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MAGNETORESISTIVE VECTOR MAGNETOMETER USED IN GEOMAGNETIC APPLICATIONS – FIRST RESULTS

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Abstract: *A new magnetoresistive vector magnetometer with improved thermal stability has been developed. The instrument is installed in an observational place without magnetic disturbances near the Stara Zagora city. A comparative analysis between collected geomagnetic data and data from different INTERMAGNET observatories is made. Preliminary results show similarity in the observed time series and in the dynamics of registered geomagnetic processes.*

МАГНИТОРЕЗИСТИВЕН ВЕКТОРЕН МАГНИТОМЕТЪР С ПРИЛОЖЕНИЕ В ГЕОМАГНИТНИТЕ ИЗСЛЕДВАНИЯ – ПЪРВИ РЕЗУЛТАТИ

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Ключови думи: *Анизотропна магниторезистивност, векторен магнитометър, геомагнитни изследвания.*

Резюме: *Разработен е нов магниторезистивен векторен магнитометър с подобрена температурна стабилност. Инструментът е инсталиран в чист от магнитни смущения наблюдателен пункт, намиращ се недалеч от гр. Стара Загора. Направен е сравнителен анализ на получените данни с данните от различни геомагнитни обсерватории от мрежата INTERMAGNET. Предварителните резултати показват сходство в наблюдаваните времеви редове и в динамиката на регистрираните геомагнитни процеси.*

Introduction

The anisotropic magnetoresistive (AMR) effect in ferromagnetic materials was discovered by William Thomson (Lord Kelvin) in 1856. It takes more than a century until the advance of the thin-film technologies allowed its practical use. Sensors based on this effect are suitable for industrial applications with strong magnetic fields and for measurements within the range of the Earth's magnetic field. Modern implementations of such type of sensors show sensitivity, frequency response and signal-to-noise ratio comparable and sometimes superior to these shown in the conventional magnetometers used in geophysical research, such as a fluxgate magnetometer, proton precession magnetometer or magnetometers based on the effect of Overhauser. Moreover, AMR sensors are superior in terms of low cost, miniature size and negligible electric current consumption. From this point of view, naturally arises the question of their applicability in geomagnetic research. An attempt to give a short preliminary answer to this question is the essence of this report.

Magnetometer description

The new vector magnetometer (Fig. 1) is an advanced version of the previously used USB portable magnetoresistive magnetometer muMeter [1] [2]. Present instrument implements a system for temperature stabilization of the magnetic sensor, based on the negative feedback with PI

(Proportional, Integral) algorithm implemented through PWM (Pulse Width Modulation) with variable duty cycle, driven by the embedded microcontroller. The magnetic measuring module and the temperature sensor are mounted on the pcb in adjacent places, so that the temperature of both chips is established to be the same through a common aluminium block mounted on top of them. For better contact between surfaces thermally conductive compound is used. A non-magnetic resistor, embedded inside in the aluminium block, acts as a heater. The controlling system uses single N-channel MOSFET connected as a low-side switch to drive the current through the heating resistor.

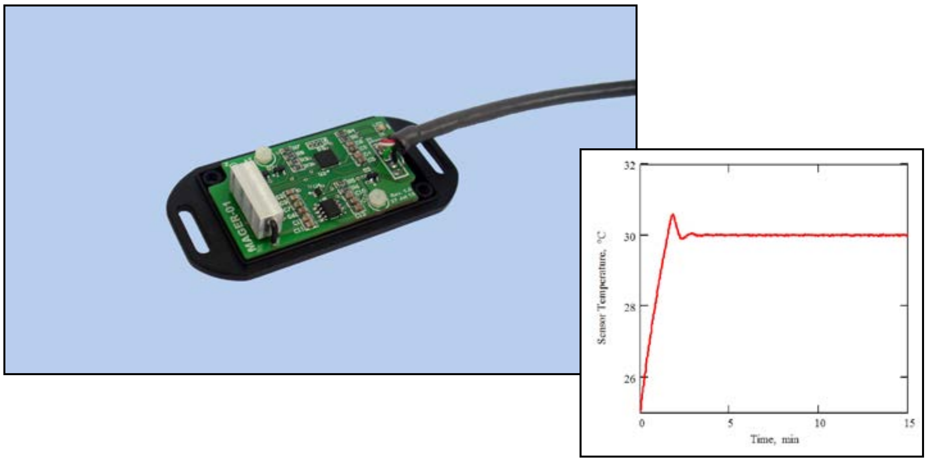

Fig. 1. Common view of the magnetometer and result of the sensor temperature stabilization system operation

The signal of the temperature sensor is digitized by an ADC and is fed to the microcontroller, where is numerically processed in order to calculate the current duty cycle value of the PWM. A minimum limit of 40% duty cycle is set (values vary between 40% and 100%) and the magnetic data are obtained during the off-state time (from 0% to 40%) in order to avoid interference with the current flowing through the heating resistor (remaining leakage current of the MOSFET is with magnitude of tens of nA and in this case can be ignored). The temperature control system operates with frequency of 4 Hz. Fig. 1 shows the common view of the magnetometer with the aluminium heating block. On the right bootom corner of the image is demonstrated the result of the operation of the temperature stabilization system. Notice the initial settling time for the temperature around its final set value. The achieved accuracy is better than 0.01 °C at 1 Hz sampling frequency.

