Journal of ELECTRICAL ENGINEERING, VOL 61. NO 7/s, 2010, 10-12

TEMPERATURE STABILITY OF SENSITIVITY AND OFFSET IN COIL-LESS FLUXGATE SENSORS

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Temperature stability of fluxgate sensors is very important issue, because this kind of sensors has found applications in several field where temperature is not constant. Temperature determines dilatation of the material which can result in mechanical stress to the core. In this paper we compare orthogonal fluxgates in coil-less mode, obtained with bi-phase Copper/Permalloy microwires with and without glass layer between them. We show that a glass layer between Copper and Permalloy strongly decreases the dependence of both offset and sensitivity on the temperature. We explain this by the fact that glass has lower thermal expansion coefficient than copper, therefore it compensates its dilatation which is source of mechanical stress for the Permalloy.

Keywords: orthogonal fluxgate, coil-less fluxgate, temperature stability, offset, sensitivity, characteristic, thermal expansion, permalloy, copper, glass coated microwires

1 INTRODUCTION

Magnetic microwires find several applications in the field of magnetic measurements, because they can be used as core of orthogonal fluxgates in different configurations: classical orthogonal fluxgate with second harmonic output, fundamental mode with DC bias [1] of excitation current, coil-less fluxgate [2].

In all these sensors the core is composed of a magnetic microwire whose stability in a wide temperature range is extremely important. Indeed, fluxgate sensors could be employed in various applications where temperature varies: a change of temperature usually causes a mechanical stress to the core of the fluxgate due to thermal dilatation. As a result the output characteristic of the sensor can dramatically change. One could compensate change of fluxgate characteristic due to temperature variation by measuring the temperature, and then recalculating the characteristic of the fluxgate at measured temperature. However, this technique requires additional components and increases the complexity of the magnetometer. Compensation of temperature with no additional hardware has been presented in [3], but it cannot be applied to this sensor since no bias is used in the excitation current. We would rather prefer to minimize the effect of temperature change on fluxgate's output characteristic by improving the microwire used as core for such sensors.

2 STRUCTURE OF THE SENSOR

In this paper we compare coil-less fluxgates composed of two different type of microwire. The first type of microwire was manufactured by Dr. Kraus at the Academy of Sciences of the Czech Republic by electroplating 5 μm of Permalloy on 100 μm diameter bare copper wire [4]. The second type of wires were produced by electroplating a 6 μm layer of Permalloy on gold seed layer sputtered on 50 μm glass coated copper wire [5].

In both cases torsional stress was applied during the electroplating process in order to generate built-in helical anisotropy in the magnetic layer of the microwires once released, due to back torsional stress. Indeed, helical anisotropy is necessary to make the magnetic microwire working in coil-less fluxgate mode.

We chose coil-less fluxgate mode because in this case the only element composing the sensor is the wire itself. Therefore, if we observe any change in the output response of the sensor this is clearly due to the change of the microwire properties. On the contrary, when using orthogonal fluxgate modes with coil, a temperature variation could cause thermal dilatation of the pick-up coil, and we cannot determine whether the change of output response is given by change of the wire or of the coil without further investigation.

3 MEASUREMENT SETUP

The output characteristic of a sensor is generally identified in its linear range by two parameters: the offset (output signal when no field is applied) and the sensitivity (slope of the output characteristic). By giving the dependence of these two parameters on temperature we can understand how the characteristic changes with temperature.

The offset has been measured by inserting the coil-less fluxgate in a 6 layer magnetic shielding: the temperature inside the shielding was decreased by cooling liquid pumped in the structure, while the shielding was warmed up by high-frequency AC-powered resistive heating system. The temperature range spanned from -15°C to 50°C approximately.

The sensors was excited by 100mA, 10 kHz sinusoidal current, provided by function generator, which was enough to saturate the core in both cases of wire with and without glass insulation.

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ISSN 1335-3632 © 2010 FEI STU

We obtained the output signal by extracting the second harmonic from the voltage at wire terminations by using a DSP lock-in amplifier (Signal Recovery 7265).

Finally the temperature inside the shielding was measured by PT1000 sensor, acquiring its resistance by means of HP34401 multimeter and 4-wire method.

On the contrary, the sensitivity of the output characteristic was measured by inserting the sensor in Helmholtz coils which changed the magnetic field applied to the sensor in a range from – 50 μT to + 50 μT. Also in this case the output signal was obtained by extracting second harmonic by means of lock-in amplifier. The sensor was inserted in a thermal chamber located in the middle of Helmholtz coils.

4 RESULTS

First of all let us analyse the dependence of the sensitivity on the temperature. In Fig. 1 we can see the variation of the sensitivity, calculated as percent of the value obtained at 20 °C, in case of microwire electroplated directly on copper, without glass layer.

