Orthogonal fluxgate employing discontinuous excitation

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In this work, we suggest a new method for the reduction of the power consumption of an orthogonal fluxgate employing an amorphous wire. In order to reduce the power consumption, we introduce idle intervals in the fluxgate excitation. In fluxgates where the excitation current is applied directly to the wire core, the excitation wave form can easily be manipulated due to the very small impedance of the wire core. The resulted discontinuities in the excitation increase the fluxgate noise by a factor of about 3.5. In order to eliminate this excess noise, we simply discard the data related to the excitation idle intervals from the signal processing of the fluxgate output. As a result, we have reduced the fluxgate power consumption by a factor of 16, from 6.4 mW at 100% duty cycle down to 0.4 mW at 6.25% duty cycle. It is important to note that the reduction of power consumption is obtained without decreasing the fluxgate resolution. © *2010 American Institute of Physics*. [doi:10.1063/1.3360632]

I. INTRODUCTION

Fluxgates are the most frequently used room-temperature magnetometers due to their high resolution, high thermal stability, and small size.[1] However, their relatively high power consumption impedes their use in micropower applications.

The most power consumed by fluxgates can be related to their excitation. A radical way to reduce the power consumption is to employ a discontinuous excitation, where the excitation is present only during relatively short active intervals and is absent during relatively long idle intervals. Such an excitation may be especially effective in applications where it is unnecessary to measure the magnetic field continuously. For example, in many mobile applications, most of the time the fluxgate may sample the environment at a low rate while in the case of an event a higher rate can be employed.

It is known that discontinuities in the excitation increase the fluxgate noise. However, existing literature[2–7] does not suggest thorough quantitative analysis of this phenomenon. In this study, we bridge this gap and analyze the noise level of an orthogonal fluxgate employing discontinuous excitation. Moreover, we suggest a method for eliminating the excess noise caused by the excitation discontinuities.

II. NOISE MEASUREMENTS AND ANALYSIS

A. Orthogonal fluxgate

Our experimental model of the fluxgate comprises (see Fig. 1) a U-shape Co-based amorphous wire (AC-20 type made by Unitica) of a 120 μm diameter, 50 mm length, and a sensing coil with 180 turns of a 45 μm copper wire. The excitation current is applied directly to the fluxgate wire core and the output voltage is measured by the sensing coil. The output voltage is measured at the harmonics that provides highest sensitivity. We employ ceramic isolators (see Fig. 1) in order to thermally stabilize the fluxgate. We have selected for our experiments the above fluxgate type because its wire core impedance is very low, thus, the excitation current can easily be manipulated.

The fluxgate core is excited by a TTI TG4001 arbitrary function generator. The external magnetic field is applied to the fluxgate by a calibrated solenoid. The fluxgate and the solenoid are placed inside a three-shell closed magnetic shield to reduce the ambient magnetic noise. The fluxgate output is sampled by an NI PXI-4461, 24 bit, 204.8 kSps data acquisition module, which is connected to the fluxgate output through a low noise BB INA103KP instrumentation amplifier. The data sampling is synchronized with the PXI data acquisition clock. All the measurements are post processed using NI LABVIEW software.

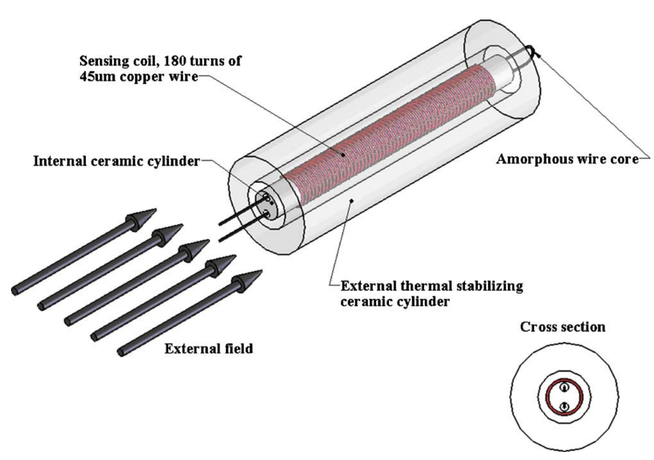

FIG. 1. (Color online) Orthogonal fluxgate employing an amorphous wire.

