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**DYNAMIC MODEL OF EDDY-CURRENT AIRBORNE
ELECTROMAGNETIC SYSTEM WITH A GENERATING AND
RECEIVING LOOPS**

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In this paper the original airborne eddy current system with a generating and receiving loops for searching of conductive underground and underwater objects are reviewed. The dynamic model of such a system is created. The model justifies the possibility of using a system for search conductive objects with properties such as non-magnetic and magnetic. The depth of search can be hundreds of meters.

Keywords: *eddy current method, airborne electromagnetic systems, magnetic and non-magnetic leading objects, generating and receiving loops*

INTRODUCTION. Geophysical explorations of the earth's interior, shelf of seas and oceans and their water depths by the eddy-current method by harmonic electromagnetic fields are important for the economy [1]. Therefore, in many countries terrestrial and airborne means of detection, search and prospecting of various leading objects and bodies have been created [2,3]. Such objects and bodies can be a deposits of polymetallic ores with diamagnetic properties, large-sized conducting bodies, for example, deposits of iron ore, sunken ships, underwater bodies, and the like.

Airborne vehicles are characterized by high performance of finding objects and bodies. A terrestrial means allow to detail and precise their location and size. But in shelf and water zones, only airborne vehicles are suitable for use.

ANALYSIS OF THE PROBLEM. Today, there are many means available for air electromagnetic prospecting of polymetallic ores and other deposits of lead ores [1,2,3]. From them it is possible to allocate complex means with electric and magnetic channels [1]. The electric channel is used to detect diamagnetic deposits and bodies, magnetic - to detect deposits and bodies with magnetic properties. In some complex means, the simultaneous operation of both channels is impossible because they create each other obstacles. Therefore, only the alternate work of channels is used. This is a significant disadvantage of these complex means. The main disadvantage of the electric channel is that when interpreting the results of its work using a static model [4], which does not take into account the speed of the electric exploration unit.

FORMULATION OF THE PROBLEM. The author's studies of recent years have shown that moving eddy-current airborne electromagnetic means are suitable for detecting not only diamagnetic, but also magnetic conducting objects and bodies. Such means are based on the use of a harmonic field. Fig. 1 shows an example of an electromagnetic system installed on board an aircraft [5,6]. On the basis of Fig. 1, taking into account the velocity of the system, the

author managed to theoretically substantiate the form of the signal from bodies with magnetic properties. Such a signal was almost known, but did not have an explanation. Therefore, in contrast to the static model [4], which does not take into account the speed of movement, the author called the model in Fig.1 a dynamic model.

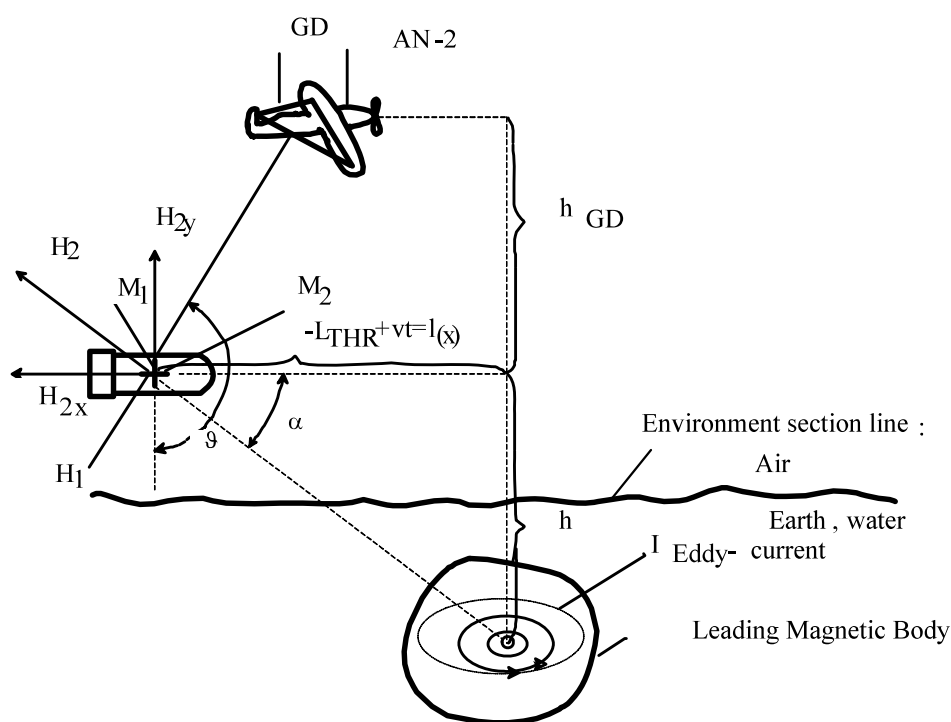


Fig.1. Dynamic model of the aircraft system that measures the ratio of the half-axes of the polarization ellipse of the magnetic field

When such systems flying over a body with magnetic properties, it fixed a signal in the form of a single period of the sinusoid. Explaining the appearance of such a signal based on the static model was impossible. After many years of work on this task, the author succeeded in developing a dynamic model for the airborne system that measures the ratio of the half-axes of the polarization ellipse of the magnetic field. This dynamic model explains the presence such of a signal from objects and bodies with ferromagnetic properties. It speaks of such large-scale conducting bodies as iron-ore deposits, sunken ships, and other underwater bodies. The key element of this model is the concept of threshold distance L_{THL} introduced by the author.

