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Precise Magnetic Sensors and Magnetometers for Military and Space Applications

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Abstract: Presented paper describes high precise fluxgate magnetic sensors designed and realized in our laboratory and their applications for military and space systems. In military applications the sensors are used in the systems for localization of unexploded ammunition in ground, where two different projects will be presented. The sensors were also used for realization of precise fluxgate magnetometer for new Czech scientific satellite MIMOSA.

Keywords: fluxgate sensor, fluxgate magnetometer, military systems, space systems

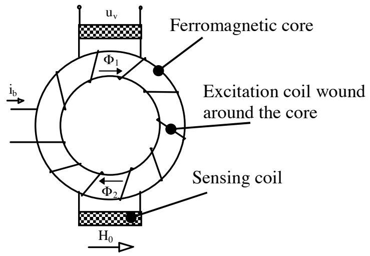
1. Introduction

Although the fluxgate sensors are not the most sensitive magnetic sensors, they are still the most popular sensors for high-sensitive and high-accurate magnetic measurement applications, such as investigation of the Earth magnetic field and interplanetary fields study and military applications [1]. Their popularity comes out from their high linearity, good stability in relatively wide temperature range and good resistance to cross-field effect and to high-magnetic field shocks [2]. In last several years the AMR and GMR magnetic sensors reached sensitivity comparable to fluxgate sensors [3], but their temperature and long-time instabilities make them suitable for use in lower-performance applications only [4].

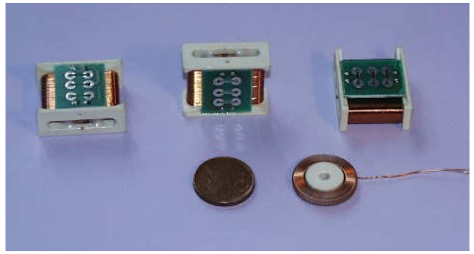
Fluxgate sensors are mostly operated in the feedback configuration and then their dynamic range can simply run into 130 dB and their linearity error is less then 10 ppm. From that it can be seen that the proper design and practical realization of sensor interface is also very important.

2. Precise Fluxgate Sensors Realized in Magnetic Laboratory of CTU-FEE

The precise fluxgate sensors designed and realized in magnetic laboratory of CTU-FEE use classical Aschenbrenner and Goubau configuration (Fig. 1). Although this configuration was firstly published in 1936, it is still the most popular and nowadays practically the only one that has been used.



a)



b)

Fig. 1. *Precise fluxgate sensors realized in magnetic laboratory of CTU-FEE a) Aschenbrenner and Goubau configuration; b) realized sensors.*

The advantage of our sensors is replacing of standard used wound core (core is wound from thin ferromagnetic strip) by the core compounded from etched Permalloy76 annular rings. The goal of this patented technology is substantial suppressing of the dispersion field in the air gaps of wound core known for example from measuring of closed-samples of ferromagnetic materials. Big attention was also devoted to choice of materials of sensor body framework, material of core holder and used glues. The design of the sensor took several years and we reached very stable sensor parameters in wide temperature range and furthermore the sensor parameters are also well resistant to mechanical vibrations and to vacuum, which is important notably in the space application. The sensor parameters are summarized in Table 1. More details about the sensors can be found in [5].

Table 1. *Basic parameters of fluxgate sensors.*

Maximum measuring range	1 mT
Resolution	100 pT
Offset	> 5 nT
Offset temperature drift	0.2 nT/°C
Parameters guarantied in temperature range	-40 to + 80 °C

3. Military Applications of Sensors

The sensors described above were used in the military systems for the detection of unexploded ammunition. The first system was fully designed and produced in our laboratory and it is used for the localization of unexploded bombs from the Second World War in subsoil of the big German cities. The application is following – before the building of new skyscraper or another big building, the subsoil under the intended building should be studied if it does not contain unexploded air bomb from the WW2. The constructional company makes deep holes to the ground arranged to the matrix and then our tri-axial magnetometer is pushed into the holes. Operator of the system watches the output data from magnetometer and if he finds some magnetic anomaly, i.e. ferromagnetic object close to the magnetometer, this object should be carefully dug out, because there is some probability it is unexploded bomb.

The system described above has analog output with transfer constant of 40 µV/nT, measuring range is ±100 µT, noise is 100 pT/√Hz@1Hz. The size of the system was adapted to the application – the total diameter of whole system including tri-axial sensor head and electronic circuitry is 55 mm.

The second system using our sensors is the military detection system produced by Schiebel Company from Austria and it is called DIMADS™. The system is used for the detection of iron bombs and unexploded projectiles in the ground and it has been used in locations around the world. System consists of two tri-axial magnetometers with digital output in gradiometrical configuration. The system operator maps the gradient of magnetic field. The data from detection system are stored during the mapping and then transferred to PC, where complete map of the magnetic gradient distribution is visualized. If some magnetic anomaly is found, it is compared with wide databases and then it is possible to predict which type of projectile or mine was found and how it is deep. System also includes differential GPS (DGPS) for the accurate determination of the position. The Schiebel system together with its application and example of results is shown in Fig. 2.

