

Systematic Method of Measuring and Evaluating Sensitivity and Linearity of a Micro-Fluxgate Sensor

Jiri Maier¹, Pavel Ripka¹, Poki Chen²

¹ Czech Technical University in Prague, Technická 2, 160 00 Prague, Czech Republic

² National Taiwan University of Science and Technology, Taipei City 106335, Taiwan
maierjir@fel.cvut.cz

Summary:

We describe a rigorous method of measuring open-loop sensitivity of a fluxgate sensor. The most important aspects are to ensure that the applied magnetic field lies inside the linear range and select the optimal phase at which the output voltage is detected. The phase and open-loop sensitivity are required to correctly calculate the noise of the sensor, which is a very important characteristic.

Keywords: Fluxgate, micro-fluxgate, magnetic sensor, measurement, open-loop sensitivity

Introduction

Fluxgate sensors are widely used in various applications, such as navigation, geophysics, and industrial automation. The principle of their operation is based on the saturation of a magnetic core by an alternating excitation field and measuring an induced voltage in a pick-up coil. Voltage signal proportional to the measured field is detected at even harmonics of the excitation frequency.

Important parameters of a fluxgate sensor are the sensitivity and noise. While open-loop sensitivity is not critical for closed-loop sensor operation, its value is required to correctly calculate the noise.

Our team focuses on miniaturization of fluxgate sensors using microfabrication technology. Our first-generation design was published in [1]; with following design improvements published in [2]. Comparing different designs requires a robust approach to conducting automated measurements and evaluating important characteristics.

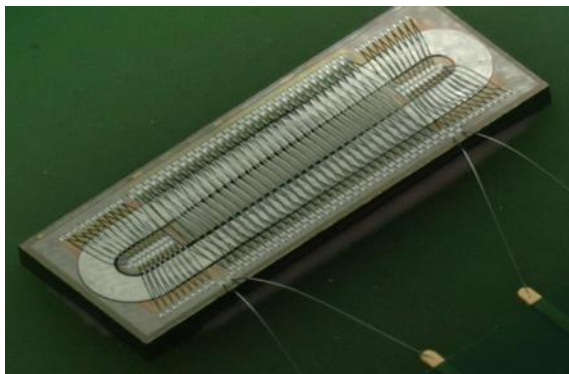


Fig. 1. Micro-fluxgate with racetrack core and solenoid coils made using wire-bonding [1]

Measurement setup

Lock-in amplifier is used to measure the output signal (pick-up coil induced voltage). Excitation current is used as the reference signal. For simplicity, sinusoidal excitation signal is used in the following example. Excitation signal parameters are 1 MHz, 40 mA, which is an optimum operating point of the used sensor.

Sensitivity Measurement

Measurement of fluxgate's sensitivity requires placing the fluxgate in a known magnetic field. The basic method of doing that is to place Helmholtz coils in such way, that the horizontal component of Earth's magnetic field is perpendicular to the axis of the coils, so that the field is zero in the coils' direction. A current is then passed through the coils to create the desired field. The sensitivity will then be the output voltage divided by the applied field.

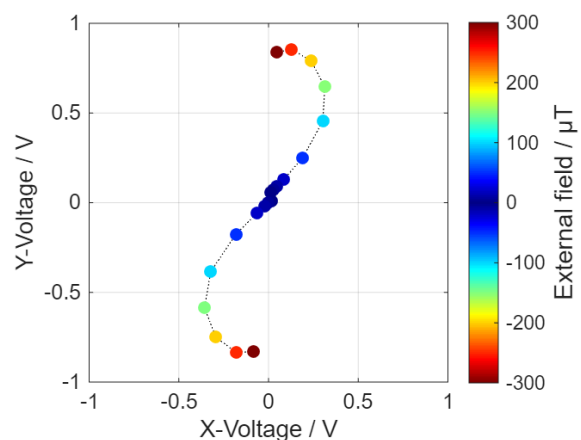


Fig. 2. X and Y components of the induced voltage at 2nd harmonic in pick-up coil for applied external fields in range $\pm 300 \mu\text{T}$. Results are composed of positive and negative halves, measured separately.

Selecting the strength of the field is a peculiar task. The Earth's field might not be perfectly zeroed out in the sensitivity axis, and the fluxgate might have some offset. When the applied field is low, those inaccuracies cause high relative error. On the other hand, if the applied field is large enough for the offset to be neglected, it is possible that the field is outside the linear range.

Figure 2 shows results of such measurement. We can see that the phase of the output is constant up to around 50 μT and then it starts changing dramatically. The magnitude is also not linearly dependent on the field for larger fields.