Fig.1 shows the dynamic model of the airborne system installed on a board the aircraft AN-2 [5]. It contains a mobile oscillator and dipole, which are located aboard the AN-2 aircraft. Two orthogonal magnetic receivers M_1 and M_2 located in the vertical and horizontal planes transform the corresponding

projections of the magnetic field intensity into an electrical signal. Magnetic receivers are located in a special gondola that is suspended to the aircraft on a cable-cable. The cable length can be changed from 30 to 120 meters. The meter connected to the magnetic receivers and placed on board the same aircraft AN-2. It measures the ratio of the semi-axis of the ellipse of the polarization of the magnetic field [1].

The depth of research of such a system is determined by the distance between the generator dipole and magnetic receivers located in the gondola. The maximum value of the distance is 120 m with the power of the onboard generator 300 W. A further increase in depth will require an increase in the power of the onboard network and increase the height of the aircraft. But this is not effective, because the intensity of the magnetic field decreases inversely proportional to the square of the distance. The minimum height of the gondola from the surface to be studied, taking into account the safety of the airplane and its crew, shall not be less than 50 m. Therefore, it would be desirable to place an element that generates an electromagnetic field as close as possible to the investigated surface.

PRESENTING MAIN MATERIAL. A more economical system with a greater depth of research is known, which uses combined generator and measuring loops [5,6]. But it is a terrestrial eddy current geophysical system. It is only necessary to lift this system into the air and move it at a certain speed along the surface to be studied. Such a system with loop exciter and magnetic field receiver is shown in Fig. 2 [7]. In this variant, loops are moved by unmanned aerial vehicles (UAVs).

In Fig. 2, the GL is a generator and the ML measuring loops. They have inserted a groove made in a rigid, non-conductive frame F. Here G is a generator, V is a variometer, an M is a measurer of the relative value of the quadrature component of the secondary magnetic field, and RMR is the recorder of measurement result. The frame F is suspended to a plurality of UAVs, which work are synchronized from one computer. The generator G, the variometer V, the M measurer, the measurement result recorder MRR, and the wireless equipment of the UAV and the MRR are also located on the UAV.

Let's consider the reaction of the system to the body with ferromagnetic properties. For simplicity, we assume that in the receiving plane (in the middle of the measuring loop of the ML), the modulus of the tensions of the primary magnetic field $H_{1m} \sin \omega t$ and the secondary magnetic field $\pm H_{2m} \sin \omega t$ are in-phase (or anti-phase).

The tensions of secondary magnetic field in the middle of the measuring loop ML is directed along a line that connects the center of the measuring loop ML with the center of the body with ferromagnetic properties. The direction of tension of the primary field is perpendicular to the plane of the generator and measuring loops (Fig. 3). The system moves horizontally to a ferromagnetic body at a velocity v . This is a dynamic model of such a system.