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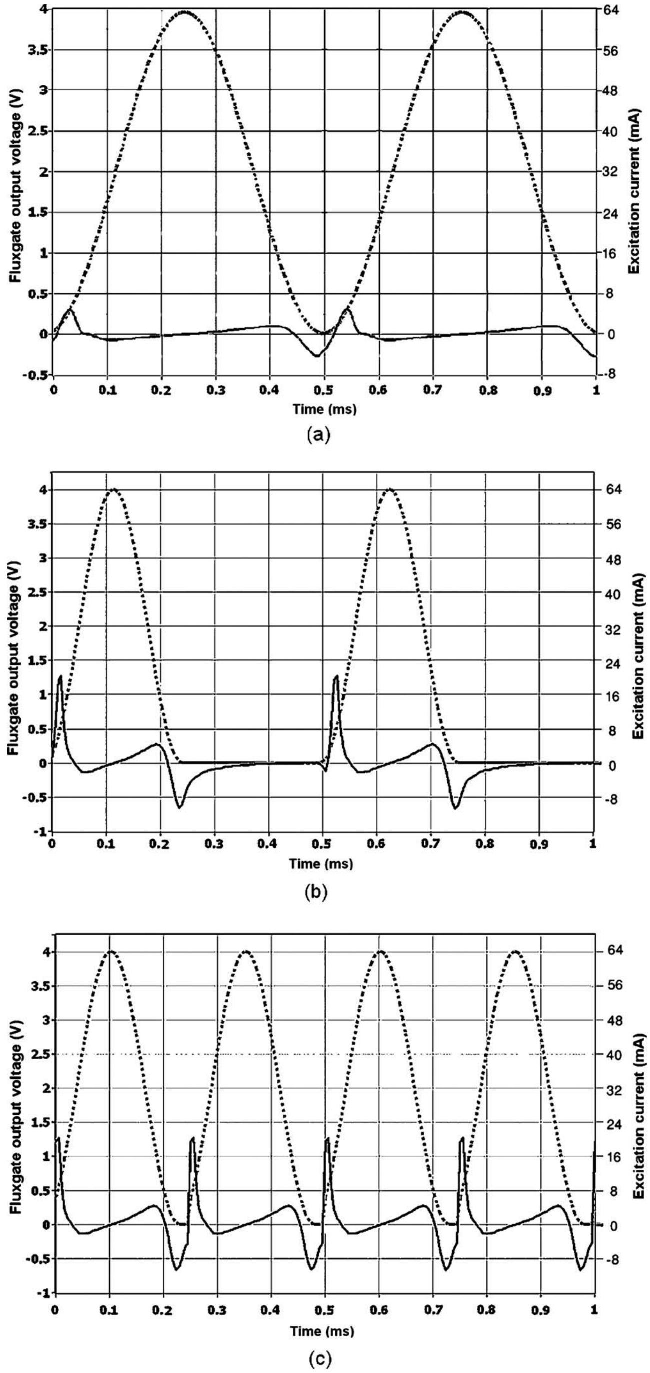

FIG. 2. Fluxgate output signal (the solid curves) and the excitation current (the dashed curves) in different excitation modes. (a) Continuous excitation (100% duty cycle). (b) Discontinuous excitation (50% duty cycle). (c) Discontinuous excitation (50% duty cycle) after discarding the data related to the idle intervals.