There is a distortion or discontinuity at the plot's origin (zero field). This is caused by the positive and negative half being measured separately, while environmental conditions might have slightly changed in-between. It would be more suitable to cover the low-field range by continuous measurement.

An Alternative Approach

Instead of placing the Helmholtz coils perpendicular to Earth's field, we can place them parallel to its horizontal component. The field created by the coils will then oppose Earth's field. This way, we can smoothly transition between negative and positive direction of applied field without swapping polarity of the Helmholtz coil current.

This way, we also get rid of any possible cross-field effects (there is no field perpendicular to the fluxgate's sensitivity direction in the horizontal plane.) We still have the vertical component of Earth's field, but this should not have any effect, as the thin flat core [2] has very high demagnetization factor in the vertical direction.

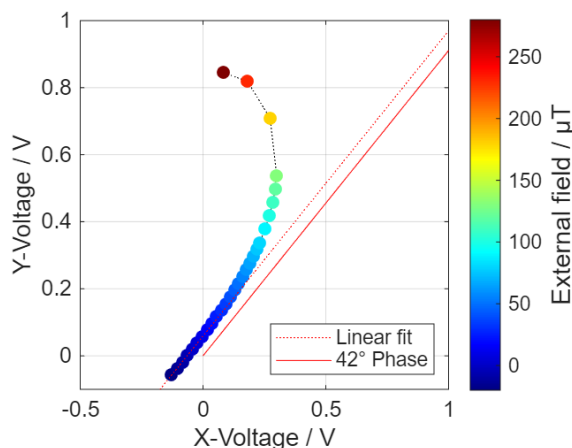


Fig. 3. X and Y components of the induced voltage at 2nd harmonic in pick-up coil for applied external fields in range 0 to 300 μT biased by 20 μT Earth's field

Figure 3 shows the results. With the horizontal component of Earth's field being approximately 20 μT at the location (Prague), the applied field can be swept from -20 μT to any positive value, giving us a continuous ± 20 μT interval where we

can linearly fit the data and obtain the phase of the useful signal, which in this case is 42°.

By projecting the data onto the 42° phase (rotate by -42° and use the new X), we obtain the relation between field and voltage, from which we determine the sensitivity, as shown in Figure 4.

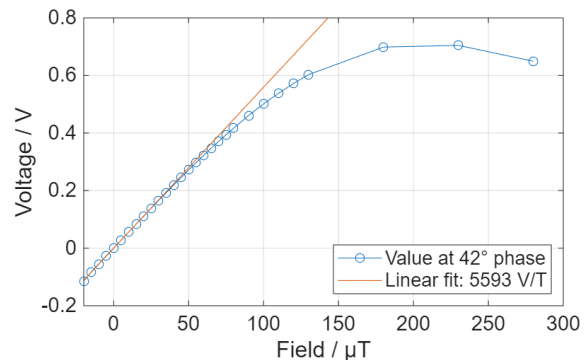


Fig. 4. Linear dependency of signal at the previously determined phase on the external (measured) field.

Conclusion

We presented a systematic method for measuring the open-loop sensitivity and linearity of a micro-fluxgate sensor. By aligning the Helmholtz coils parallel to the horizontal component of Earth's magnetic field rather than perpendicular to it, we achieved a continuous sweep through both polarities of the applied field without reversing the coil current. This eliminates discontinuities near zero field and does not require manually swapping polarity of the power source, which makes it suitable for automated measurements.

The method allows reliable determination of the signal phase within the linear range. Projecting the lock-in output onto this phase yields a clean linear relationship between the applied field and the output voltage, from which the sensitivity is easily determined. Crucially, the exact value of the Earth's field bias does not need to be known, since sensitivity is determined from the slope of the fit rather than its constant term.

The described approach is well suited for automated characterization of multiple sensor designs, enabling consistent and reproducible comparison. Accurate knowledge of both the sensitivity and the detection phase is essential for correctly computing the sensor noise, which is the main figure of merit in our ongoing miniaturization effort.

References

- [1] J. Maier, P. Ripka, P. Chen, CMOS-based micro-fluxgate with racetrack core and solenoid coils, *Sensors and Actuators A: Physical* 379, 115886 (2024); doi: 10.1016/j.sna.2024.115886
- [2] J. Maier, P. Ripka, P. Chen, High-Frequency Low-Power Microfluxgate, *IEEE Sensors Letters* 9, 1-4 (2025); doi: 10.1109/LSENS.2025.3585367