FLUXGATE SENSOR WITH INCREASED HOMOGENEITY

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Abstract - **Several types of fluxgate sensors were developed for measuring of the microvariations of the Earth´s field. Sensor cores were produced by etching which brings better geometric homogeneity and long-term stability. This technology allows to produce oval-shape sensors with both higher sensitivity and low noise.**

INTRODUCTION

Short-time variations of Earth´s magnetic field are intensively studied since they are closely related to ionospheric and magnetospheric currents and to hydromagnetic wawes. Some of these microvariations have quasiperiodical nature with duration from 10 minutes (so called Pc6 waves with amplitude of 10 nT) to 1 second (Pc1, 100 pT). These waves were discovered using time-derivative magnetometers with large induction coils. Such sensors use ferromagnetic cores for increasing sensitivity and therefore their frequency characteristics are nonlinear. They are awkward because of their dimensions (2 m length, 10 kg weight typically) and have resistance of several kiloohms (10^6 turns) resulting in higher Johnson noise.

Typical magnetic observatory systems based on fluxgate magnetometers display one value per minute each the average of 60 readings during the last minute. In this way pulse noise from artificial sources is elimininated and sensor noise is also filtered; such a system, however, cannot register microvariations. Our objective is to develop a magnetometer system based on improved fluxgate sensors which would be able to measure microvariations as well as large-scale slow variations.

THE TOROIDAL SENSORS

We use conventional parallel-gating sensor with evaluation of the second harmonic [2]. The sensor core is produced by etching in the form of rings. The main advantage is better homogeneity of the core compared with conventional tape-wound type. This brings better long-term stability and an increase of the angle accuracy, as shown in reference [3]. Even the residual anisotropy may be further reduced by spreading uniformly the easy axes of individual rings. Geometry of the core also reduces additional stresses caused by temperature variations. It is possible to produce sensors with oval-shape or ellipse cores by this technology with better sensitivity than that of toroidal ones because of lower demagnetization. Other shapes for special purposes may also be produced.

TABLE I
DEVELOPED SENSORS

4000 turns of sense winding in all cases

Sensor 1
20 rings of 18/22 mm diameter
Permalloy Py 79 M, thickness 20 μm

Sensor 2a, 2b
20 rings (32 rings for 2b) of 18/22 mm
Amorphous CoFeCrSiB thickness 36 μm
(Vitrokov 8116 produced by Institute of Physics SAV, Bratislava)

Sensor 3a, 3b
oval shape 70x12 mm, width 2 mm, thickness 36 μm
material: same as Sensor 2a, 2b
8 sheets for 3a, 16 sheets for Sensor 3b

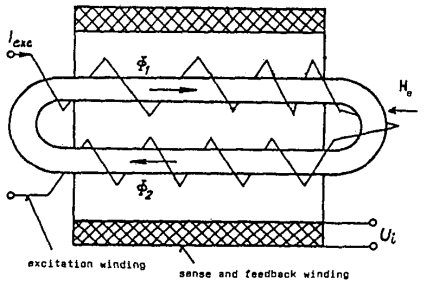

Fig.1 Oval-shape fluxgate sensor
H_e ... measured field
U_i ... output voltage

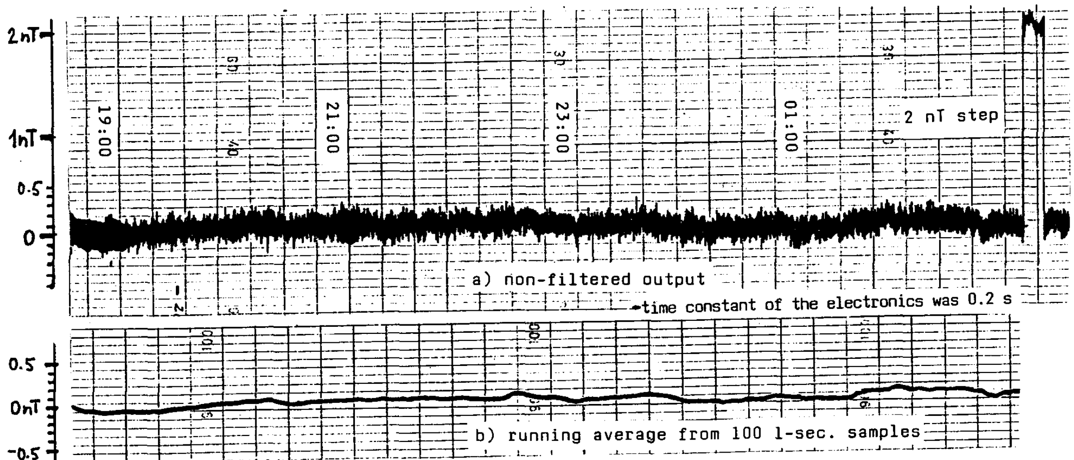

Fig.1 Long-term zero stability of the Sensor 1 measured in the MAVACS active shielding described in ref. 3

Core frame is made from machinable ceramics, and glass or marble is used for sensing and feedback coil framework, since mechanical stability is very important. No resonance capacitor at the sensor output was used since we believe that the use of parameter amplification can decrease the long-term stability (because of high sensitivity on sensing coil inductance).

Sensor 1 output with 2 nT calibration step is in Fig.2a. Output filter constant was 0.1 Hz. Noise of 200 pT p-p (5 Hz to 0.01 Hz) was caused partly by spikes from power line. Stability of the zero is seen from Fig.2b, where calculated running-average from 100 1-sec. samples is drawn. During 8 hrs the filtered output remained in +/- 50 pT region with no visible trend to systematic drift.

