Induction Magnetic Field Sensor as an Organ of Robot Perception

Keywords: magnetic field, gradient, sensor, industrial interferences, geomagnetic sources, oscillations

1. INTRODUCTION. MAGNETOMETERS AND THEIR ROBOTIC APPLICATIONS

The measurement of magnetic fields (MFs) is an important task for the majority of autonomous missions. The distribution of permanent and the value of periodical MFs gives the data about placement of ferromagnetic objects and sources of EM radiation respectively. On the other hand, these signals will be a reference point and guiding line for a walking robot.

Detection of some magnetic anomalies of the Earth MF and their variations is provided by fluxgate sensors [1]. When the spectrum of EM signals in the environment lies in a wide frequency range (10Hz-500kHz), the application of highly-sensitive induction sensors is necessary. The application of a low-Tc SQUID device is able to embrace both of the said frequency ranges with maximum sensitivity. It is made of non-magnetic material and the principle of operation is to detect two magnetic signals at different distances from the source and arrange for these to be in opposition around a local supercooled circuit. This 'gradiometer' approach eliminates most of the noise—caused by spurious MFs originating from, for example, electrical devices or natural (geomagnetic-GM) sources. A typical unshielded laboratory has a noise level in the 0÷10 Hz frequency region of about 10^{-7} T and GM noise in the same frequency range is of the order of 10^{-10} T. Any small field changes the direction of the MF vector in the space and this produces a distortion in the waveform of the signal in the detection coils. The very expensive use of the SQUID magnetometer up until now has produced many advances in the understanding of MFs from weak sources. The advance of much cheaper room—temperature sensor technologies offers the prospect of much greater use of MF monitoring [2].

2. INDUCTION (SUPERCONDUCTING) SENSOR AS THE ORGAN OF VISION

Taking into account the said restrictions, it is undesirable to use in robot a fluxgate sensor due to its active type of action. Also is impossible exploiting SQUID device since it needs the liquid helium container. SQUID systems being almost ideal for the detection of very small amounts of flux from small samples, but less well-suited to the detection of low flux densities (i.e. where very low MFs are encountered). The high coil inductance of the induction system, on the other hand, can couple to a large quantity of flux [3]. It appears that these difficulties frequently reduce, in principle, the performance of SQUID magnetometers to a level below that demonstrated in this article using an ambient-temperature induction system. This induction sensor is also compact, robust, operates at room temperature, exhibits a wide dynamic range, and may be easily integrated into differential or multiple sensor gradiometric configurations which are feasible in a multi-limb walking robot.

A pickup coil (PC) of walking robot is connected in parallel with the drain of a SuFET cryogenic device or an ordinary OA which are placed in the body. A PC realizing the oscillatory-forward movement along both AC industrial interferences and quasi-DC natural (Earth) environmental MFs. These fields are distributed on a surface and in space randomly. The movement in quasi-DC MF H_{DC} with the defined speed υ and oscillating frequency ω with a magnitude $\Delta\alpha$ gives e.m.f. from PC:

$$E_{PC}=SN\omega\mu_{eff}\mu_0 H_{DC}\sin\alpha\cdot\Delta\alpha\ , \qquad (1)$$

where $S=\mu_{eff}\pi d^2N/4$ with μ_0 -the permeability of free space, $\mu_0=4\pi\cdot10^{-7}$ henry/meter; μ_{eff} -the effective relative permeability of a high-μ metal core; d-the average diameter of a PC; N-total turn number of solenoid; α- an angle between PC's magnetic axis and the vector of H_{DC}. Further amplifying/processing circuit depends on the measuring conditions and can vary from the simplest of the ordinary induction sensor modifications to the superconducting one [4].

3. THE DESIGN OF THE MF TRANSDUCER

Some combined device, that includes all the best features of the said MF sensors/transducers seems to be the preferable trend for further development as a vision organ [4]. The proposed magnetometer (SIM) circuit consists of both room-temperature or cooled (up to superconductive) PC and a SuFET [my]. Moreover, it gives the possibility of repudiating both windings and electronics of feedback loops that are used in the known magnetometers.

Magnetic induction B_{PC} of AC MF with the frequency ω_{limb} of limbs' oscillations produce an e.m.f. in PC:

$$E_{PC}=B_{PC}\omega_{limb}SN, \tag{2}$$

where S- a cross-section of PC, N- its number of turns. All AC MFs with the frequencies ω, high than ω_{limb} can be rejected by the passive HF filter [5].On the other hand, the value of E_{PC} can be determined from the output voltage U_{out} of the specific kind of the induction transducer [4] with known its transfer function G according to the formula:

$$U_{out}=GE_{PC}. \tag{3}$$

As a result, an output signal receiving spontaneously, during two-dimensional travel of a walking robot in a quasi-DC MF. Moreover, by picking up the signals from both horizontal and vertical parts of the limbs, the robot derives its' directional information from the axial course of the field lines and their inclination (defined as the angle between the direction of the field lines and the horizontal) in space. Executing the oscillations of PC with parameters (number of turns $N=2\cdot10^4$ and a cross-section area $S=\pi\cdot10^{-4}$ m^2) [4] in the earth MF B_0=50 mkT [6] with the frequency 2 Hz and $\alpha=30°$, $\Delta\alpha=30°$ arouse e.m.f. with a magnitude 50 mV according to Eq. 1 (see Table).

