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ORIGINAL PAPER

A Comparative Study for Optimization of Sensitivity and Noise Levels in Race-Track Sensors

Emel Özkök[1,2] · Hava Can[1,3] · Fedai İnanır[2] · Uğur Topal[1]

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Abstract In this study, we have designed fluxgate sensors at race-track geometry which were used to measure DC or low-frequency magnetic fields. The type of core material and the number of core layers on the sensitivity and the noise level were specifically examined. We could achieve to get a sensitivity of 440 kV/T and a noise level of 56 pT/$\sqrt{\text{Hz}}$ at 1 Hz in a large dynamical range extending up to 1.5 Oe.

Keywords Fluxgate magnetometer · Race-track sensor · Sensitivity · Noise level

1 Introduction

An increasing demand of magnetic sensors gives rise to many studies in the improvement of sensor structures. Comparing other types of sensors, fluxgate sensors have much more advantages such as applications on large areas, having high sensitivity, low offset, and high temperature stability. These features ensure their continuous popularity since the 1930s.

✉ Uğur Topal
ugur.topal@tubitak.gov.tr

[1] TÜBİTAK-UME National Metrology Institute, P.K. 54, 41470 Gebze, Kocaeli, Turkey

[2] Physics Department, Yıldız Technical University, Davutpaşa, Istanbul, Turkey

[3] Physics Department, Gebze Technical University, Gebze, Kocaeli, Turkey

The aim of this work was to design a fluxgate magnetometer at a race-track geometry [1, 2]. Unlike the conventional ones, at which the tracks are prepared by wrapping of thin ribbons around a template, the sensing cores were prepared by milling out thin sheets at desired dimensions. In this way, the sensitivity limit was targeted to become much higher than the conventional ones due to the minimized demagnetization factor. We built three different configurations having different numbers of core layers—from one to three—and different core materials—Metglas 2714A and Vitrovac 6025. At the end of all processes, we could support the idea of these sensors' irreplaceable status by the perfect linearity of the second harmonic signals versus external DC magnetic field graphs between −1.5 and +1.5 Oe.

2 Experimental

A schematic view of the race-track core geometry designed in this study is shown in Fig. 1. The cores of the sensors have been prepared by using raw Metglas 2714A ($Co_{66}Ni_1Fe_4Si_{15}B_{14}$) and Vitrovac 6025 ($Co_{66}Fe_4Mo_2Si_{16}B_{12}$) sheets. Initially, the sensor core with a length of 40 mm and a width of 20 mm and the track width of 3.5 mm were milled out from the sheets. In order to prevent possible damages of the cores by the pressure of excitation coil, the cores were sandwiched between the PEEK tracks having the same dimensions with the cores (see Fig. 1). The excitation coils with 130 turns of copper wire having a diameter of 300 μm were wounded in one layer around the tracks.

The pick-up coil with 130 turns of copper wire having a diameter of 200 μm was wounded tightly on a rectangular frame. The second harmonic measurements were carried out by a SR830 Lock-in Amplifier. A calibrated coil with a

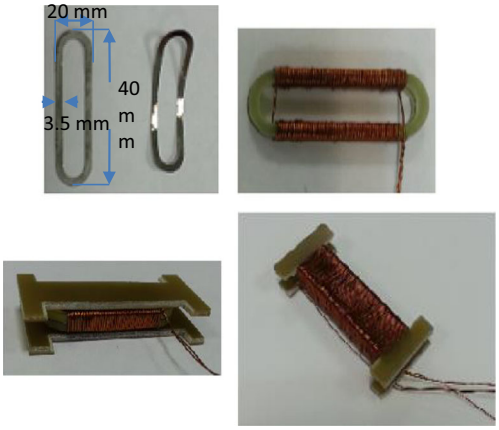

Fig. 1 Schematic view of the preparation stages of race-track sensors

coil constant of 15.9 Oe/A was used as a DC field source. The noise analyses were carried out in four layered mu-metal shields with a dynamic spectrum analyzer 35670A from Agilent Technologies.

3 Results and Discussions

Figure 2 shows the sensitivity and the noise measurements of the studied sensors containing Co-based amorphous metallic glass cores at different chemical compositions and the number of core layers. From the optimal frequency measurements, the working frequency of excitation signal was determined and the sensitivity and noise measurements were carried out at those frequencies. The sensitivities in units of volts per tesla were determined from the slopes of V_{2f} versus