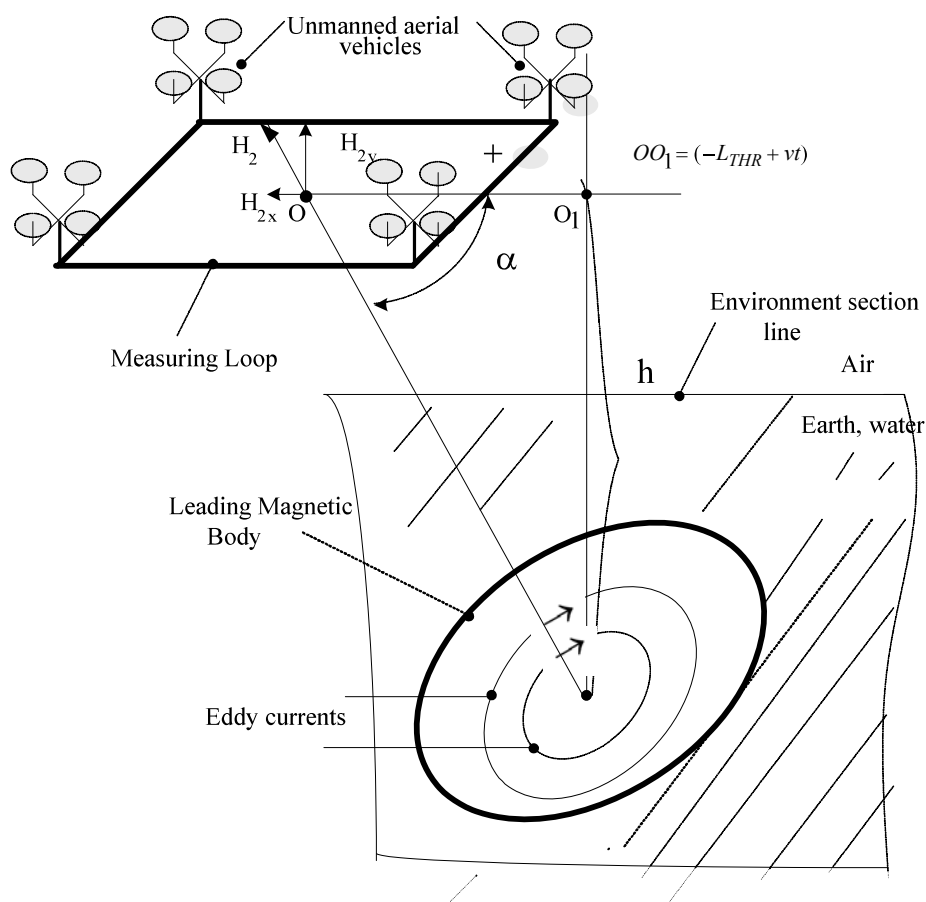


Fig.3 To substantiate the signal from bodies with ferromagnetic properties

On the basis of (1) we write the expression for the e.m.f. in the measuring loop, induced by the secondary magnetic field

$$e_{2y} = -\frac{d\Phi_{2y}(t)}{dt} = -WS \frac{dH_{2y}(t)}{dt} = -WSH_{2m} \left\{ \cos \omega t \cdot \omega \cdot \sin(\arctg \frac{h}{-L_{THR} + vt}) + \sin \omega t \cdot \frac{d}{dt} \left[\sin(\arctg \frac{h}{-L_{THR} + vt}) \right] \right\} \quad (2)$$

where:

- Φ – magnetic flux;
- W – number of turn of the receiving loop;
- S – area of one turn.

The second member in the last expression is a quadrature component that arises in the measuring loop ML from the in-phase component when the magnetic flux is differentiated by a measuring loop ML. It will measure the M meter, and its results will be recorded by the register R.

Let's analyzed the behavior of the quadrature component of the signal when the system approaches the ferromagnetic body, fly over it and leaves it.

On the basis of expression (2) we write the dependence, which describes the behavior of only the quadrature component

$$e_{qdr y} = -WSH_{2m} \sin \omega t \frac{d}{dt} \left[\sin \left(\arctg \frac{h}{-L_{THR} + vt} \right) \right] \quad (3)$$

Expression (3) describes a signal that looks like a one sinusoidal period (Fig.4).

At the moment t_1 when aircraft system flying over the body with magnetic properties the signal sharply changes the sign. If at this moment to register the coordinates of the system, then them can be interpreted as coordinates of the body with magnetic properties, which is under the system.

It does not matter at all what moves: whether a system is relative to the body or a body relative to the system. The shape of the signal will be the same.

Therefore, using a stationary system, can to register moving bodies.

But with the help of a moving system can track the change in the coordinates of the moving body.

In order to clarify the coordinates of the detected body, it may be necessary to change the direction of flight, in particular, to fly through a point in which the body was detected to a direction perpendicular to the previous route.

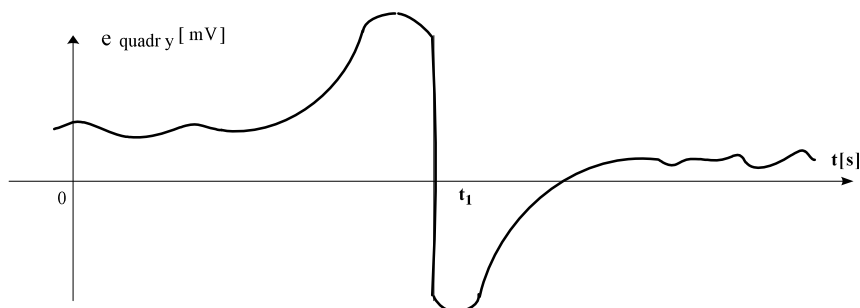


Fig.5. The signal which appearances from a body with ferromagnetic properties

CONCLUSIONS

Thus, by fixing the coordinates of the airborne device at the moment of the signal transition in the form of one period of the sinusoid through zero, one can determine the location of the body with ferromagnetic properties, which is underground or under water. To clarify the coordinates of the body's location may require another flight through a definite point, but on a route perpendicular to the first one. If the body moves, it is obvious that for tracking its movements must will have to do more than one flight.