The sensitivity strongly depends on the temperature: at -10°C we can see that it is reduced by 80% of the sensitivity at room temperature. For temperature arising to 50°C the sensitivity increases by 40%. Finally, in a range from -10°C to +50°C we have a total variation of the sensitivity of 120%.

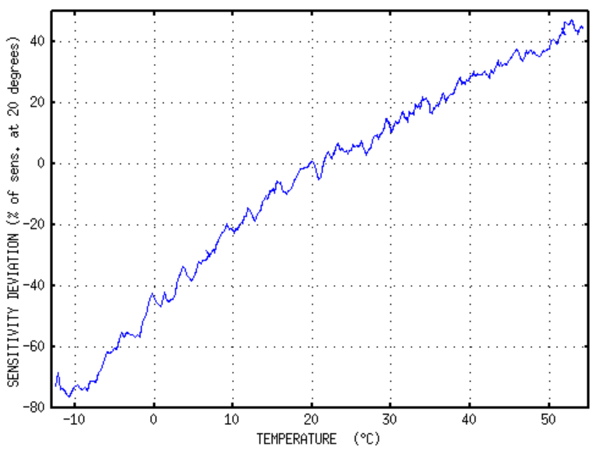

Fig. 1. Sensitivity deviation from value at 20 °C in case of simple microwire Copper/Permalloy without glass insulation (% of sensitivity at 20°C)

Such variation is strongly reduced when we used microwires with glass insulation, as shown in Fig. 2. Here we can see that if we warm up the sensor to 50°C the sensitivity increases by less than 20%, and for lower temperature the deviation is at most 8% up to -15°C. Therefore, we can derive that the employment of glass layer between the copper core and Permalloy layer is strongly increasing the thermal stability of the microwire parameters.

We should note that in both cases the dependence of the sensitivity on the temperature is not fully linear; on the contrary we can identify a polynomial behaviour: assuming a linear dilatation of the magnetic microwire, this could be due to the effect of the torsional stress of the sensitivity of the sensor, which is linear only for low stress (in practice, we cannot unlimitedly increase the sensitivity by increasing the torsional stress). Indeed, the sensitivity increases as the sine of the skew angle of the anisotropy, as explained in [6]

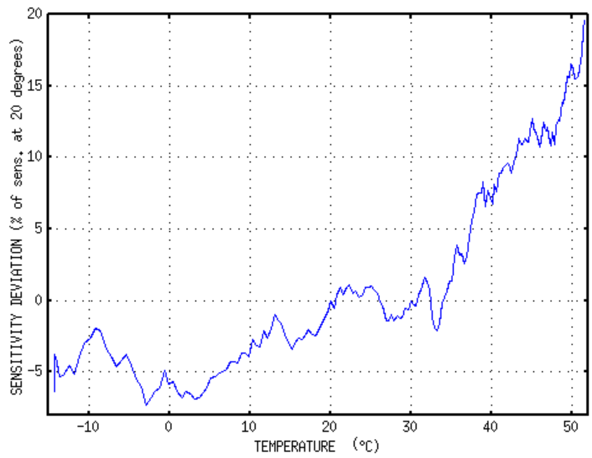

Fig. 2. Sensitivity deviation from value at 20 °C in case of microwire with glass insulation [% of sensitivity at 20°C]

In Fig. 3 we can see that the offset variation (in percent of the value at 20°C) is extremely high in simple wires with Permalloy/Copper structure, and without glass insulation. When the sensor is cooled down to – 10°C the offset increases up to 250% of the offset at 20°C. However it has a different behaviour, since the slope of the curve changes sign for temperature higher than 30°C.

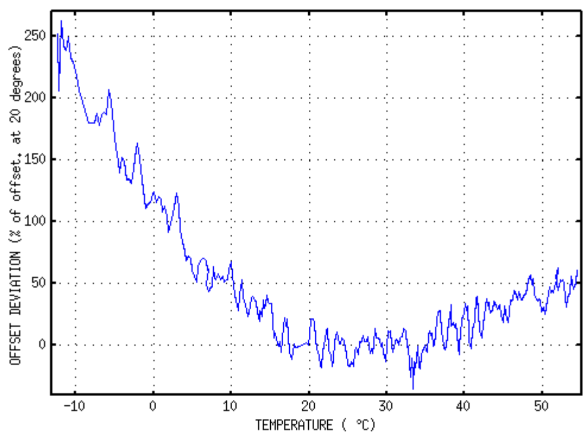

Fig. 3. Offset deviation from value at 20 °C in case of simple microwire Copper/Permalloy without glass insulation

The offset dependence on the temperature is strongly reduced by using wires with glass insulating layer.

