Response to Peer Review Referee Comments

Response to RC3 "Tesseract – A High Stability, Low-Noise Fluxgate Sensor Designed for Constellation Applications" by Kenton Greene et al. by an Anonymous Referee #3 on May 23, 2022:

We thank the referee for the constructive comments which we have incorporated into the manuscript. The referee raised an important issue about the description of the thermal testing procedure, which we address below. Referee comments are in plain text our responses in *italics* and any content added to or changed in the manuscript are in "*quoted italics*".

Specific Comments:

1. The references (Brauer et al., 1999; Miles et al., 2017) exploit some other approaches in comparison with that described in the manuscript. Brauer et al. (1999) used so-called "thin shell" calibration - the calibrating signals "were randomly distributed over shells of fixed field magnitudes". The data processing was also different – the overdetermined system of linear equations was solved for a parameters matrix by singular value decomposition. Miles et al. (2017) did not estimate orthogonality. In both references, a fluxgate magnetometer as a whole unit was calibrated, whereas the manuscript estimates the temperature characteristics of the feedback coils only, without magnetic cores inside.

It was not our intention to imply that the temperature test procedure described in section 3.2 uses the same methods as these previous experiments (Brauer et al., 1999; Miles et al., 2017). We agree with the reviewer that there are important differences between the calibration method presented in this paper and methods in previous temperature tests referred to: Miles et al. (2017). Brauer et al. (1999). While the temperature calibration test presented in this work draws form the designs of their experimental apparatus, we use different method to estimate sensitivity and orthogonality which address below in our response to comment #4.

We have made the following changes on lines 339-341 in order to clarify this: "This test usually requires sophisticated equipment. simpler, low-cost experimental setups have been created (i.e., Brauer et al., 1999; Miles et al., 2017) to calibrate a magnetometer using an insulated cooler filled with dry ice placed within some form of calibration coil. Here, we extend the method of Miles et al. 2017 to characterize both sensitivity and orthogonality"

The reviewer highlights another important distinction from the referenced experiments: the experiment described in this manuscript measures the temperature characteristics of the feedback coils only, without magnetic cores or driving fluxgate electronics.

We have changed the title of the section and added clarifying context in the opening paragraph of the section 3.2 and to highlight this important distinction in line 335: "Here, we describe a test to measure the sensitivity and orthogonality of the Tesseract sensor's feedback windings over temperature by temporarily configuring it as an air-core search coil magnetometer. This allows us to assess the temperature stability of sensor base and feedback windings without any dependence on cores or electronics."

2. Were the feedback coils used in the air-core search coil magnetometer to form feedback signals or to serve as sense windings? What was a sense winding in the first case? In the second case (the feedback winding is used as a sense one) the temperature dependence of the sensitivity or gain of such air-core search coil magnetometer was actually tested. The temperature stability of the fluxgate magnetometer's scale factor depends on the stability of the coil constant of the feedback winding. Is it assumed that the gain of the air-core search coil magnetometer based on the feedback winding depends on the temperature in a similar way as the coil constant of the feedback winding does?

We agree with the reviewer's remarks about the importance of distinguishing between Tesseracts sense coils and feedback coils. Unlike some other fluxgate instruments, such as the Ringcore design described in this paper, which use the sense winding to provide magnetic feedback, The Tesseract Sensor has purpose-built (Merritt Coil) windings to provide magnetic feedback and separate solenoidal windings (shown in figure 3) wound directly on the racetrack core bobbin to act as sense windings.

For temperature testing (Section 3.2), The feedback coils alone were used as an air-core search coil. It is assumed that the gain of the air-core search coil magnetometer based on the feedback winding depends on the temperature in a similar way as the coil constant of the feedback winding does once the cores are inserted since the dominant effect should be the coefficient of linear thermal expansion of the single-piece sensor base.

We have added text to address this in lines 138-140: "Production cores are interleaved with a polymer between the foil layers to prevent them from moving during the magnetizing drive pulses. A plastic lid closes the core and serves as a base upon which to wind a quasi-toroidal drive of AWG 32 magnet wire (Figure 2b). Finally, a solenoidal sense winding of AWG 34 magnet wire is wrapped around the bobbin"

We have made the following changes at the end of line 335 to make clear that this test is not a calibration of a full fluxgate (with cores and driving electronics) over temperature: "In this section, we describe a test to measure the stability of the Tesseract sensor's feedback windings over temperature by temporarily configuring it as an air-core search coil magnetometer to directly access the attributes of the sensor base and feedback windings without any dependence on cores or electronics."