Installation and operation

The instrument is installed in the observational place 12 km far from Stara Zagora city. The location was chosen as a relatively easily accessible and yet far enough from the city in order to minimize magnetic interference of the urban environment. Magnetometer was placed in a watertight plastic box, mounted on the bottom of the special non-magnetic shaft, dug into the ground at a depth of about 1m. Control is fully automatic and is carry out by a PC workstation placed at a distance of 10m from the shaft. The data are saved to the computer hard disk in continuous mode as a text format files with sampling frequency of 1Hz. Time is recorded as UTC (Coordinated Universal Time) and synchronization is done via Wi-Fi connection to the Internet. Prior the installation the magnetometer was calibrated *in situ* following the procedure described in [3].

Results

In the initial analysis of magnetometer data a residual dependence from daily variations of the ambient temperature was established. Although with a thermo stabilizing system of the magnetic sensor, described earlier, the device as a whole is placed in an environment without constant ambient temperature and its drift affects the work of the other electronic components in the magnetometer circuit. In order to reduce this effect we use the following procedure: the relation between uncorrected observational data and ambient temperature T_a, finded in the form of third-degree least-squires regression polynomial is subtracted from the raw magnetometer data, or:

$$(1) \qquad F_{corr} = F_{raw} - \left(a_3 \cdot T_a{}^3 + a_2 \cdot T_a{}^2 + a_1 \cdot T_a + a_0\right),$$

where F_{corr} and F_{raw} are corrected and row values of the magnetometer data respectively, a_0 to a_3 are coefficients of calculated third-degree polynomial. A similar procedure is described in [4], with the difference that there is used a linear function of temperature. Fig. 2 depicts Stara Zagora corrected data averaged to one-minute samples and filtered with a 5-minute bidirectional low-pass digital filter and the minute data series from three different INTERMAGNET (International Real-time Magnetic Observatory Network) geomagnetic observatories situated in the region of Eastern Europe. As an attempt of preliminary analysis we can emphasize the fact of nearly perfect correlation (coefficient of correlation is more then 96%) between Stara Zagora series and the other observational data.

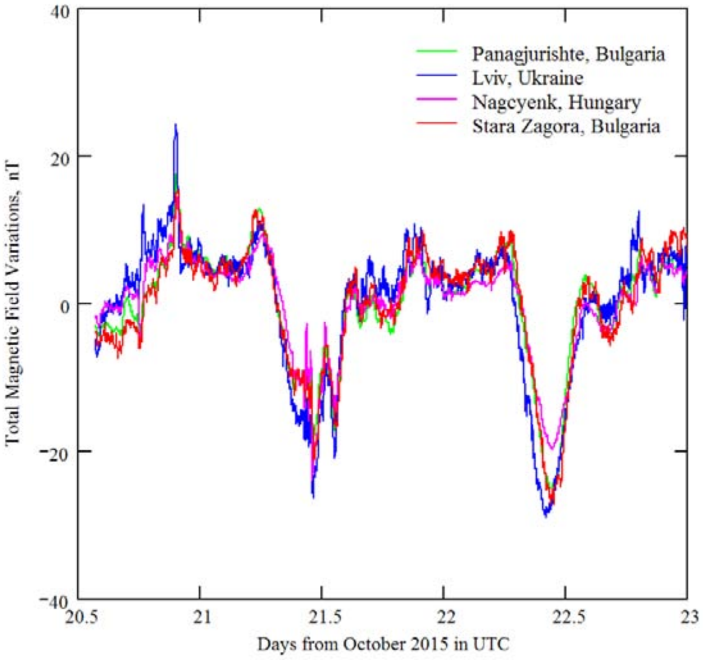

Fig. 2. Stara Zagora geomagnetic data and minute-format data from three INTERMAGNET geomagnetic observatories. Our data are filtered with 5-minute low-pass bidirectional filter. Series cover the period from 20th to 23th October, 2015.

Conclusions

A new AMR magnetometer with improved temperature stabilization of the magnetic sensor has been developed (and reported in this work). The obtained results are demonstrated in comparison with the results of other geomagnetic observatories located in the region of Eastern Europe. Preliminary analysis shows a high correlation between our instrument data and those of the other observatories (the correlation coefficient is higher than 96%).

As a future work, we plan to improve the conditions at which the magnetometer is placed in order to reduce the influence of the ambient temperature to the recorded geomagnetic data series.

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