The absolute offset of the sensor may be adjusted by rotating the core to its minimum value of a few nT. The dependence of the sensor offset on the angle of rotation of the core is seen from Fig.3a (for tape-wound core) and 3b (for Sensor 1). Because of better geometric homogeneity of Sensor 1, the maximum offset is much lower than that of tape wound sensor. This allows us to adjust the offset to its maximum value, where the sensitivity for small changes of core position is very low and the long-term stability of the sensor zero is expected to be increased.

Long-term stability of the offset was about 2 nT/3 months. The angle accuracy allows us to evaluate magnetic declination and inclination with 5 minutes resolution. Without an output filter AC fields with frequencies upto 1 kHz may be measured with 10% error (using 5 kHz excitation frequency). Both these frequencies may be increased when using amorphous materials for sensor cores (due to higher resistivity).

Sensor 2 was made from as-cast amorphous low-magnetostriction material. The sensitivity of the Sensor 2a was 40 µV/nT; the increase of the number of sheets from 8 to 32 (Sensor 2b) did not result in higher sensitivity because of the simultaneous increase of the demagnetization factor. The noise level of this sensor is slightly higher (300 pT p-p), but the main

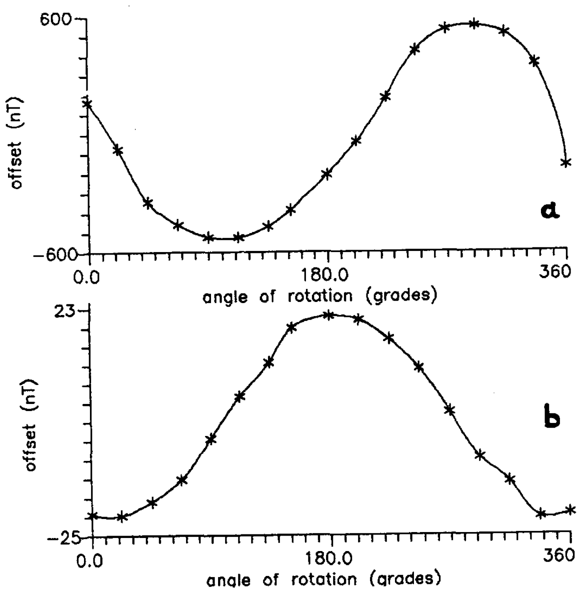

Fig.3 Dependence of the sensor offset on the angle of rotation of the core
a) for tape-wound sensor
b) for Sensor 1

advantage of amorphous-based sensors is the ease of its production. The photoresist used for etching need not be removed and serves as an insulation because high-temperature annealing is not used for these materials. The core frame may be from plastic. Low-cost robust sensors for compasses may be produced in this way.

THE OVAL SENSOR

As known from previous studies, oval-shape sensors (Fig.1) have better sensitivity than the toroidal ones. They have been only used for simple magnetometers since their noise level and stability was much worse. One of the possible reasons might be the regions with higher stress at the ends of tape-wound oval-shape core [5]. The proposed technology allows us to produce oval-shape sensors with no problems of this kind. The sensitivity of the Sensor 3a was 200 μV/nT (400 μV/nT for Sensor 3b). Due to low demagnetization, the optimum cross-sectional area may be even higher than that of Sensor 3b. Since the sensitivity was increased by the factor of 5 and 10 for Sensors 3a and 3b, respectively, and the sensor noise is caused by imperfections in the core, effective magnetic noise is expected to be reduced. As seen from Fig.4, we have reached noise 100 pT p-p, which is the level of the intrinsic noise of the MAVACS system.

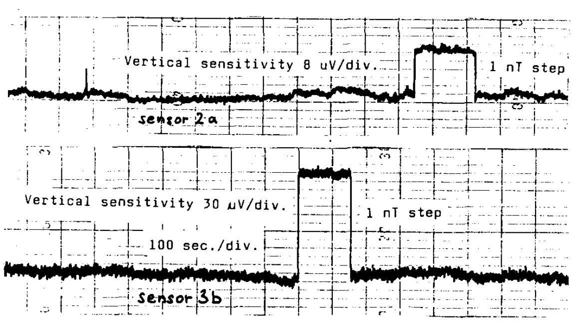

Fig.4 Noise and 1 nT step response of the
a) Toroidal Sensor 2
b) Oval Sensor 3b from the same material

Another advantage of this type of the sensor is a further increase of symmetry and therefore lower level of odd harmonical components in the sensor output. Because of this fact, the demands on the electronic circuits of the magnetometer, especially input filters, are reduced.

Since the temperature and time drift of the sensor itself is very low, the stability of the compensation field becomes decisive when measuring the Earth´s field. 1 ppm stability of the compensation current was reached, which corresponds to 50 pT in the worst case (when measuring the vertical component of the field). But still there remains about 0.5 nT/^{0}C temperature dependence of the sensor output (caused mainly by dilatation of the compensation coil) which may be partially suppressed by a program in which the coil temperature is monitored by measuring its resistance.

CONCLUSION

Long-term stability of the fluxgate magnetometer is strongly dependent on the sensor geometry and its machanical stability. The proposed technology of sensor core increased significantly long-term stability in comparison with tape-wound cores. Sensor noise depends mainly on the core material; its influence, expressed as the effective noise at the input, may be decreased by the use of more favourable sensor geometry, e.g. oval-shape of the core.

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