Pulse Excitation of Micro-Fluxgate Sensors

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Abstract—Miniature fluxgate sensors with symmetrical closed core elements on both sides of the planar coils were manufactured using standard microtechnology. The new sensors have shown substantial improvement over the standard single-sided microfluxgate sensors: for the same field range the sensor noise was reduced 10-times to 20 nT rms (20 mHz...10 Hz) and the perming suppressed below 5 µT, for field shocks of 6 mT. The maximum sensitivity for sinewave excitation was 32 V/µT for 1 MHz frequency and 200 mA p-p excitation current amplitude. Pulse shape of the excitation current allows use of high current peaks to suppress perming, while the rms value is low. Using a 20% duty factor squarewave excitation with 180 mA p-p amplitude, the sensitivity was twice that of the sinewave excitation, while the chip temperature dropped from 80°C to 40°C.

Index Terms—Fluxgate, magnetic field sensors, magnetometers, microfluxgate.

I. INTRODUCTION

TRADITIONAL fluxgate sensors are popular for measuring the magnetic field in the range of 1 nT to 1 mT. They can reach better than a 0.1 nT resolution and high precision such as 10 ppm linearity error and 30 ppm/°C temperature coefficient of sensitivity. These devices need to be manually adjusted and individually calibrated which causes manufacturability issues, and leads to expensive devices [1], [2].

Many applications require cheap sensors or sensor arrays with a 10 nT to 1 nT resolution. These include magnetic ink reading, detection of ferromagnetic objects such as weapons and vehicles, reading of magnetic labels, magnetic 3-dimensional position tracking for virtual reality systems and robots [3]. Some of these applications can be successfully addressed by ferromagnetic magnetoresistors: commercially available AMR with flippin and newly developed linear GMR with a AC bias [4]. But there is still a strong demand for development of cheap and small vectorial magnetic field sensors, which could offer better accuracy than magnetoresistors.

Microelectronic technology has already been used to lower the production cost and further decrease the size of the fluxgate sensors. The first approach is to replace the excitation and

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practically does not influence the apparent permeability, which is mainly given by the core geometry.

The technical details of the new sensor are:

- **Chip size:** 2.5 mm × 4 mm
- **Core material:** NiFe (electroplated)
- **Core thickness:** 4 μm
- **Core size:** 700 μm × 1 mm × 2
- **Coil pitch:** 15 μm width/5 μm space → 20 μm pitch
- **Coil thickness:** 3 μm
- **Coil turns:** 40 each for pickup and excitation

**III. Excitation**

Micro-fluxgate sensors should be excited at a high frequency in order to increase their sensitivity, which is low as the number of turns of the sensing coil is limited. The sensor parameters for sinewave excitation were described in [11], [12]. Maximum sensitivity of 32 V/T was reached for 1 MHz, 220 mA p-p excitation. The linear range in the open-loop was 1 mT, the hysteresis was 2.5 μT (compared to 30 μT for the single-core sensor) and also perming was reduced from 50 μT to 5 μT (for 6 mT field shock in any direction).

The main drawback of the new sensor is the high resistance of the excitation coil, which is given by the technology used. When excited by a high amplitude sinewave, the sensor chip is excessively heated which results in nonstability of its characteristics and also in limited reliability.

Use of short pulses for excitation allows us to decrease the current rms level and thus the heating, while the current amplitude can even be increased, which was shown to reduce noise and further suppress the perming. Using a 20% duty factor squarewave excitation and 180 mA p-p, the sensitivity was twice that of the sinewave excitation, while the chip temperature dropped from 80°C to 40°C. Symmetrical driving circuits and good impedance matching was necessary to prevent reflected waves and distortion of fast signals caused by the parasitic capacitances.

The principle diagram of the excitation power stage is shown in Fig. 2. The bridge made of low on-resistance and fast Hexfet transistors is controlled by two squarewaves in anti-phase. Supplying the sensors through normal shielded cable brings problems with reflected waves and ringing. This can be solved either by placing the power stage into the sensor chip, or by using a fully balanced connection by two coaxial cables and terminal resistors. The correct current waveform for sensor supplied by a 1.5 m long cable is shown in Fig. 3(a). Fig. 3(b) shows the sensor output for a zero measured field. The ringing at high frequencies caused by parasitic capacitances is easily filtered off by processing circuits.

**IV. Measured Values and Discussion**

The double-side sensor properties for excitation current in the form of short pulses with variable duty factor, amplitude and repetitive frequency were measured. Here are presented only the results for the optimum repetitive frequency of 500 kHz.

The sensor output was measured by SR 844 RF lock-in amplifier SR 844 with a reference adjusted to 1 MHz (2nd harmonics).

This instrument has a switching-type detector, so it is sensitive also to odd harmonics of the reference, i.e., to 6th, 10th, ..., harmonics of the excitation frequency.

Fig. 4 shows the high-field characteristics of the sensor supplied by a 20% duty-factor squarewave for several values of the excitation current rms value. The linear range was 0.5 mT which is a surprisingly lower value than for sinewave excitation. The sensor sensitivity and chip temperature as a function of the excitation current rms value are shown in Fig. 5. 55 mA rms excitation was selected as an optimum. Fig. 6 shows the sensor...
Fig. 5. Sensitivity and chip temperature as a function of rms value of the excitation current (500 kHz, 20% duty factor squarewave).

Fig. 6. Sensitivity and chip temperature as a function of the duty factor (500 kHz, 55 mA rms squarewave).

V. Conclusion

Pulse excitation improves the properties of the micro-fluxgate sensors. Even the sensors manufactured in low-cost technology, with a thin metallic layer can be excited by strong peaks, which reduce the perming and noise. The sensor sensitivity can be increased by lowering the thickness of the permalloy layer, which would simultaneously reduce the sensor range.

The presented microfluxgate sensor works in the open loop, which limits the achievable linearity to about 1%, still enough for many monitoring and industrial applications. In general, the advantage of using feedback in flat-coil sensors is questionable, as the compensation field is nonhomogeneous.

Pulse-excited 2.5 mm × 4 mm microfluxgate sensor with double layer permalloy has 20 nT rms noise, 2.5 μT hysteresis in 1 mT range and 5 μT perming error for 6 mT field shock. The power consumption can be lowered by increasing the thickness of the metallic layer.

REFERENCES