3. The mutual orientation of the axes of the calibrating system and the device under test is not clear in Figure 9a. How accurately were aligned the magnetometer feedback coil axes with that of the Merritt coil system and what method was used to achieve this?

The Tesseract sensor was roughly aligned with the coil system by hand (i.e: X axis of the feedback coil was lined up with the X axis of the calibration coil system) and then rotated slightly until the measured signal was maximized in each axis. The maximum of the 10,000 nT applied field was found to within +/- 5 nT which corresponds to an alignment accuracy within +/- 1.8 degrees. This alignment is not critical to the calibration, as long as the sensor does not rotate over the course of the test, since we express changes in sensitivity and orthogonality with respect to a reference (i.e. The sensitivity measured at room temperature).

We have made changes on line 388: "The Tesseract sensor's axes are manually aligned with the coil system's axes (Figure 9b) and then slowly rotated until the measured 23 Hz signal is maximized in each axis. The sensor base is then firmly fastened to a mount, so that it does not rotate over the course of the test."

4. The equations (2), (3), and (4) for estimating sensor orthogonality have to be explained in detail or appropriate reference should be added. The way Equations (2), (3), and (4) for estimating orthogonality angles were derived is not clear. Why are these equations different for the XY pair and the XZ, and YZ pairs? How was the total magnitude (A) of the applied field calculated or measured?

We define the orthogonality angles based on figure 1 and equation 2 in Olsen et al. 2003. The equations (2) (3) and (4) are different for the XY pair because the *Olsen et al. 2003 convention define the x axis to be projection invariant, the y axis has a single degree of freedom in the XY plane, and the z axis has two degrees of freedom. We have also changed the notation to be in agreement with that in Olsen et al. 2003*

Line 419 has been changed to include this reference: "The Tesseract sensor's three orthogonality angles; the angles between the X and Y axes u_1, X and Z axes, u_2 and Y and Z axes u_3 as defined in (Olsen et al., 2003)"

We have added a new figure as Figure 11 (taken from Olsen et al. 2003 Figure 1 Left) that illustrates the definition of the three angles.

We have added a definition of the total magnitude (A) and a description of how it was measured. Lines 376-380 now reads: "A is the total magnitude of the applied field which is defined as $A = \sqrt{Xx^2 + Yy^2 + Zz^2}$, Where Xx is the field measured in the X axis when the coil system applies a field in the X axis and Zz is the measured field in the Z axis when the coil system applies a field in the Z axis. Figure 11b plots the change in these angles, u_1, u_2 and *u_3, over temperature."*

We have added text to the caption to Figure 11 to explain the differences between equations (2) (3) and (4) in this convention: "The equations (2) (3) and (4) are different for the u_1 because the *Olsen et al. 2003 convention define the x axis to be projection invariant, the y axis has a single degree of freedom in the XY plane, and the z axis has two degrees of freedom."*

Technical Changes:

1. Which component of the magnetic field generated by the feedback coil is presented in the color map in Figure 4a? Bx? It would be useful to clarify.

The magnetic field rendered in Figure 4 is generated by the x-axis feedback coil (Line 207). We have clarified this in the Figure caption as well in Line 203: "Here we show a render of the x axis feedback coil"

2. The length of the racetrack sensor is equal to 31.45 mm (Subsection 2.1, p. 5, line 132), but the Racetrack boundaries are equal to +/-14.5 mm in Figures 6, 7, and +/-15 mm in Figure 8.

The racetrack boundary line on Figures 6, 7, and 8 have been changed to the actual core length which is 31.45 mm long (or +/- 15.725 mm)

3. The last part of the caption of Figure 6: "...Configuration (b) was optimized for best homogeneity while sensor while (c) was chosen for good homogeneity with very low power consumption." Should it be "...Configuration (b) was optimized for best homogeneity within the sensor while (c) was chosen for good homogeneity with very low power consumption." or "...Configuration (b) was optimized for best homogeneity while sensor (c) was chosen for good homogeneity with very low power consumption."?

This has been corrected in the caption of Figure 6: "Configuration (b) was optimized for best homogeneity while sensor (c) was chosen for good homogeneity with very low power consumption.".

We have also added a sentence in the text to avoid misinterpretation of our prototype selection process: "Prototype #1 was lowest power consumption configuration; Prototype #2 was the low inhomogeneity and Prototype #3 was chosen for a balance of low inhomogeneity and low power consumption."