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Simulation Study of Side-by-Side Spiral Coil Design For Micromagnetometer

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Abstract. Magnetic field measurement has many applications particularly in the field of navigation, military, space exploration, and medical. Among many magnetic devices, magnetometer is significant due to its capability of detecting direction and measuring strength of magnetic field. Through the years, many types of magnetometer had been invented with fluxgate magnetometer being one of the most well-known. In the advances of MEMS processing technology, fluxgate magnetometer is increasingly developed into micro-scale. Fluxgate magnetometer is made up of three major components consisting of sensing coil, driving coil and magnetic core. The physical characteristics of the coil structure play an important factor in miniaturization as well as in performance of the device. Therefore, investigations on the physical characteristics of the coils are relevant. In this paper, the side-by-side spiral coil structure is investigated in terms of its physical characteristics such as width of the coil and distance between successive coils. The aim is to observe and analyze the effects of varying the coil physical characteristics on certain important parameters that could influence the performance of the device. The work is done with the aid of FEM simulation software, where the physical characteristics of the coils were varied and simulated. With the simulated results, dimension of coils can be appropriately designed to optimize the performance of the device.

Introduction

The importance of application based on the principle and theory of magnetism have been realized since the early of 20th century. The applications cover a very wide spectrum ranging from space exploration and navigation up to medical diagnosis and treatment. This situation resulted in the invention of many magnetic devices including the device known as magnetometer. The important function of a magnetometer is to determine the direction and measure the strength of surrounding magnetic fields. There are many types of magnetometers based on different operating principle and one of the prominent type is the fluxgate magnetometer. The principle of operation for fluxgate is based on the detection of second harmonics voltage induced at sensing coil [1].

As MEMS processing technology progresses, many micro-scale devices have been developed. Micro-scale fluxgate with diverse coil designs have been reported which includes multilayer double coil [2], toroidal type [3], three-dimensional solenoid [4] and stack planar type [5]. Coil design is one of the important factors in the performance of fluxgate magnetometer as it has direct effect on the inductance, magnetic flux and magnetic energy of the device. Based on this fact, a simulation study on the physical characteristics of side-by-side spiral coil is presented in the next section.

Coil Structure

There are three main components of a fluxgate consisting of driving coil, sensing coil and ferromagnetic core. The structure of coils is made up of driving and sensing coils winding side-by-side. This design has the advantage of reducing the surface area as well as increasing the magnetic flux linkage between coils. The illustration of the coil structure is shown in Fig. 1(a) where the gray coil represents driving coil while the white coil is sensing coil. Both coils have two windings and are made identical so as to simplify the simulation process.

