil and coaxial cable. The resistance of the pickup coil and coaxial cable (~10 Ω for the pickup coil and below 0.1 Ω/m for the coaxial cable at 1 MHz) are neglected in Fig. 1(b), because they are sufficiently smaller than reactance values of pickup coil and coaxial line. The axial component of the alternative magnetic flux which is proportional to an external magnetic field generates an electromotive force in the pickup coil. The amorphous wire was soldered to the electrode on a PCB. In order to prevent the electrical field noise, the sensor mounted on a PCB was put in an aluminum case with 5 mm thick.

In this study, impedance of the pickup coil is as important as sensor output, since we try to establish a connection between impedance of the pickup coil and sensitivity. Fig. 2(a) shows the measurement setup for impedance spectra of the pickup coil using a network analyzer (HP 8714) through reflection method. The 50 Ω-matched coaxial lines with the length of 0.5 m - 5 m were used to connect the pickup coil to a network analyzer. Fig. 2(b) shows the measurement setup for the output signal of the fabricated orthogonal fluxgate. The coaxial lines with the length of 0.5 m - 5 m were used to connect the pickup coil to a RF lock-in amplifier (SR 84412). The output of the sensor was measured with both alternative excitation current of 50 mA and DC bias of 30 mA, and the operating frequency was varied from 300 kHz to 2 MHz. The DC bias was applied to suppress a magnetic noise caused by movement of magnetic domain walls. And, the DC bias makes a unipolar excitation of the magnetic wire and a fundamental mode output. Sasada *et al* explained well how to suppress a magnetic noise with adequate DC bias and how to improve sensitivity and resolution of OFG by applying a unipolar [8, 9].

3. Results

Since the sensitivity of an OFG is typically proportional to its winding number *N*, cross section area of its magnetic core *A*, and operation frequency *f*, the *f* should be as high as possible to prevent reduction of the sensitivity in the case of small-sized OFG sensors in which the *N* and *A* are restricted [10]. The *f* is limited due to the LC resonance occurred by inductance and stray-field capacitance of the pickup coil around the magnetic core and transmission line, coaxial line in this study, as well as perfor-

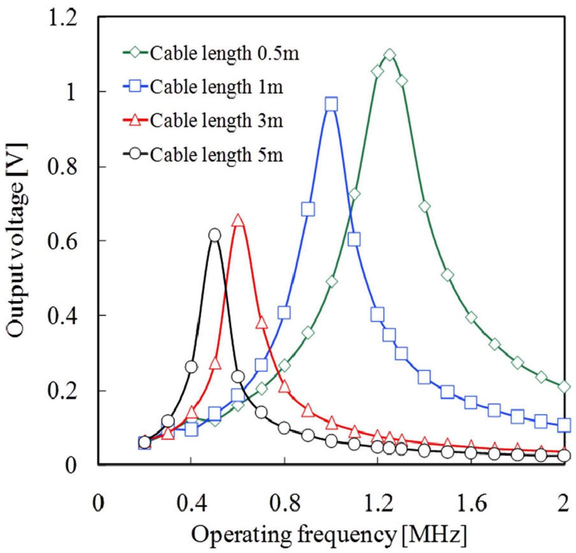

Fig. 3. (Color online) Frequency dependence of output voltages of the sensor. The sensor output was connected to RF lock-in amplifier by using a coaxial cable with 0.5-5 m long.

mance of the signal conditioning circuit in common.

Fig. 3 shows the operation frequency dependences of output voltages of the fabricated OFG sensor. The sensor was connected to a RF lock-in amplifier by using the coaxial cable with 0.5, 1, 3 and 5 m.

The output voltage was checked by applying the external magnetic field of 1 Oe. The output voltage was largely dependent on operation frequency, and the maximum sensitivities were obtained in the optimal frequencies which were dependent on the cable length. The maximum sensitivity and optimal operation frequency were respectively 1.1 V/Oe (= 11000 V/T) and 1.25 MHz in the case of 0.5 m-coaxial cable. The optimal frequencies and sensitivities tended to decrease with increasing of the cable length. This tendency could be well explained with the measured frequency dependence of impedance of the pickup coil including coaxial cable. Fig. 4 represents the frequency dependence of impedance of the pickup coil. The calibration point for impedance measurement was indicated in Fig. 2(a).

In this study, we have employed the lumped parameter model (shown in Fig. 1(b)) because the total length is very shorter than wavelength (at 1 MHz, 300 m in air). From the equivalent circuit shown in Fig. 1(b), it is easy to understand that the series inductances and parallel capacitances, respectively, can be added together. Since the resistance of the cable and pickup coil can be neglected, the impedance resonance frequency can be calculated approximately by Eq. (1).

$$f_r = \frac{1}{2\pi}\sqrt{\frac{1}{L_t C_t}} \tag{1}$$

$L_t = L_p + L_c$, where $L_c = l \times d$
$C_t = C_p + C_c$, where $C_c = c \times d$

