Design and development of a magnetometer calibration device

S Angelopoulos
School of Electrical and Computer Engineering, Laboratory of Electronic Sensors, National Technical University of Athens, Zografou Campus, Athens, 15780, Greece
E-mail: spyrosag@central.ntua.gr

Abstract. This paper describes the development of a new magnetometer calibration device, which is able to provide accuracy of 1fT/√Hz. The mentioned device is able to eliminate the ambient magnetic field, using an active shielding technique. This can be achieved by the use of a solenoid or a pair of Helmholtz coils. In order to measure the existing magnetic field, it is necessary to develop and use accurate magnetometers with amorphous ribbons as core magnetic materials. The whole system works as a closed-loop system, which is able to control and adjust the produced counter magnetic field.

1. Introduction

Magnetometers are used in a variety of applications, in a wide range of fields, which include sciences, transportation and industry [1-3]. As a result, it is mandatory to be able to maintain their accuracy at the required level. This is achievable by the use of a magnetometer calibration device. Such a device, is able to eliminate the ambient magnetic field, in order to produce a space where controllable magnetic measurements can be conducted.

The elimination of the ambient magnetic field is called magnetic shielding and is divided into two different methods; the passive magnetic shielding and the active magnetic shielding. The main parameter that differentiates the two methods is the frequency of the magnetic field that they are able to eliminate. The high frequency magnetic field can be eliminated more easily using passive magnetic shielding methods. These techniques are based on the use of materials with high magnetic permeability, such as aluminium or mumetals. Those materials are used as a cover, shielding a certain space. As a result, the external magnetic field “prefers” the easiest way of transmission, which is through the materials with the highest magnetic permeability, ignoring the internal space which they cover. The disadvantages of passive magnetic shielding, except for the frequency range, is the requirement of a thorough covering of the space where the measurements will be conducted and the cost of the shielding [4-7].

In order to avoid passive shielding techniques, active shielding can be used. These techniques are based on the generation of a counter-acting magnetic field, which will be able to oppose to the ambient magnetic field. The main advantage of the active magnetic shielding is its ability to be adapted via a closed-loop system to the variations of the external magnetic field. A sensing element, e.g. a magnetometer, can provide the input of the system, in order to precisely adapt the required opposed

1 Tel: +30 2107723737, E-mail: spyrosag@central.ntua.gr
magnetic field. As a result, the active shielding techniques can be used even in the case of either DC magnetic fields, or low frequency magnetic fields.

2. Operating principles

The main purpose of the magnetometer calibration device is the zeroing of any offset of the magnetometer’s reading, in order to correlate its output voltage value to the magnetic field’s strength value. This is possible to be applied on more than one axes. In this case, it is required to use three perpendicularly placed magnetometers, in order to measure the strength of the magnetic field in each direction.

The accuracy of the measurement of the existing magnetic field depends on the choice of the type and the design of the magnetometer, which will be used as the sensing element of the device. More precisely, the choice of the core material of the magnetometer is a matter of great significance. The best choice is to use amorphous magnetic ribbons or wires as core materials, such as FeSiB or CoFeSiB, which are able to provide rapid output response to the changes of the magnetic field [8-10].

The calculation of the offset value of the magnetometer is based on the measurement of a time difference. Specifically, Figure 1 resembles the output signal of the receiving coil of the magnetometer, in the case of absence of any external magnetic field. The excitation signal of the magnetometer is sinusoidal, however, there are positive and negative peaks at the received signal. These peaks indicate that the core material of the magnetometer has reached its positive or negative magnetic saturation value, because of the existence of a magnetic field, which is produced by the excitation coil. It is obvious that the time difference between a positive and the following negative peak is the same, which can be explained by the use of sinusoidal excitation signal and the hysteresis loop of the soft amorphous magnetic material.

Figure 2 represents the received signal in the case of presence of an external magnetic field. It is easily observed that the minima and the maxima of the output signal have been changed, despite the fact that the excitation signal is still the same. This is due to the reduction of time which is required for the core material to reach its magnetic saturation value, because of the additional magnetic field strength, which affects it.

As a result, a device which is able to accurately measure and eliminate the time difference between the positive and the negative peaks of the output signal, can lead to the elimination of the undesirable magnetic field.

3. Development of the magnetometer calibration device

3.1. The arrangement

The chosen arrangement is based on the active shielding method of calibration. It includes a signal generator, which produces the excitation signal, a magnetometer as a sensing element, a solenoid as a
magnetic shielding device and an oscilloscope, in order to view the final signal. The above-mentioned parts will be described and analysed below.