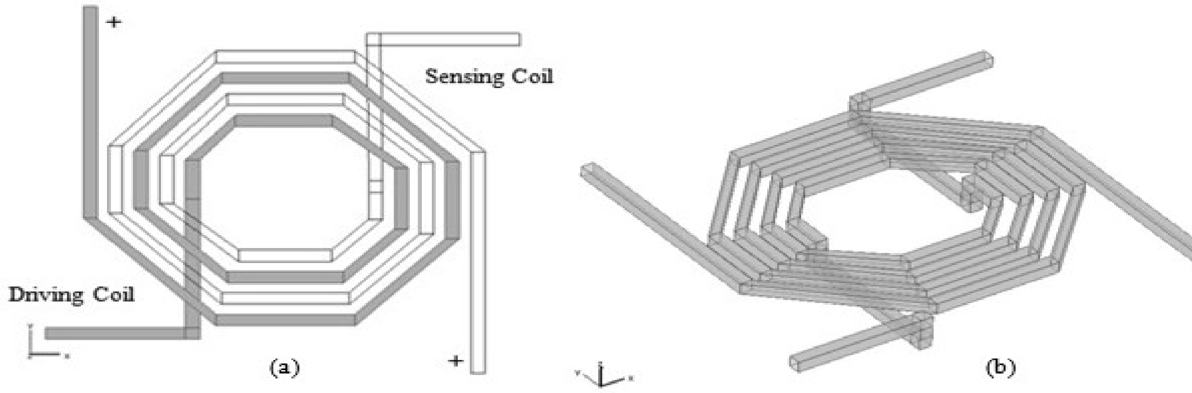

Fig. 1 (a) Coil structure and (b) Coil model in 3-D view

Simulation Process

Simulation was executed with the aid of FEM simulation software. The objective is to simulate the physical characteristics of the coils and observe the effects on inductance, magnetic flux and magnetic energy. The simulation process was done under static magnetic (*magnetostatics*) environment, due to its simplicity and adequate result. The first step was geometrical modeling of the coil by using draw function. In this process, coil dimensions such as width and distance between successive coils were specified.

The number of coil windings is two for both driving and sensing coils. This is to simplify the simulation processes especially during *meshing* and *solving*. Fig. 1(b) illustrates the coil model in three-dimensional view. Next process involve on specifying module and application mode. The module was *AC/DC Module* while application mode was *magnetostatics*. This was followed by *Mesh* and *Solve* processes.

Simulation Analysis and Results

Fluxgate is measured based on the second harmonics induced voltage at sensing coil. Generally, induced voltage at sensing coil can be given as Eq. 1 [6].

$$V_{ind} = NA\,\mu_o H_o \,\frac{(1-D)}{\{1+D[\mu(t)-1]\}^2}\,\frac{d\mu(t)}{dt}\ . \quad (1)$$

This equation take into account the magnetizing and demagnetizing effects of ferromagnetic core where N, A, μ_o are respectively number of coil turns, core cross-sectional area and permeability. H_o is magnetic field on the outside of magnetic core, and D is demagnetizing factor.

Since the focus of this simulation study is on physical characteristics of coils, magnetic core is omitted and the simulated environment is made in static magnetic fields. This will reduce the complexity of the modeling process at the same time produce adequate results. With the exclusion of magnetic core, basic formulas for induced voltage as stated in Eq.2 and magnetic energy in a coil given in Eq.3 are applicable. The inductance, magnetic flux, number of turns, and current passing through coil are denoted as L, Φ, N and I respectively.

$$V_{ind} = -N\,\frac{d\Phi}{dt} = -L\,\frac{dI}{dt}\ . \quad (2)$$

$$E_m = \frac{LI^2}{2}\ . \quad (3)$$

Coil Width. The width of the coil is varied from 20 μm up to 70 μm. Other geometrical dimensions of the coil are kept constant. Fig. 2 presents the resulting plots between inductance, magnetic flux density and magnetic energy against various width of coil.