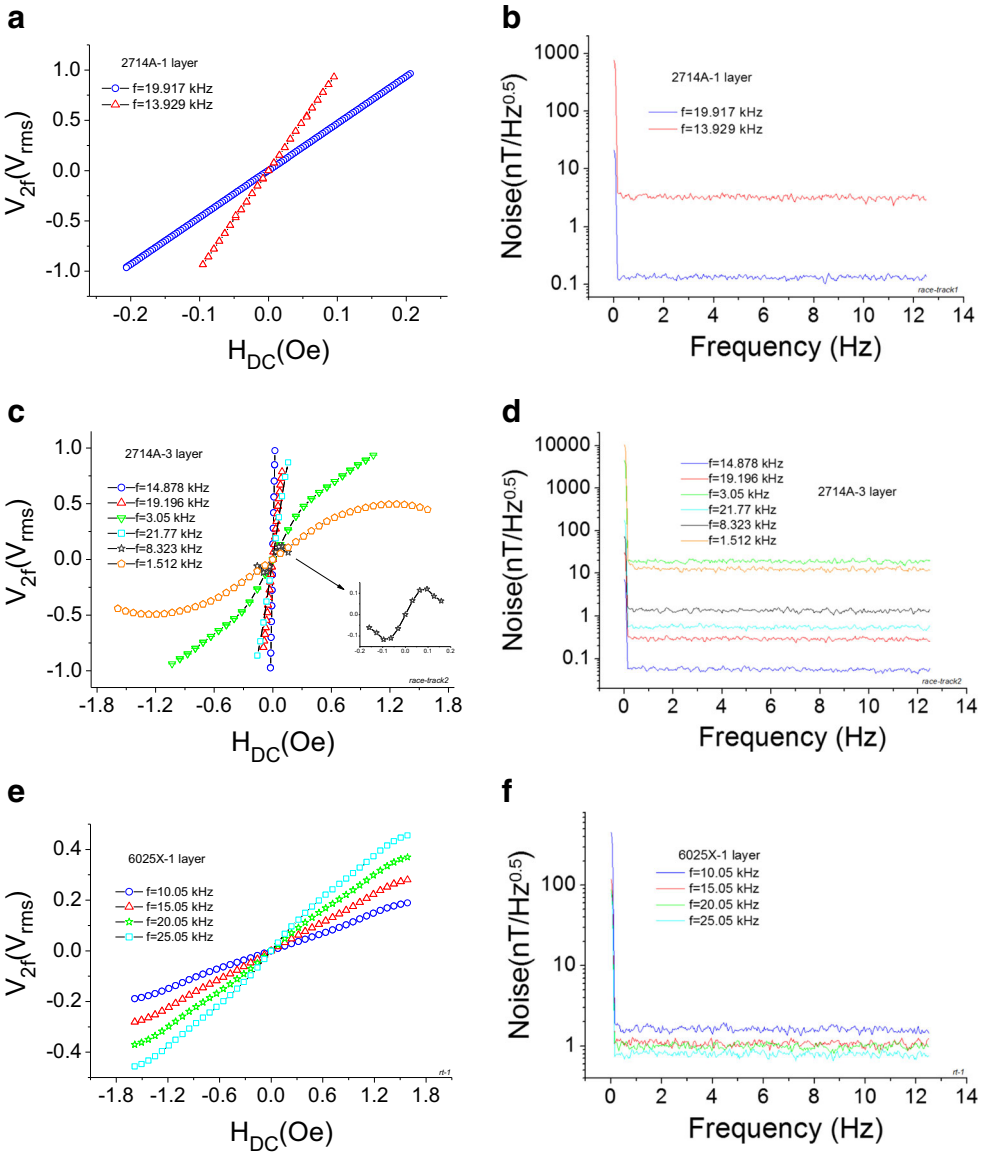

Fig. 2 The graphs of the sensitivity and noise measurements of Metglas 2714 single-layer core (a, b) Metglas 2714 three-layer core (c, d), and Vitrovac 6025X single-layer core race-track sensors (e, f)

H_{DC} curves at a linear region. Due to the limited upper range of lock-in amplifier, the sensitivity measurements could be done up to 1 V. The noise levels at 1 Hz and the sensitivities of studied sensors are tabulated in Table 1. The data in Table 1 show that the noise levels of both types of the cores (2714A and 6025X) have almost the same magnitude in case one layer of the core is used. So, both cores may be preferred as a core material for the race-track geometry presented in this study. Their noise levels are around 0.4–0.5 nT/$\sqrt{\text{Hz}}$ at 1 Hz. Later, our measurements on the sensor containing three layers of 2714A core have shown that the noise level decreases down to 56 pT/$\sqrt{\text{Hz}}$ at 1 Hz. A similar behavior can also be expected for the 6025X. It means that the number of core layers has a crucial role on the sensor performance. The sensitivity values increase up to 440 kV/T. Table 1 also reveals the importance of working frequency on the sensor performance. Optimal excitation frequency seems to be around 14–15 kHz. If we look at the $1/f$ corner of all examined sensors, which is important for determination of application area, it is seen that the $1/f$ corner takes values as small as 0.1 Hz. This is smaller than most of the values reported in the literature [3, 4]. It implies that these sensors excellently meet the prerequisites for a magnetic pulsation study, the frequencies of which are within f-band, and the applications requiring fast measurements [5]. We believe that the noise level can be further decreased with proper annealing of the cores since there may be structural deformation during a milling process [6].

Table 1 The sensitivity and noise levels of studied sensors as a function of core material and the number of core layer at certain excitation frequencies

Frequency (kHz)	Sensitivity (V/T)	Noise (nT/$\sqrt{\text{Hz}}$ at 1 Hz)
2714A (one layer)		
13.929	98,048	3.5
19.917	46,678	0.4
2714A (three layers)		
3.05	16,397	19.8
8.323	18,275	0.14
14.878	441,080	0.056
19.196	84,590	0.26
21.77	59,602	0.53
1.512	6330	3.48
6025X (one layer)		
10.005	1217	1.7
15.005	1844	1.1
20.05	2484	0.5
25.05	5246	0.5

4 Conclusion

In this work, we investigated the influence of the core material and the number of core layers on sensing performance of the race-track fluxgate sensors. Works on two different core materials having different chemical compositions of cobalt alloys have shown that there is no significant difference on the noise levels. On the other hand, an increase of the number of core layers from 1 to 3 improves both the sensitivity and the noise level. The noise level decreases down to 56 pT/$\sqrt{\text{Hz}}$ at 1 Hz with a sensitivity of 440 kV/T. In our future studies, we will further increase the number of layers in order to find its optimum value. Besides, the influence of annealing at appropriate conditions will be another task of our future plans.

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