Author's response on *Interactive comment on "Possibilities of further improvement of 1-second fluxgate variometers" by Andriy Marusenkov*

Anonymous Referee #1

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Referee's comments

I have a few thoughts/questions/suggestions:

Page 2, lines 5-8 The described ring-core is relatively large with comparatively large magnetic material content. This added mass is a tried-and-true method for improving sensor performance. Cobalt is the typical primary material used in the best amorphous materials. A great deal more could be written here about the material and its process ing. I shall assume this is proprietary knowledge. That could be confirmed. It is long known that saturation induction or Curie temperature are both guides to noise performance. Would the author give guidance to readers by providing such data? If the Curie temperature is higher than 200C that would be welcome news.

Author's response

We collaborate with the research-and-production enterprise MELTA Ltd. - a local manufacturer of the amorphous magnetic alloys, which provides us both row and annealed materials. In our lab there is facilities for annealing small strips of the amorphous tape, that are suitable only for rod-core fluxgate sensors. For the ring-core sensor described in the manuscript we used the samples of the alloy heat treated by the manufacturer. I have added the reference, where the properties of the similar alloy are given, and have changed the text in the following way.

Author's changes in manuscript

"A modified version of the Co-based amorphous alloy MELTA® MM-5Co (Nosenko et al., 2008) with the Curie temperature T_C = 185°C and saturation induction B_s = 0.48 T was used as a magnetic core. The samples of this alloy were supplied by the manufacturer in the shape of 0.03 mm thick and 3 mm wide tape annealed at the temperature 710 K in the atmosphere of an inert gas. "

Referee's comments

The use of a fiberglass [and resin] bobbin implies the tape was heat treated prior to its assembly onto the bobbin as resin can't take the heat.

Author's response

Yes, it is true. We spool the annealed tape onto the core support.

Referee's comments

The temperature stability of fiberglass is generally large and indeterminate, so that could hinder the collection of good data, at least at the very longest periods. Does the author propose using fiberglass bobbins in final designs?

Author's response

The zero field temperature tests of the sensor with the fiberglass bobbin showed quite good results. In the final design we intend to keep the sensor core in the near zero field using separate feedback/compensation windings wound on mechanically stable materials. Perhaps, in this case the possible negative impact of the fiberglass support will be minimized.

Author's changes in manuscript

"During our tests of the described sensor in small fields (inside the magnetic shield or installing its sensitivity axis perpendicularly to the Earth magnetic field vector) we used the sectoral measuring windings as feedback ones. However, this way is not applicable for large magnetic field measurements, because in such case the compensation field would be considerably non-uniform and, probably, unstable with temperature and time. In order to solve this problem we are going to use these sensors as zero field indicators inside the vector compensation coil system similar to those used in space-born magnetometers (Auster et al., 2009; Nielsen et al., 1995). "

Referee's comments

The sectoral sense windings as described are difficult to imagine. Are they also used for feedback current? A photograph of the sensor would be helpful. If there are separate feedback windings their descriptions would be helpful too.

Author's response

The photograph of the sensor as well as connection diagram of the sense windings are provided. The text had been modified.

Author's changes in manuscript

"The 11 turns of this tape are spooled into the 32 mm diameter fiberglass bobbin that also serves as a support for the toroidally wound measuring and excitation coils (Fig. 1, a). The four sectoral coils, the opposite pairs of which are connected in series, form the two measuring windings for sensing orthogonal components of the magnetic field (Fig. 1, b). Such unusual construction of the measuring windings was selected mainly because we found experimentally that (for this kind of magnetic cores) it provides slightly better noise level in comparison with a traditional wrapping coil. The excitation winding consists of the two layers of 0.4 mm Cu wire and has small resistance, what is preferable for minimizing drive power consumption. ”

Referee's comments

The drive field amplitude of 6800 A/m is huge. Was this difficult to achieve?

Author's response

In order to achieve high drive field amplitude we used enlarged excitation winding with low resistance.

Referee's comments

The saturation fields of low noise ring cores can be a few 10s of A/m. Why so large a drive field?The 7.5 kHz drive frequency is fairly typical. Does the author have any thoughts about sensor noise vs drive frequency?