Where, l and c are series inductance per unit length and parallel capacitance per unit length of the coaxial cable respectively. From the characteristic impedance of the coaxial cable 50 Ω, it is not so hard to calculate the $l \approx 2.5 \times 10^{-7}$ H/m and $c \approx 1 \times 10^{-10}$ F/m. And, the inductance $L_p \approx 2.1 \times 10^{-4}$ H and the capacitance $C_p \approx 1.5 \times 10^{-11}$ F of the pickup coil was deduced from the measured impedance spectra. In this configuration, $Z \approx j\omega L_t$ at sufficiently low frequency and $Z = j(\omega L_t - 1/\omega C_t)$ at high frequency neg-

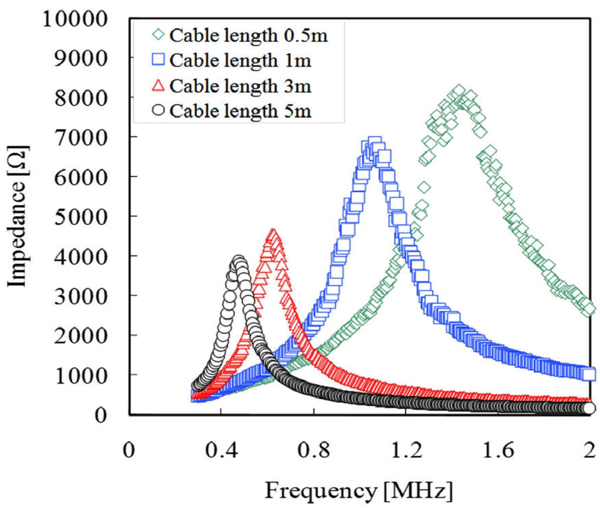

Fig. 4. (Color online) Frequency dependence of impedance of the pickup coil. The pickup coil was connected to network analyzer by using a coaxial cable with 0.5-5 m long.

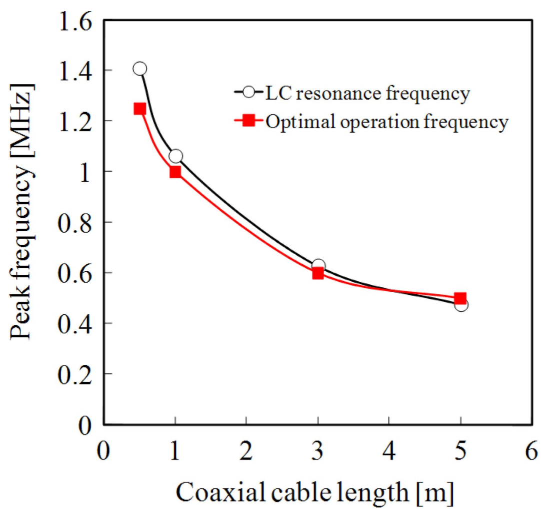

Fig. 5. (Color online) Cable length dependence of the LC resonance frequency and optimal operation frequency.

lecting the series resistance R and parallel conductance G. The calculated resonance frequencies by using Eq. (1) were 1.36 MHz, 1.02 MHz, 618 kHz and 483 kHz for the cable lengths of 0.5 m, 1 m, 3 m and 5 m, respectively. Fig. 5 clearly shows the correspondence of the LC resonance frequency and optimal operation frequency in which the maximum sensitivities were obtained. The higher output was obtained as the impedance of the pickup coil was larger. This could be explained with the maximum power transfer theorem [10]. Because the input impedance of the lock-in amplifier was ~1 MΩ, the larger impedance of the pickup coil close to 1 MΩ was profitable to obtain high sensitivity.

4. Conclusion

The output voltage and impedance of the orthogonal fluxgate sensor, which was fabricated with a Co-based amorphous wire and a pickup coil, were investigated in this study. The optimal operation frequencies, in which the maximum sensitivities were obtained, and maximum sensitivities of the sensor were decreased with increasing of the cable length. The tendency of output voltage dependent on frequency was much similar to the impedance spectra of the pickup coil showing possibility of that the sensor performance could be estimated by evaluating the impedance spectra, and of that the operation frequency could be decided by that. These correspondences are explained with the maximum power transfer theorem.

Acknowledgement

This research was financially supported by a grant to MEMS Research Center for National Defense funded by Defense Acquisition Program Administration.

References

[1] Magnetic sensors edited by R. Boll and K. J. Overshott, VCH, 201 (1989).
[2] P. Ripka, Sens. Actuators: A **106**, 8 (2003).
[3] T. J. Peters, IEEE Trans. Veh. Technol. **35**, 41 (1986).
[4] D. I. Gordon and R. E. Brown, IEEE Trans. Magn. **8**, 76 (1972).
[5] M. H. Acuna, IEEE Trans. Magn. **10**, 519 (1974).
[6] X. P. Li, J. Fan, J. Ding, H. Chiriac, X. B. Qian, and J. B. Yi, J. Appl. Phys. **99**, 08B313 (2006).
[7] E. Paperno, E. Weiss, and A. Plotkin, IEEE Trans. Magn. **44**, 4018 (2008).
[8] I. Sasada, J. Appl. Phys. **91**, 7789 (2002).
[9] E. Paperno, Sens. Actuators: A **116**, 405 (2004).
[10] S. H. Choi, IEEE Trans. Magn. **47**, 2573 (2011).
[11] http://ww.unitika.co.jp
[12] http://www.home.agilent.com
[13] http://www.thinksrs.com/