Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Sensors and Actuators A 130–131 (2006) 184–188
SENSORS AND ACTUATORS A PHYSICAL
www.elsevier.com/locate/sna

PCB racetrack fluxgate sensor with improved temperature stability

J. Kubik*, L. Pavel[1], P. Ripka[2]

Czech Technical University in Prague, Faculty of Electrical Engineering, Technicka 2, CZ-16627 Praha 6, Czech Republic

Received 21 September 2005; received in revised form 22 November 2005; accepted 11 December 2005
Available online 19 January 2006

Abstract

A low-cost flat fluxgate magnetic field sensor with amorphous racetrack core embedded in the printed circuit board (PCB) is presented. The excitation and pick-up coils are formed of copper routes and vias on the PCB. Sensor versions with single and double layer of the core material are compared. The improved core-embedding technique reduced internal temperature-induced stresses and thus significantly increased the temperature stability: 20 nT offset temperature stability in the −20 to +70 °C range was achieved at the excitation frequency of 10 kHz. The untuned sensitivity for 27-turn pick-up coil was increased to 4400 V/T at 200 kHz excitation frequency (double-core sensor), which is the highest reported value for PCB fluxgate sensor. However, sensitivity is not a key parameter for magnetic sensors. We show that high sensitivity at elevated excitation frequencies is paid by degradation of offset stability and noise; from that point the optimum excitation frequency was 10 kHz, where we achieved 24 pTrms/$\sqrt{\text{Hz}}$ @ 1 Hz noise PSD level and sensitivity of 241 V/T (for double-core sensor).

Keywords: PCB; Fluxgate sensor; Racetrack; Temperature stability

1. Introduction

The fluxgate sensors are the most precise room-temperature vectorial magnetic sensors [1]. Their disadvantage against magnetoresistors is the complicated production process. Several research groups have introduced alternative designs using either microtechnology [2–6] or PCB technology with amorphous [7,8] or electrodeposited crystalline core [9,10]. Many of the reported designs suffer from low sensitivity and poor temperature stability of both offset and sensitivity. In this paper we present novel design of PCB sensor, which leads to an increase in sensitivity and substantial reduction of temperature offset drift over previously reported devices. The novelty of this design consists in new core-embedding technique which reduces the effect of thermal stresses on the core material substantially improving temperature stability of the sensor sensitivity and offset. The racetrack shape of the sensor core has lower demagnetisation factor than the ring-core, which increases sensitivity and suppresses crossfield effect. The layout of the PCB conductors and vias was optimized to increase the number of PCB-embedded turns of the excitation and pick-up coils.

2. Manufacturing process

The sensor is created with four-layer PCB manufacturing process using three 0.2 mm thick layers of DURAVER®-E-Cu thin laminate (standard PCB core material) and prepreg adhesive in between. The sensor ferromagnetic core was prepared separately from the PCB laminate by wet etching from 25 μm thick VITROVAC® 6025X amorphous alloy foil by Vacuumschmelze (whereas in [8] photolitography of amorphous material already glued to PCB laminate layer is used to create the core shape and electroplating of the core material on the PCB is used in [9]). This material was chosen due to its high relative permeability μ_r combined with low saturation magnetization B_S and low magnetostriction, which guarantees low dependence of its magnetic properties to mechanical stresses. The high μ_r and low B_S is important to reach core saturation with low excitation currents, resulting in low power consumption. The core is 30 mm long, 8 mm wide and the racetrack width is 1.8 mm. The novelty is also in the core-shaped hole which is drilled in the middle layer

* Corresponding author. Department of Measurement, CTU FEE, Technicka 2, CZ-16627 Praha 6, Czech Republic.
Tel.: +42 02 2435 3964/+42 06 0848 0883; fax: +42 02 3333 9929.
E-mail addresses: jan.kubik@centrum.cz, kubikj@fel.cvut.cz (J. Kubik), pavell@email.cz (L. Pavel), ripka@fel.cvut.cz (P. Ripka).
[1] Tel.: +42 02 2435 3964; fax: +42 02 3333 9929.
[2] Tel.: +42 02 2435 3945; fax: +42 02 3333 9929.

0924-4247/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.sna.2005.12.027

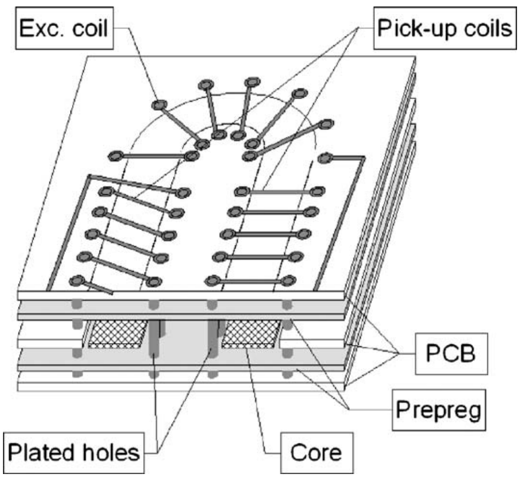

Fig. 1. Cross-sectional view of the sensor.