B. Excitation wave forms

Since the fluxgate noise level in the unipolar excitation mode[8] [see Fig. 2(a)] is lower than in the bipolar mode,[9,10] we analyze the fluxgate noise for the unipolar excitation only. We keep the period of the excitation constant (0.5 ms) and, in order to change the duty cycle, introduce idle time intervals as shown in Fig. 2(b). The excitation wave form in the active intervals is the minus cosine plus a dc bias that is equal to the cosine amplitude. In the idle intervals the excitation is zero. The minus cosine ac part of the excitation is

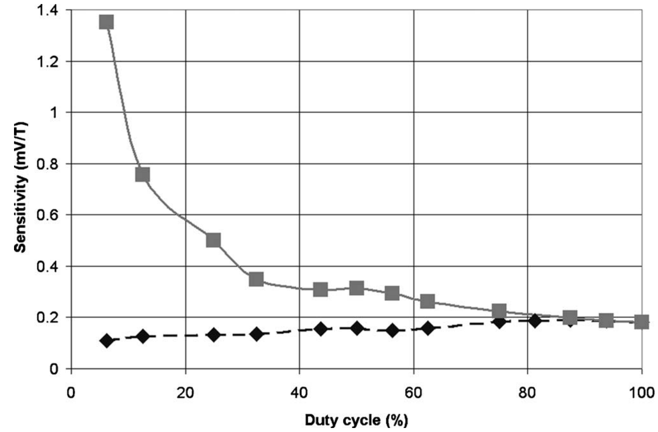

FIG. 3. Fluxgate sensitivity as a function of excitation duty cycle. The dashed curve represents the fluxgate sensitivity without eliminating the data related to the idle excitation intervals [see Fig. 2(b)]. The solid curve represents the fluxgate sensitivity after omitting the data related to the excitation idle intervals [see Fig. 2(c)].

chosen to smoothen the transitions between the active and idle excitation intervals. By reducing the excitation duty cycle from 100% to 6.25% we increase the effective excitation frequency $f_x=1/t_a$, where t_a is the duration of the active excitation intervals, from 2 to 32 kHz.

C. Noise measurements

To calculate the noise at the fluxgate input, we first have measured the fluxgate sensitivity. The sensitivity has been measured at the effective excitation frequency f_x. The measured sensitivity is presented by the dashed curve in Fig. 3. As one can see from Fig. 3, the fluxgate sensitivity slowly decreases with decreasing the duty cycle, despite increasing f_x. This is so because the fluxgate output averaged over the entire excitation period decreases with decreasing the duty cycle and increasing the excitation idle intervals.

Dividing the noise at the fluxgate output by the fluxgate sensitivity, we have obtained the noise at the fluxgate input. This noise as a function of the excitation duty cycle is rep-

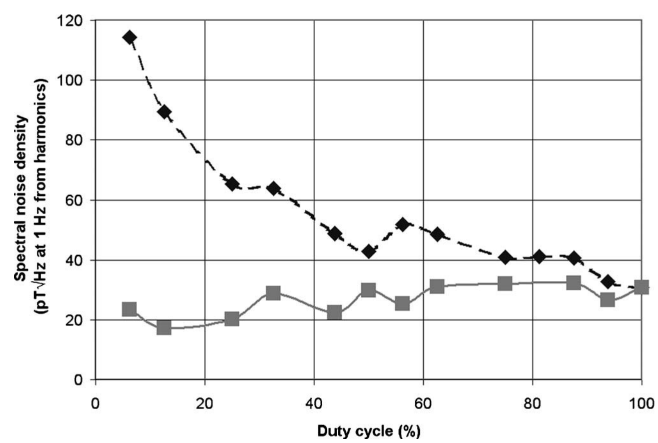

FIG. 4. Fluxgate noise density referred to the fluxgate input as a function of the excitation duty cycle. The dashed curve represents the fluxgate sensitivity without eliminating the data related to the idle excitation intervals [see Fig. 2(b)]. The solid curve represents the fluxgate sensitivity after omitting the data related to the excitation idle intervals [see Fig. 2(c)].

resented by the dashed curve in Fig. 4. One can see from this figure that the fluxgate noise significantly increases with decreasing the duty cycle. For an example, when the duty cycle decreases from 100% down to 6.25%, the noise increases by a factor of 3.5.