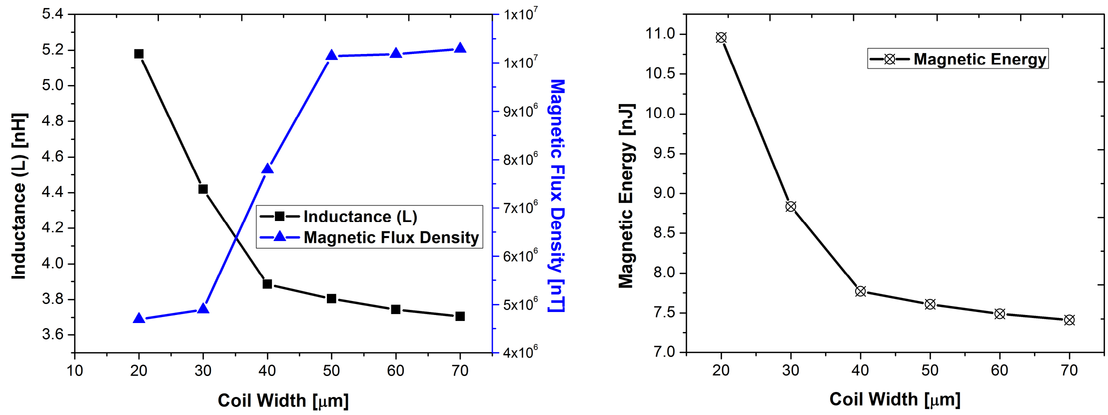

Fig. 2 Inductance, magnetic flux density and magnetic energy versus coil width

From the plot, inductance decreases as coil width increases. This is expected since increase in width of the coil also means increase in cross-sectional area of the coil. This results in higher conductivity, and less resistance and inductance of the coils. On the contrary, magnetic flux density increases as the coil width increases. This is due to the fact that increase in coil width leads to increase in surface area of the coil which results in an increase in number of flux. As for magnetic energy in coil, it can be seen that as the coil width increases, magnetic energy decrease. This is also anticipated based on Eq. 3, in which magnetic energy in a coil is directly proportional to inductance.

Distance Between Successive Coils. The method is similar as before except that only the distance between successive coils is varied while other geometrical dimensions are kept constant. The resulting plots are as shown in Fig. 3.

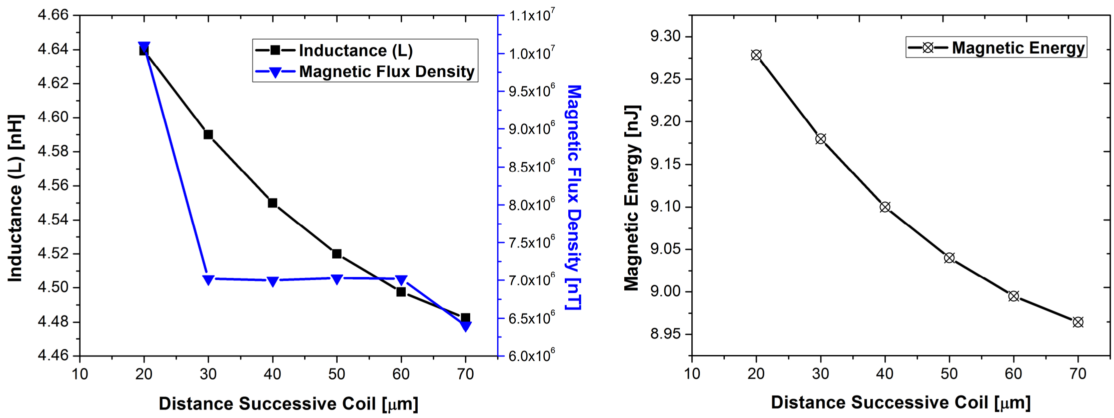

Fig. 3 Inductance, magnetic flux density and magnetic energy versus distance successive coils

Both inductance and magnetic flux density shows reduction as distance between successive coils increases. This is because increase in distance between successive coils also causes increase in distance between turns leading to less flux linkages between coils. This situation results in less inductance and magnetic flux density. Magnetic energy also decreases due to its relationship with inductance value.

From the results of the simulation, it can be seen that the width of coils and distance between successive coils play an important factor in the output of the device. It is preferable to have a condition in which the coils have high inductance and at the same time also produce high magnetic flux density. However, to achieve high inductance, the coils need to be less in width size and have small distance between successive coils. On the contrary, high magnetic flux density can only be achieved when width of coils are large.

Besides this contradiction, increase in width and distance between successive coils would result in increase in the surface area of the spiral coils. This would defeat the purpose of miniaturization. Therefore, moderation during coil design stage is crucial to compromise important aspect that would affect the performance of the device.

Conclusion

The simulations on side-by-side spiral coil have been executed. From the results, it shown that the change in width and distance between successive coils would affect parameters such as coil inductance, magnetic flux density and magnetic energy. It is also shown that contradiction between preferable parameter conditions due to varying physical characteristics of the coils occurs. Therefore, moderation in coil design is recommended.

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