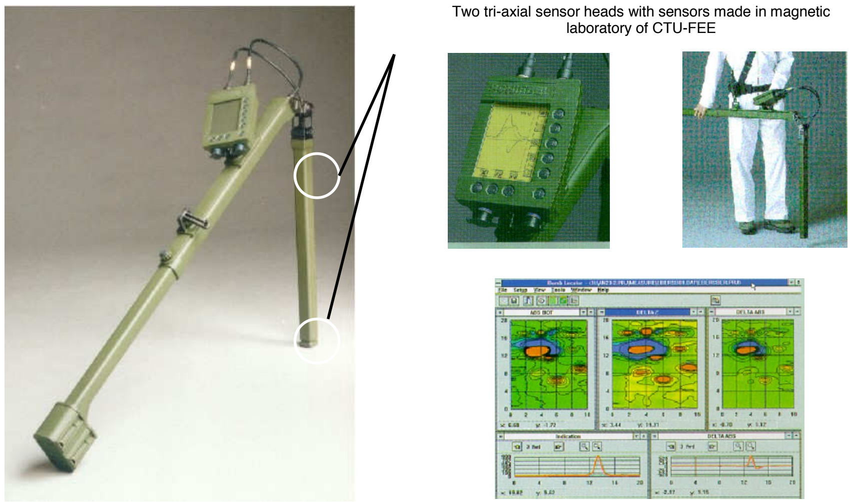


Fig. 2. *Professional UXO detection system made by Schiebel [6].*

4. Magnetometer for New Czech Scientific Satellite MIMOSA

Trajectories of the low-level satellites are disturbed by influences of the upper atmosphere and the Earth. The strongest influences are gravitation and magnetic field of the Earth, but also other environmental conditions can divert satellites from their calculated trajectories. The most significant additional influences are non-homogeneous resistance of upper atmosphere, pressure of solar radiation and radiation reflected from the Earth surface (Earth albedo) and the Earth thermal radiation. Although the gravitational field of the Earth can be simply calculated and magnetic field in the Earth vicinity has been deeply mapped, the distribution of other impacts was practically not

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study.

Due to this the new Czech scientific satellite MIMOSA (MIcroaccelerometric Measurement Of Satellite Acceleration) was designed and built. The main on-board measuring system is tri-axial micro-accelerometer called MAC-3 and having resolution of 10^{-10} ms^{-2}. For the determination of the vector of acceleration it is necessary to know also the position of the satellite with respect to the Earth gravitation field (subtraction of the gravitational force) and also the direction and the speed of the satellite rotation (subtraction of the centrifugal force caused by the satellite rotation). And it is just the task of the precise tri-axial magnetometer, which measures the vector of the Earth magnetic field. The actual result of the measurement determines the satellite position with respect to the Earth and time-changes of the resulting magnetometer data are used for the determination of the direction and speed of the satellite rotation with respect to the Earth magnetic field. Pay-mass of the satellite also includes other measuring units: GPS navigational system used for the determination of the satellite position in the orbit, optical sensing system appointed for determination of the position of Sun and range finder measuring distance from the Earth surface. Direction and speed of the satellite rotation can be changed by changing of the mass distribution, respective by the changing of the center of gravity. These measuring systems, power management unit and communication with ground station are controlled by central on-board computer.

Our laboratory became to be a designer of the magnetometer for the described satellite. The magnetometer is tri-axial analog magnetometer with digital output. Whole magnetometer must fulfill several requests given by work in hard conditions in the space – working temperature range from –20 to +80 °C, vacuum resistance of all circuits, resistance to the temperature shocks, resistance to the vibrations during the launch of carrier rocket and radiation resistance of integrated circuits (radiation deposition in altitudes of low-level satellite is not strong enough to make structural changes in discrete circuits). Resulting parameters of the MIMOSA magnetometer are summarized in Table 2.

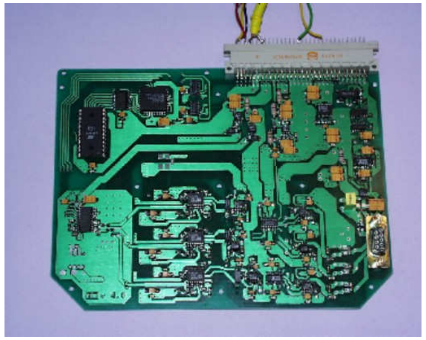
Table 2. *Summary of the MIMOSA magnetometer parameters.*

Measuring range	±250 µT
Angular resolution in working temperature range	0.05°
Effective digital resolution	17.5 bits
Working temperature range	-20 to +60 °C
Communication with central satellite computer	RS422 with protocol RS232, 54600 bsps
Power consumption	0.6 W

Photo of the realized magnetometer (without sensor head, which is placed outside the PCB) and MIMOSA satellite are shown in Fig. 3. Satellite was successfully launched to the space in June 2003.

5. Conclusions

Precise fluxgate magnetic sensors made in the laboratory of magnetic measurement of the Czech technical university were described. Presented sensors have been used for wide range of application. Two of them – military and space – were explained in detail. Apart from these two prestigious applications the sensors can be and they are used also in medical application (magnetopneumography), geophysical applications, material diagnostic and more.



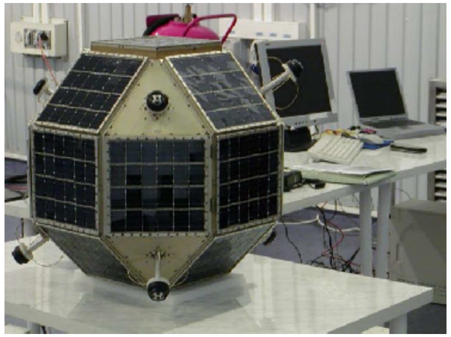


Fig. 3 *Satellite magnetometer and MIMOSA satellite*.

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