Design and Analyzes a New Ring core Fluxgate Sensor

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Abstract - **For advanced applications, fluxgate sensor should offer high magnetic field sensitivity as well as directionality. There has been a large demand for the integrated fluxgate sensors containing sensor and the supporting circuit on the same silicon chip.Since integrated circuits have driving current limitation, main motivation of this research is to optimize sensor core geometry to achieve high sensitivity and directionality at operating current. In this work, fluxgate sensors have been simulated and analyzed and by changing the core shape, the excitation current of the sensor has been reduced multiple times, which results in drastic reduction in overall power consumption. Sensors with different core geometries are also analyzed for the optimization of directionality.**

Key words – fluxgate, magnet, modeling, sensor

I. INTRODUCTION

Fluxgate sensors are one of the most versatile magnetic field sensors, which are extensively used for various defense and industrial applications[1]. These sensors fill the gap between low sensitivity solid-state sensors (like Hall affect based sensors) and high quality but very expensive and fragile, quantum affect based sensors (SQUID).

The main advantages of fluxgate sensors are:

- High sensitivity (upto 1nT)
- Linearity and stability
- Reliability
- Ruggedness and simplicity
- Economical operation

Fields ranging from nT to mT cover a wide range of critical applications, applying from space navigation to medical applications. Thus, there is keen interest to develop a sensor that can sense these fields both economically and effectively. Also, since magnetic field as a vector quantity has both magnitude and direction, a sensor which offers both high sensitivity and high directionality is very desirable. Several papers have been presented over the fluxgate sensors, reporting sensitivities between several μT to mT [2], [3], [4].trifon M. Liakapolous in his work at the University of Cincinnati emonstrated the feasibility of a micromachined fluxgate sensor on silicon, fabricated using UV-LIGA lithography and lectroplating process [5],[6],[7]. Abdur Rahman Rub, from University of Cincinnati, has also explored the affect of 4 core dimensions on sensor sensitivity and directionality for rectangular core sensors [8],[9].

In this paper, these sensors have been simulated and optimized for attaining better sensitivity and directionality. Excellent matching between simulated in this work and measured in above researches values has been achieved and minimum current requirement for operation of the sensor has also been attained.

II. THEORY OF SENSOR OPTIMIZATION

Now if we consider ring core geometry, we can consider the various parts of the magnetic core as serially connected magnetic components[10].So instead of saturating complete core to block the external magnetic field we can saturate just a part of it, from which external field flows. Figure (1),(2) shows the arrow plot for external field through magnetic core. It can be observed that flux is entering through Arm 1 and passing through Arm 2 & 3 and moving out of the core from Arm 4,

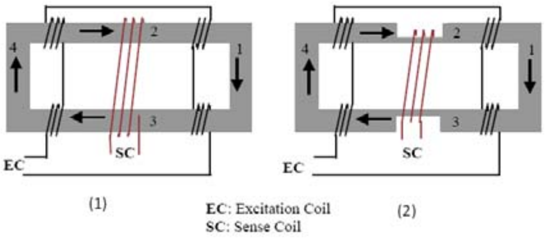


Figure 1, 2. Schematic of ring-type fluxgate sensor: (1) Original design and (2)Modified design

So instead of saturating complete core, if we just saturate a part of arm 2 & 3, it would not allow external flux to pass through these arms, as various parts of Arms 2 & 3 are serially connected. In this case, just by saturating a part of fluxgate, we can achieve proper functionality of fluxgate. Figure (3) shows the schematic new design.New design can be analyzed as follows Reluctance of a magnetic path is given by

$$R_L = l_m \mu / A \tag{1}$$

Where R_L is reluctance, l_m is magnetic path length and μ is permeability of the core, Now for Arm 2 & 3, magnetic paths are :

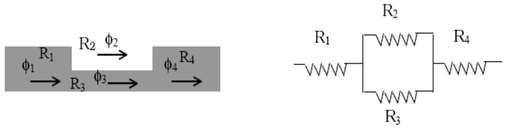


Figure 3. Magnetic paths and flux distribution in the modified design

Since these parts are series connected, so net flux will be the same,

Since R_2 and R_3 are in parallel,

The flux through them, will be

$$\phi_2 = \phi_3 R_3 / (R_2 + R_3)$$
$$\phi_3 = \phi_2 R_2 / (R_3 + R_2) \quad (2)$$
$$\phi_3 / \phi_2 = R_2 / R_3 = \mu_r (A_3 / A_2)$$