On the contrary we can see in Fig. 4 the behaviour of the offset for the same temperature range in case of microwire with glass insulation. In this case the deviation of the offset is much lower, namely it varies from +20% to -40% of the value at 20°C.

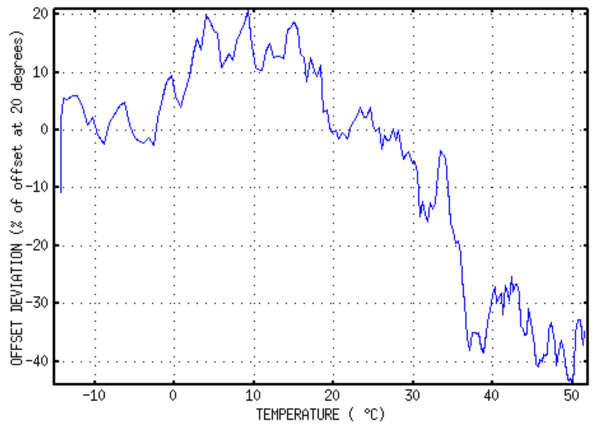

Fig. 4. Offset deviation from value at 20 °C in case of microwire with glass insulation

All the measurements presented in these sections were made after two thermal cycles from -15°C to +50°C, in order to release the initial stress which could be present in the microwire. This does not affect to the backstress which is source of helical anisotropy, as the sensors proved to work even after several thermal cycles.

The temperature has been slowly increased from -15°C to +50°C, in a time range of approximately 4 hours, as shown in Fig. 5.

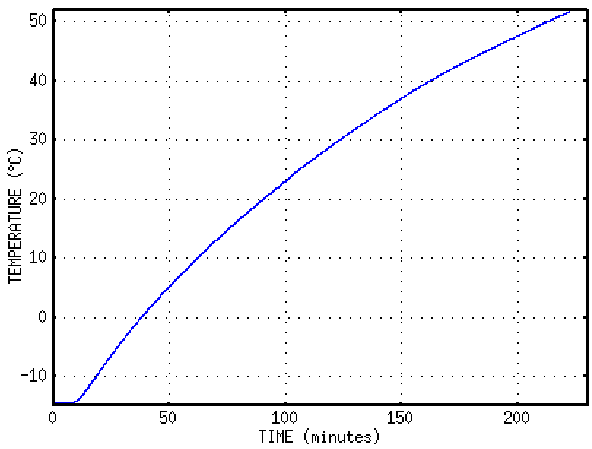

Fig. 5. Temperature increment during measurement vs. time

5 CONCLUSIONS

In order to understand why microwire with glass layer shows much lower dependence on temperature for both sensitivity and offset, we should first of all consider the thermal dilatation of each component of the microwires. Copper has thermal expansion coefficient 16.6×10^{-6} K^{-1} which is larger than that of Permalloy (12.3×10^{-6} K^{-1}) [7]. Therefore, we expect that a microwire composed only of Copper and Permalloy will have an inner core whose dilatation is higher than the dilatation of the outer shell. This will result a mechanical stress applied from the Copper core to the Permalloy layer. In fact, this stress can strongly affect the output response of the coil-less fluxgate, especially because the output signal depends on the helical anisotropy, whose orientation changes under the effect of mechanical stress.

However, glass has much lower thermal expansion coefficient (8.5×10^{-6} K^{-1}). If we consider a glass coated Copper microwire we have an inner core which is composed of copper expanding at 16.6×10^{-6} K^{-1} and glass expanding at 8.5×10^{-6} K^{-1}. The high dilatation of the Copper is therefore partly compensated by low dilatation of the glass, so that the global expansion of the glass coated Copper core will be closer to the value of expansion of Permalloy, than in the case of only Copper core.

This is the reason why when we use microwire with glass layer this has a lower variation of sensitivity and offset in the output characteristic.

We should also note that the thermal coefficients stated above must be multiplied by the volume of the material in order to get the actual expansion (as function of temperature). By properly tuning the diameter of the Copper and the diameter of the Glass cover we could achieve a microwire whose total expansion is equal to the expansion of Permalloy. In this case the stress applied to the Permalloy shell by the inner core is minimized. Estimation of the proper ratio of Copper and Glass can be achieved by finite element simulation of such structure.

Acknowledgement

The work was supported by Grant Agency of Czech Republic, No.102/08/0743.

We would like to thank Dr. Luděk Kraus of Academy of Science of the Czech Republic for magnetic microwires he provided us, and Prof. Manuel Vazquez, of Institute of Material Science of Madrid for the wires manufactured in his facilities.

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Received 30 September 2010