Table. The dependence of signal's value U_{out} from the varying MF B_{PC}.

$B_{PC}(U_{out})$	a	b	c	d
50 mkT	10 V	70 mV	1.4 V	3 mkV+0.1 V
5 nT	1 mV	7 mkV	0.14 mV	0.3 pV+0.1 V (0.1 mkT)

Sensitivity of the robotic vision makes it possible to recognize the linear translation of 10^{-2} m and disposal in space of 10^{-3} m^3.

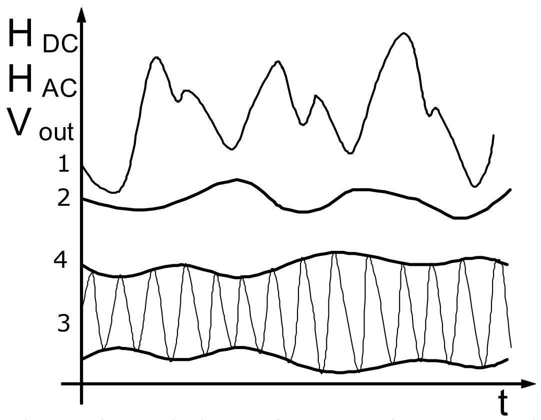

Fig. 1 The variations of measured MF strength H_{DC}, H_{AC}.

1- oscillations of a PC modulated by variations of external natural MF;

2- an envelope of sensor's output voltage U_{DC} as the appropriate quasi-DC MF along the walking way;

3- changing of an AC industrial MF interference into the travel space;

4- the integral output voltage U_{AC} which determines changing of the interference's power by a distance.

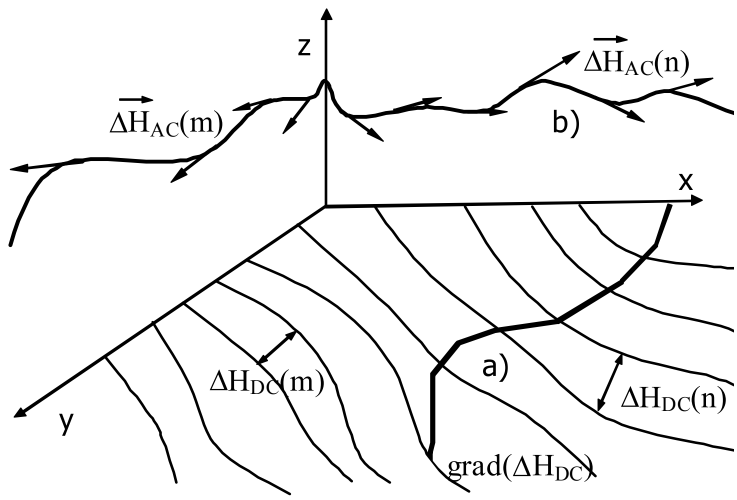

Fig. 2 Orientation of the walking robot in an environmental MF.

a) distribution of the detected gradients of DC natural MF over the x-y plane;

b) distribution of DC MF interference in the space around z axis as a difference between the limbs.

4. USING AN AMBIENT DC AND AC MFs FOR ROBOT'S WALKING.

An output signal of the sensor will be involved into differential (gradiometric) operation between the robot's limbs. After envelope detection of the quantity U_{out}, can be presented by changing the corresponding quasi-DC MF by the robot's movement as defined in Fig. 1. In the similar manner, way an AC MF partial can be shown.

A portable single axis magnetic gradiometer, which is a relative instrument because it measures the spatial variation of the MF, has been described [7]. The finite distance between the magnetic sensors d for detecting the field difference is used to get an expression for the estimate of the exact magnetic gradient, adjusted by a function of the field distance, as follows:

$$\Delta B_z = B_z(z+(1/2)d) - B_z(z-(1/2)d) \quad (4)$$

5. MEASURING OF THE MF SIGNAL (NOISE) IN A TRIAXIAL ARRANGEMENT

A flux transformer detects more environmental noise if its baseline is long (or if it is a magnetometer). Thus long baseline gradiometers detect not only stronger signal from deep sources, but also larger environmental noise. The noise parameters for different baselines were measured and are shown graphically [8].

Gradiometers can also be configured to detect radial gradient of the tangential MF. Two orthogonal 'tangential radial gradiometers' and one 'radial gradiometer' can be combined to form a first-order gradiometer equivalent of the vector magnetometer. The vector of the industrial or household man-made AC MF (noise) ω can be measured during the complete pass of the robot's walking. Placing of the PC's triplets (the three orthogonal components at each location) on the respective limbs dive the necessary data for the triaxial MF determination according to the geometrical summation. In such case, frequency of the limb's oscillations much lower than ambient MF noise. That is why, they do not influence the measured components and, moreover, these oscillations can be additionally suppressed by a passive LF filter [9]. The value of MF induction along a single component will be calculated similarly to Eq. 1 and Eq. 2 by the formula:

$$B_{PC} = \omega S N U_{out}/G \quad (5)$$

Some example of the result of the calculations according Eq. 5 shown in Fig. 2. The dependence of volumetric error on the baseline for environmental noise is shown [8].

6. REFERENCES

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