Now since $\mu_r \sim 1{,}000$ and even if $(A_3 / A_2) \sim 50$

We can say that,

$$\phi_3 >> \phi_2 \quad (3)$$

We see at figure (4), most of the flux will passing through the core and not through the air gap and we can neglect ϕ_2

Figure 4. Actual flux distribution in the modified core

So for this distribution:

$$\phi_1 \approx \phi_3 \approx \phi_4 \quad (4)$$
$$B_1 A_1 = B_3 A_3 = B_4 A_4^{\cdot}$$

If we assume that $A_1 / A_3 = K$

$$B_3 = K \times B_1 \quad (5)$$

The above equation shows that in second portion of the core, magnetic field strength (B)is K times higher than the other portions of the core, i.e. this portion of the core can be saturated by generating K times less flux in the other areas of the core.

Since ϕ = MMF/ magnetic path length

$$BA = NI / Lm$$
$$\Rightarrow B \, \alpha I_{applied} \quad (6)$$

So this portion of the core can be saturated by applying K times less excitation current.Sensor sensitivity depends upon the external flux passing through the sensing coil along the sensor axis. Sensitivity of the sensor will be comparable to the original structure as net exteral flux passing through the sensing coil is almost same (external flux is captured by the ends of Arm 2 & 3, which have the same area as of original design) ,though the excitation current requirement has been reduced by a factor of K. The above results are valid only for the following assumptions:

- Fringing flux through the air gap is negligible
- Demagnetization at the corner of the groove is also negligible.

III. SIMULATION AND MODELNIG SENSOR

In this research, I have also tried to study the result of above mentioned theory by simulating this sensor. MEMS-based Fluxgate sensors have been modeled via the finite element method using Infolytica’s MagNet 6.0 software. MagNet is an FEA program designed specifically for modeling magnetic devices. It is a simple, yet powerful tool for determining magnetic fields, forces, and device parameters such as the inductance of coils. figure (5) shows the sensor model used for the simulation. simulation model has 36 turns of excitation coil and 12 turns of sensing coil.Excitation coil has been modeled as four series connected coils, each having 9 turns.

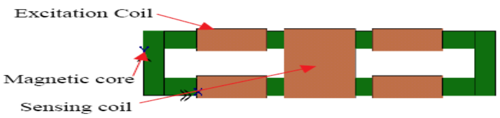


Figure 5. Ring-type fluxgate sensor: Simulation model.

We have simulated different sensor cores and compared the magnetic flux at those, for the same excitation current. The following figure shows our preliminary 300 □m core thickness sensor and the flux distribution, when 250 mA of excitation current is applied in the excitation coils. It can be observed that core is saturated for this current (For Ni-Fe permalloy core, saturation magnetization has been defined as ~ 0.86T) as we can see in figure(6):

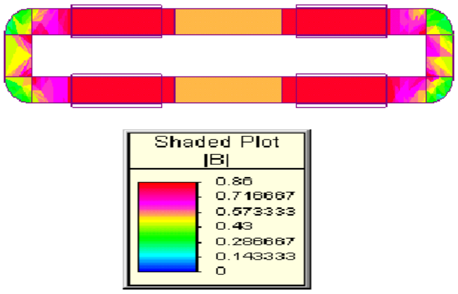


Figure 6. Field distribution along conventional core geometry, it requires 250 mA of current to saturate the core.

When the excitation current is reduced to 50 mA., flux has also been reduced to 0.20 Tesla and the core is no longer saturated as we can see in figure(7):

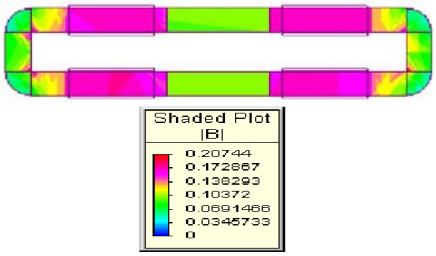


Figure 7. Field distribution along the core at 50 mA of current, core is no longer saturated.

In order to investigate the optimum design, geometries with different kinds of grooved structure have been simulated.Each geometry has the dimensions as shown in figure (8). Only the shape of grooved section has been changed.