3.2. Development of the magnetic shielding device
As it was mentioned before, the calibration device is based on the active shielding method. This means that the magnetic shielding is created by the generation of a magnetic field opposed to the externally forced magnetic field. The generation of this magnetic field is achieved by the use of a solenoid. The developed solenoid, which was used during the experiments, was made by two layers of 290 windings each, made of Ø1mm enamelled copper wire. The overall length of the solenoid is 35cm and its radius is 10cm. The space surrounded by the solenoid acts as the magnetometer calibration space, where the magnetic field can be precisely controlled, through the adjustment of the supplied DC current, produced by a controllable power supply unit.

3.3. Development of the magnetometer
The developed magnetometer was designed as a fluxgate sensor. The chosen design was based on the literature [11-17]. Its excitation and receiving coils were made by 2 layers of 550 windings each, using Ø0.1mm enamelled copper wire. The chosen core magnetic material was a wire of FeSiB (Ø111μm) [18-21]. The total length of the sensor is 7cm and its diameter is 3.2mm. The final sensor was placed on a perfboard.

4. Experimental results & Conclusions

In order to conduct the experimental procedure, the sensor was placed inside the solenoid. The solenoid was connected to a power supply unit. Furthermore, the excitation coil of the sensor was connected to a function generator and its receiving coil to a digital oscilloscope.

Using a sinusoidal 5V, 1kHz excitation signal, the received signal was the one shown in Figure 1. The signal was changed when we supplied the solenoid with DC current, through the power supply unit. As a result, it was possible to capture different output signals, based on the different supplied current values. Figure 5 expresses the measured time difference between the sequential maxima and minima of the received signal, versus the supplied current to the solenoid. The results were similar when the polarity of the supplied DC current was reversed. As it was expected, the relation between the mentioned time difference and the supplied current values, is linear.
Figure 5. Correlation between the magnetic field and the time difference of the peaks.

As a result, we conclude that it is possible to measure the time difference between the peaks of the received signal, based on the operating principles which were explained above, in order to calibrate a magnetometer. The main parameters of the developed device, which can be further improved, are the magnetic shielding space, which can be developed as a 3D arrangement of Helmholtz coils and the time measurement and current supply system, which can be constructed as a highly accurate closed-loop system.

5. References

[1] Hristoforou E 2002 J. Opt. Adv. Mat. 4 245-260
[2] Hristoforou E, Hauser H and Dimitropoulos PD 2006 IEEE Sensors 6 372-379
[3] Hristoforou E and Ktina A 2007 J. Magn. Magn. Mater. 316 372-378
[4] Kelha V, Peltonen R, Penttinen A, Ilmoniemi R and Heino J 1982 IEEE Trans. On Magn. 18 260-269
[5] Harakawa K, Kajiwara G, Kazami K, Ogata H and Kado H 1996 IEEE Trans. On Magn. 32 5226-5229
[6] Tashiro K and Sasada I 2005 IEEE Trans. On Magn. 41 4081-4083
[7] Knappe-Grüneberg S, Schnabel A, Wuebbeler G and Burghoff M 2008 J. of Appl. Physics 103 925-927
[8] Ripka P 2000 J. of Magn. and Magn. Mat. 215/216 735-739
[9] Benyosef L C, Stael G and Bochner M 2008 Mat. Res. 11 145-149
[10] Razmkhah S, Eshraghi M J, Forooghi F, Sarreshtedari F and Fardmanesh M 2011 El. Eng. ICEE
[11] Hristoforou E, Chiriac H and Neagu M 1997 IEEE Trans. Instr. & Meas. 46 632-635
[12] Dimitropoulos P, Avaritisiotis J N and Hristoforou E 2001 Sens. and Act. A 90 56-72
[13] Dimitropoulos P D, Avaritisiotis J N and Hristoforou E 2003 Sens. and Act. A 107 238-247
[14] Petridis C, Petrou I, Dimitropoulos P D and Hristoforou E 2007 Sens. Let. 5 98-101
[15] Petridis C, Ktena A, Laskaris E, Dimitropoulos PD and Hristoforou E 2007 Sens. Let. 5 93-97
[16] Petridis C, Dimitropoulos PD and Hristoforou E 2009 IEEE Sens. J. 9 128-134
[17] Petrou J, Skaifidas J and Hristoforou E 2013 Sens. Let. 11 91-95
[18] Hristoforou E and Reilly R E 1991 J. Appl. Phys. 69 5008-5010
[19] Hristoforou E and Niarchos D 1993 IEEE Trans. Magn. 29 3147-3149
[20] Hristoforou E, Chiriac H, Neagu M, Darie I 1994 J. Phys. D: Ap. Ph. 27 1595-1600
[21] Hristoforou E, Chiriac H and Nagacevschi V 1999 Sens. & Act. A 76 442 – 447