The analysis carried out is of a qualitative nature, since it is not tied to the shape, size, specific electrical and magnetic properties of the body. Also, the specific distances from the search system to these bodies are not taken into account.

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**ДИНАМІЧНА МОДЕЛЬ ВИХРОСТРУМОВОЇ АЕРОБОРТОВОЇ
ЕЛЕКТРОМАГНІТНОЇ СИСТЕМИ
З ГЕНЕРУВАЛЬНОЮ ТА ПРИЙМАЛЬНОЮ ПЕТЛЯМИ**

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У роботі розглядається оригінальна геофізична аеробортובה вихрострумове система з генерувальною та приймальною петлями для пошуку провідних підземних та підводних об'єктів. Створена динамічна модель такої системи. Модель обґрунтовує можливість використання системи для пошуку провідних об'єктів з немагнітними та магнітними властивостями. Глибина пошуку може складати сотні метрів.

Ключові слова: *метод вихрового струму, аеробортובה електромагнітні системи, магнітні та немагнітні провідні об'єкти, генерувальна та приймальна петлі*

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depends on the selected value of the logarithm base. The results of the simulation have confirmed that unlike the known methods, which provide an error of 0.4% for 8-binary digits, the suggested method gives an error of not more than 0.25% and even less than 0.1%.

Novelty. The scientific novelty of the obtained results is: 1) further improvement of the methods of analog-to-digital functional conversion; 2) further improvement of the fundamentals of constructing recurrent analog-to-digital functional converters.

Practical Significance. The results presented in this article allow increasing the speed while maintaining the high accuracy of logarithmic analog-to-digital functional conversion and high technological efficiency. Converters implemented according to the suggested method provide the increased accuracy with fewer discharges.

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Research Methodology. The methodological basis of the research is the well-known static model of the ground electrical prospecting system, based on which the eddy current method is used to search for conducting nonmagnetic bodies and which is also applicable to moving aerial electric prospecting systems. However, in addition, in moving electric prospecting systems from the bodies with magnetic properties there is a signal similar to one period of the sinusoid. For a long time this signal has had no explanation. The author has managed to create a dynamic model of a moving electric prospecting system that takes into account the speed of motion. Such a model allows us to explain the nature of the signal and its form from bodies with magnetic properties and conclude that the moving electric prospecting system is capable to detect the bodies with both non-magnetic and magnetic properties. The key role in the dynamic model is played by the concept of threshold distance introduced by the author, in which, when approaching the body, the level of the signal is compared with the threshold of the sensitivity of the system. Such a dynamic model is also the basis of this study.

An important principle used in this paper is the principle of maximum approximation of the emitter and the receiver to the studied surface, in particular, the horizontal, which is, for example, the water surface. This has predetermined the choice of system configuration with generating and receiving loops. The analysis of such a system confirms obtaining of the expected result.

Results. In the conducted study, when analyzing a signal of a secondary magnetic field from a body with magnetic properties, it has been shown that in a moving electrical prospecting system with combined generating and receiving loops, the in-phase component of the secondary magnetic field is a function of the changing angle between the horizontal and the direction to the body i.e. it is a product of two functions. By differentiating this product in the receiving loop, we obtain both the in-phase and quadrant components of the secondary field. The quadrant loop of components measured by the system has the form of a single sinusoid period, which changes a sign at the moment of its flight over the magnetic body. At this moment, the coordinates of the magnetic body are determined from the coordinates of the center of the loops. Such a system is more economical and can be used to search for bodies with both non-magnetic and magnetic properties. A structure that implements a loopback version of the electrical exploration system has been developed.

Novelty. The scientific novelty of the results obtained is in the derivation of a theoretical dependence for the quadrant component of the secondary magnetic field. Based on this dependence, an approximate graph of its loop has been presented. The structure of the device for the implementation of the electrical exploration system has been suggested. As carriers it has been suggested to use unmanned aerial vehicles (UAVs) (no more than 100), whose work is synchronized from one computer. This possibility has been proved in China, where thousands of UAVs were launched into the sky in April 2017, their work was synchronized from one computer.

Practical Significance. A patent of Ukraine has been received for the developed structure of the electrical exploration system. The structure is characterized by a large depth of research, which at frequencies in units of Hz can be several hundred meters. The computational control part of the structure can be executed on the basis of a single-board computer, for example, Arduino.

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SPECTRAL CHARACTERISTICS OF ONE-LAYER OXIDE FILMS FOR PROTECTION FROM SPEECH INFORMATION LEAKAGE

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Research Methodology. In the work the technology of passive protection of speech information from leakage through the optoelectronic channel has been used due to the use of sprayed one-layer oxide films.

Results. The paper considers the possibility of using protective films to protect the information from unauthorized reading by laser acoustic intelligence systems. The analysis of literary sources on the problem of protection of the speech