To find a possible physical reason for the above excess noise, we note that the only difference between the continuous and discontinuous excitation modes is in the time periods where no excitation field is applied to the amorphous wire [see the excitation wave form in Figs. 2(a) and 2(b)]. In the continuous excitation mode this time periods are infinitely short. As a result, the magnetic domains are always forced (to a greater or lesser extent) to be aligned in a given direction. In the discontinuous mode, the time periods where no excitation field is applied to the material are relatively long. Thus, the magnetic domains have an opportunity to relax.[11] Since the domain relaxation is a stochastic process, it may generate the excess magnetic noise.

III. METHOD FOR ELIMINATING THE EXCESS NOISE

In order to eliminate the excess noise, we suggest discarding the idle intervals from the signal processing of the fluxgate output. In order to verify this idea, we recalculated the noise at the fluxgate input after omitting the data related to the idle intervals in the excitation [see Fig. 2(c)]. As in the previous case, we first have measured the fluxgate sensitivity as a function of the duty cycle (see the solid curve in Fig. 3). One can see from this figure that, in contrast to the previous case, the fluxgate sensitivity increases with decreasing the duty cycle. This is so because the effective excitation frequency f_x increases and there are no "idle intervals" in the fluxgate output (no loss in the averaging of the fluxgate output).

Dividing the noise at the fluxgate output in Fig. 2(c) by the fluxgate sensitivity, we have calculated the noise at the fluxgate input (see the solid curve in Fig. 4). One can see from Fig. 4 that at low duty cycles the fluxgate noise remains at almost the same level compared to the continuous excitation mode (100% duty cycle).

The fluxgate noise spectrum is shown in Fig. 5. This figure illustrates the efficiency of the proposed noise reduction. One can see from Fig. 5 that the concatenation of the fluxgate output reduces the fluxgate noise (see the upper group of the curves that are measured without concatenation) down to the noise level measured at the continuous excitation (see the bottom group of the curves). For example, the fluxgate noise at 6.25% duty cycle measured with concatenation is much lower than the fluxgate noise measured at the same duty cycle after the signal without concatenation. There is almost no difference between the fluxgate noise measured at 6.25% duty cycle with concatenation and the noise measured at the continuous excitation. As a result it is possible to reduce the fluxgate power consumption, by reducing the excitation duty cycle, without decreasing the fluxgate resolution.

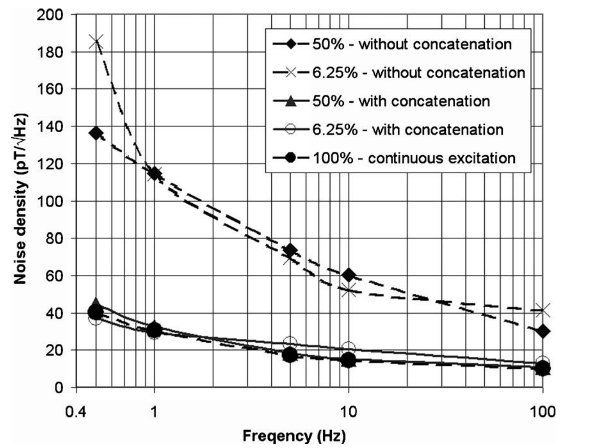

FIG. 5. Spectrum of the fluxgate noise referred to the fluxgate input.

IV. CONCLUSIONS

We have found that the power consumption of an orthogonal fluxgate employing an amorphous wire can be significantly reduced without affecting its resolution. The power consumption reduction is obtained by introducing idle intervals into the fluxgate excitation. In order to eliminate the excess noise caused by the discontinuous excitation, we have discarded the data related to the idle intervals from the signal processing of the fluxgate output. As a result, the fluxgate noise referred to its input remains at almost the same level compared to the continuous excitation mode, despite the increase of the excitation idle intervals.

Without the excess noise elimination, the fluxgate noise would increase by a factor of 3.5. Reducing the duty cycle from 100% to 6.25% corresponds to a 16-fold reduction in the power consumption: from 6.4 to 0.4 mW. Thus, our fluxgate provides a 20 pT/$\sqrt{}$Hz resolution (measured at 1 Hz) and a power consumption of 0.4 mW.

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