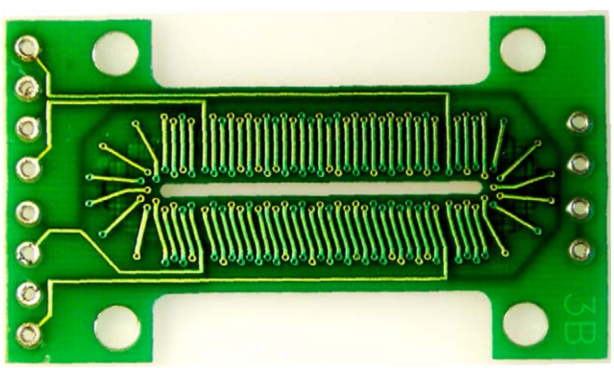

Fig. 2. Sensor photograph.

laminate to create sufficient space for the ferromagnetic core and suppress PCB laminate thermal stress transfer to the core material which could not be done in case of core-embedding technology presented in [8] or [9]. During the completion of the PCB sandwich structure, the core is inserted in the above described hole and fixed with adhesive at two points to avoid displacement during further processing. All layers are then bonded together under pressure (1.5 MPa) for 1 h while being heated up to 180 °C. The overall thickness of the sensor is then 0.7 mm. The final processing includes photolithography of the copper routes, drilling and electroplating of the through holes (see Fig. 1). The holes and copper routes then form the excitation (2 × 15 turns) and pick-up coils (2 × 27 turns). The excitation coils are placed around the core ends and the pick-up coils are placed around the straight middle part of the core. Two versions of the sensor were prepared for testing—with one layer of the core material (single-core) and with two layers of core material (double-core). The photograph of the sensor prototype is in Fig. 2.

3. Experimental

The sensor was tested in sinewave excitation mode in a wide range of excitation frequencies. The excitation was provided by Agilent 33120A generator, Krohn-Hite 7500 power amplifier and MT-56R matching transformer. Second harmonic component of the pick-up coil voltage was measured using Stanford Research SR830 (up to 100 kHz) and SR844 (above 100 kHz) lock-in amplifiers. The phase was set for the maximum sensitivity and then kept constant for each excitation frequency. No capacitors were used neither for excitation nor pick-up coil tuning. However, sensitivity at higher frequencies was enhanced by self-tuning of the pick-up coil due to its parasitic capacitance.

The sensor offset stability was measured in six-layer permalloy magnetic shielding equipped with heating and cooling chamber (−20 to +70 °C). The temperature stability of sensitivity was measured in the Helmholtz coils with inserted non-magnetic thermostat (−10 to +70 °C).

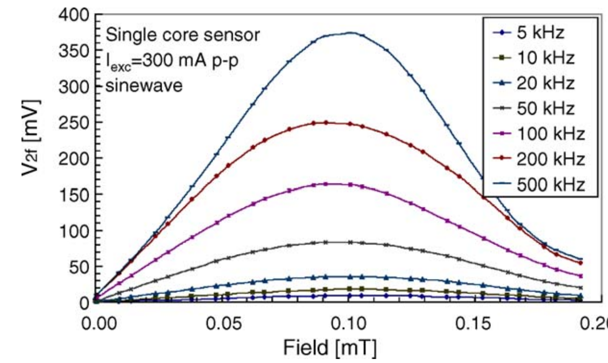

Fig. 3. Single-core sensor response to applied field—second harmonic frequency voltage.

4. Results

4.1. Sensitivity

The initial measurements with the single-core device excitation current of 300 mA p–p and frequency of 5–500 kHz showed that the linear response range of the sensor is approx. 50 μT at 100 kHz exc. current (see Fig. 3), which is slightly above the geomagnetic field magnitude. The sensitivity rapidly increases with the excitation current until 300 mA p–p is reached (Fig. 4.). However, higher excitation current amplitude decreases the perming error (sensor offset change after sustained magnetic shock of magnitude much higher than the nominal range of the sensor). The excitation amplitude corresponding to maximum sensitivity is increasing with frequency due to the effect of eddy currents

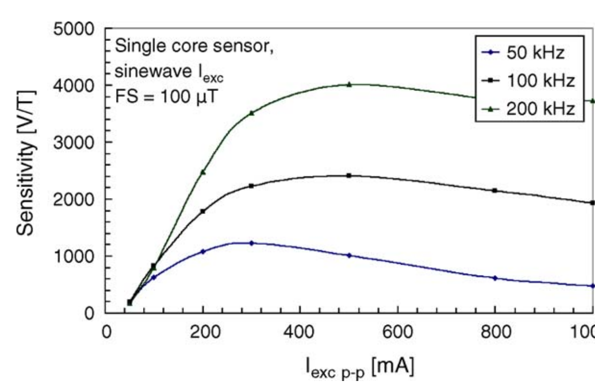

Fig. 4. Single-core sensor sensitivity vs. amplitude of the excitation current.