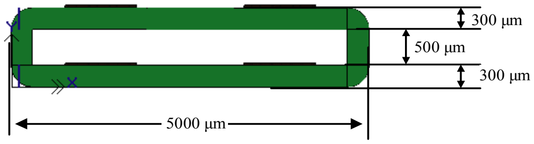
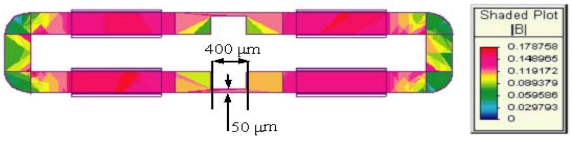
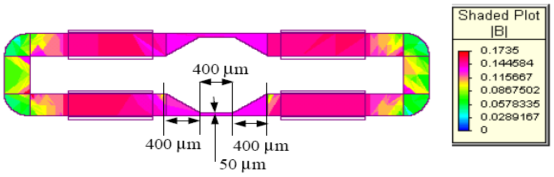


Figure 8. Sensor core dimensions

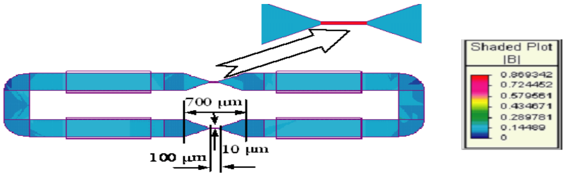
Simulation results for different geometries are shown in figures (9) , (10) and (11). in these simulations, we have for the all same excitation current (50 mA) .



(9)



(10)



(11)

Figures 9 , 10 , 11. Simulation results for different geometries with excitation current (50 mA).

Field distribution of optimum core geometry at 50 mA of excitation current,core gets saturated (0.86T).

The following figure(12) shows the simulation model used for the new core geometry.

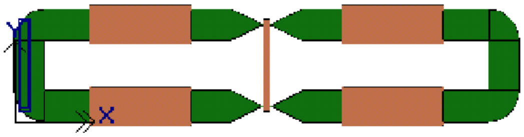


Figure 12. Simulation model of the new core geometry.

The following graph shows the simulated new sensor output for different external magnetic fields as we can see in figure(13):

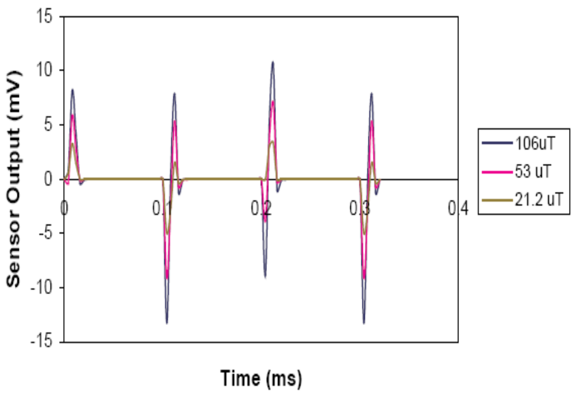
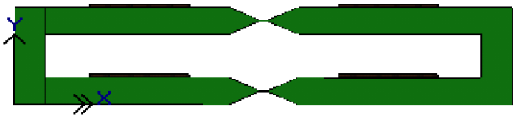


Figure 13. Simulated sensor output for new core geometry at different external fields

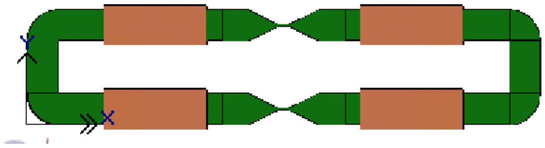
IV. DIRECTIONALITY OPTIMIZATION

In this work, directionality of the sensor has been defined as the change is sensor output as the sensor is rotated a unit degree along its axis. Directionality is directly related to percentage change in external field component along the sensor axis as the sensor is rotated.If for a given geometry, percentage variation of the field along the sensor axis is higher as the sensor is rotated, that geometry will offer higher directionality. For directionality optimization, we have considered following figure 14 different geometries and have investigated the field along the sensor axis, as the sensor is rotated.

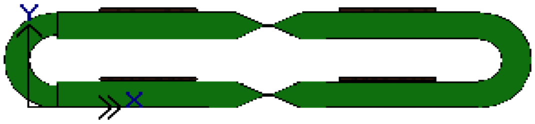
Rectangular



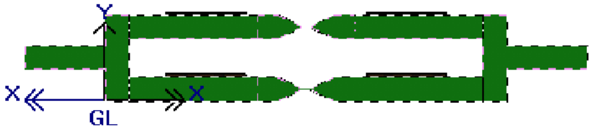
Curved Corners



Semi-Circular Ends



Rectangular Flange



Triangular Flange

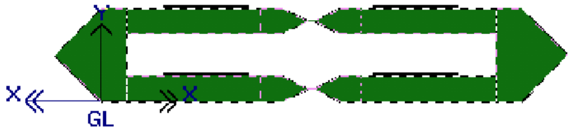


Figure 14. Different core geometries considered for directionality optimization.