Author's response

It was out of the scope of this case study to discuss the dependence of the fluxgate sensors noise level on drive field parameters. I believe the large drive field is almost always useful for decreasing both the noise level and the perming effect. For instance, it is also stated in the Chapter 3.4 (Figure 3.7 at p. 92) of the book: “Musmann G., Afanassiev Y.V. (2010) Fluxgate magnetometers for space research. Books on Demand GmbH, Norderstedt.”
We tried different drive field parameters for the sensor FGS32/11 and found that the minimal noise level was achieved with the largest possible values of the amplitude and the relative width of the drive pulse.
Our experience with permalloy core fluxgate sensors confirms the fact reported by other researches (see Musmann G., Afanassiev Y.V. (2010), Chapter 3.6.1, Eq. 3.43), that the power spectral density of noise is inversely proportional to the drive frequency. However, for the described amorphous sensor we did not observe significant noise level difference changing drive frequency in the range f_{ex} = 5...12.5 kHz. Finally, the value f_{ex} = 7.5 kHz was chosen for better fit with existing electronics.

Author's changes in manuscript

“The sensor noise level was tested at different combination of the excitation parameters in the following ranges: the drive frequency f_{ex} = 5...12.5 kHz, the amplitude of the drive pulses Hm = 2...10 kA m^{-1}, and the relative width of these pulses α_{ex} = 0.2...0.5. The minimal noise level was achieved with H_m = 10 kA m^{-1} and α_{ex} = 0.5 at the expense of considerable power consumption $P_{ex} \approx 3$ W. The compromise values H_m = 6.8 kA m^{-1} and α_{ex} = 0.4 were finally selected. As there was no pronounced noise level dependence on the driving frequency, the intermediate value f_{ex} = 7.5 kHz was selected, that gives us possibility to drive two sensors simultaneously from a generator with a moderate output voltage $U_g = \pm 14$ V. ”

Referee's comments

Are there publications, either extant or planned, regarding the sensor development?

Author's response

We intend to publish more details regarding the sensor development after complementing the sensors by the compensation windings system and testing the full field instrument.

At the moment, there is the conference presentation, where the application of this sensor for measuring human cardiomagnetic signals was mentioned.

https://www.researchgate.net/publication/279526663_Improving_temperature_stability_of_the_1-second_fluxgate_variometer p. 19-20

Referee's comments

Page 2, line 28 "current-to-voltage converter" Is this correct?

Author's response

No, this is not correct. This typo is changed to "voltage-to-current converter".

Referee's comments

Page 3, line 11 It may be worth mentioning that the buried Zener voltage reference has a long history in magnetometry, going back at least to MAGSAT's use of the LM199 diode at the time from National Semiconductor, and later from Linear Technology. I believe that MAGSAT was also the first instance of a DCCS used in a feedback.

Author's response

I have tried to change the text following recommendations.

Author's changes in manuscript

"Due to lack of the experimental data on the low frequency noise spectral density, we did not include in the table the first buried-zener voltage reference LM199 designed by Robert Dobkin. This IC part was used by Acuna et al. (1978) in the outstanding MAGSAT magnetometer, which performance characteristics are still impressive. An indisputable leader within all specified parameters (that was also designed by Robert Dobkin) is the buried-zener voltage reference LTZ1000 (Harrison, 2009, p. 494) based on the subsurface Zener diode, which positive temperature coefficient is compensated by the negative coefficient of the forward-biased base-emitter voltage of the transistor located at the same substrate. "

Referee's comments

Page 3, line 25. "Linear Technology Corp., 2015" By coincidence as of last Friday [2017/03/10] the company Linear Technology Corp. no longer exists, as it was acquired on that date by Analog Devices. If Analog Devices runs true to form the technical documentation under the Linear Technology banner will all disappear. For future readers of this paper there should be a footnote or something that will guide the reader to Analog GID Devices for information regarding the LTZ1000 component.

Author's response

The proper remark had been introduced.

Author's changes in manuscript

"This product of Linear Technology (now part of Analog Devices) has also fairly weak dependence of the output voltage on the dose of radiation (Rax et al., 1997), which may be important for space application. "

Referee's comments

Page 4, line 6 Generally DAC based DCCS's are competing with pulse-width-modulation based DCCS's. An example of the latter is found in: http://www.geosciinstrum-method-data-syst.net/2/213/2013/gi-2-213-2013.pdf , which is but one example of this strategy. The author's thoughts comparing these two approaches, would be welcome.

Author's response

In my opinion, pulse-width-modulation DAC should be used in fluxgate magnetometers very carefully, because some unwanted and unexpected effects could appear due to aliasing of PWM DAC pulsations in a sensor. As far as I know, it is quite complicated task to build PWM DAC with 1 ppm stability and sub-ppm noise level. In the special cases, like radiation tolerant instruments, the PWM technique could be the only possibility. However, for ordinal conditions, in my opinion, it is better to use off-the-shelf monolithic DACs.

Author's changes in manuscript

"As a digital-to-analog converter, one of the best monolithic models – 20 bit DAC AD5791 with temperature drift 0.05 ppm $°C^{-1}$ – was selected (Egan, 2010). "

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