The following graph shows in figure (15) the variation of external magnetic field along the sensor axis for different geometries, as sensor is rotated.

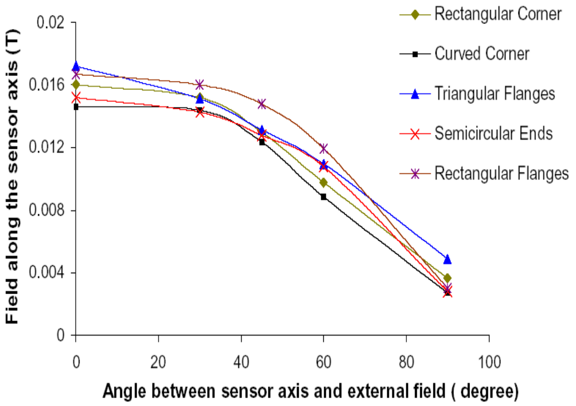


Figure 15.Simulated external field variation along the sensor core for different geometries as sensor is rotated along its axis.

After analyzing different geometries, we observed that rectangular flange geometry offers slightly better directionality in comparison to triangular flenges, but their response is not linear. On the other hand, triangular flanges offer almost same directionality, but their response is more linear.as we can see in figure (16).

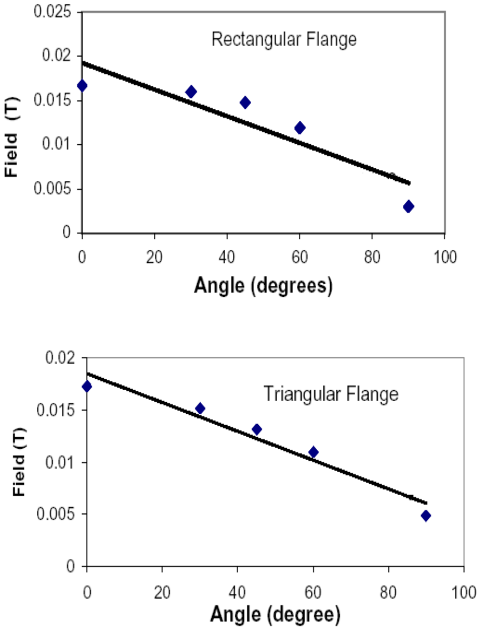


Figure 16. Simulated external field variation along the sensor core for rectangular and triangular flanges.

Since for directional application, linearity is very important, we have further explored triangular flange geometry. Figure 17 shows the variation of field as the sensor is rotated for different flange lengths. We can see that, directionality is increasing with increase in flange length.

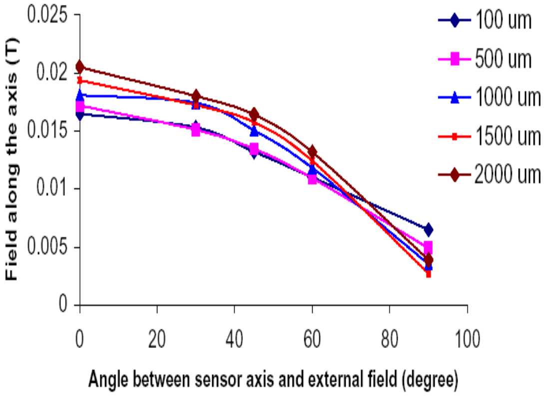


Figure 17. Variation of external field along the sensor axis as sensor is rotated along its axis for different triangular flange lengths.

V. CONCLUSION

Different core geometries have been analysed for a new sensing approach, where instead of saturating the complete a core, only a part of core is saturated. This new approach has resulted a drastic reduction in operating current requirements (50 mA instead of 250 mA) and power consumption. This suffices the main objective of this research, to achieve high sensitivity at low operating current, so that integrated sensors can be realized over a CMOS chip. Different core geometries have also been analysed for directionality optimization. Sensor core with triangular flanges at the core end has been observed as the most optimum geometry for the directional applications.

So i have come to the conclusion that by this new design, excitation current has reduced five times, which can reduce power consumption almost 25 times and sensor output increases as external magnetic field increases. and this core have been optimized for directionality.

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