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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.

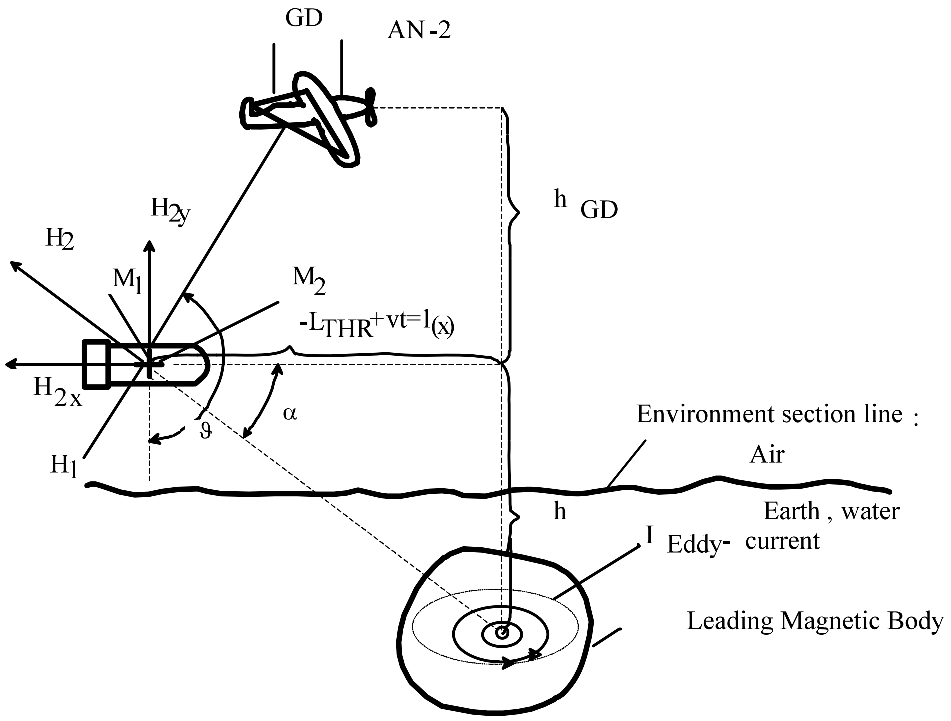

Fig.1. Dynamic model of the aircraft system that measures the ratio of the half-axises of the polarization ellipse of the magnetic field

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-axises 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-exis 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 moduls 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.

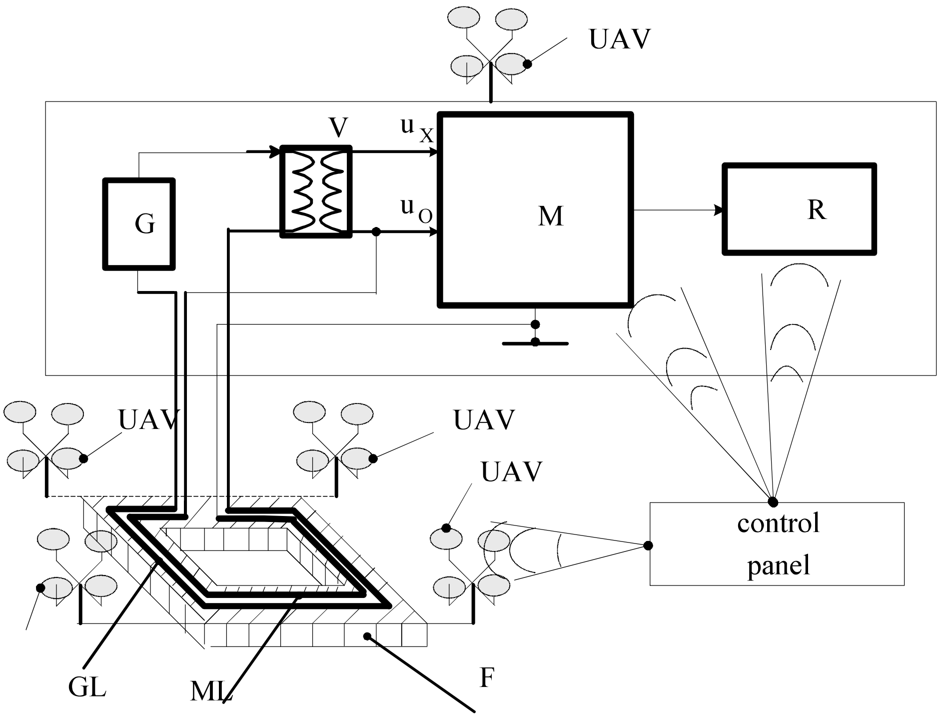

Fig. 2. Structural scheme of the system with generator and measuring loops

Based on Fig.3 for the vertical component of the tension of the secondary magnetic field in the receiving plane with a horizontal motion of the loops it is possible to write

$$H_{2y}(t) = H_{2m} \cdot \sin \omega t \cdot \sin \alpha(t) = H_{2m} \cdot \sin \omega t \cdot \sin(arctg \frac{h}{-L_{THR} + vt}), \quad (1)$$

where: H_{2m} – the amplitude of the component of the secondary magnetic field;

$\alpha(e) = arctg \frac{h}{-L_{THR} + vt}$ – time-varying angle between the horizontal flight line and the direction to the conducting body with ferromagnetic properties;

h – the height of the flight generator GL and the measuring ML of the loops over the investigated half-space (ground, water);

$l_x(t) = -L_{THR} + vt$ – the projection of the distance between the center of the measuring loop and the body on the horizontal line, which coincides with the direction of movement of the system;

L_{THR} – minimum horizontal distance in the direct flying from the center of the receiving loop to the vertical passing through the center of the body;

v – the horizontal velocity of the frame F movement, which is transmitted by a plurality of UAV.

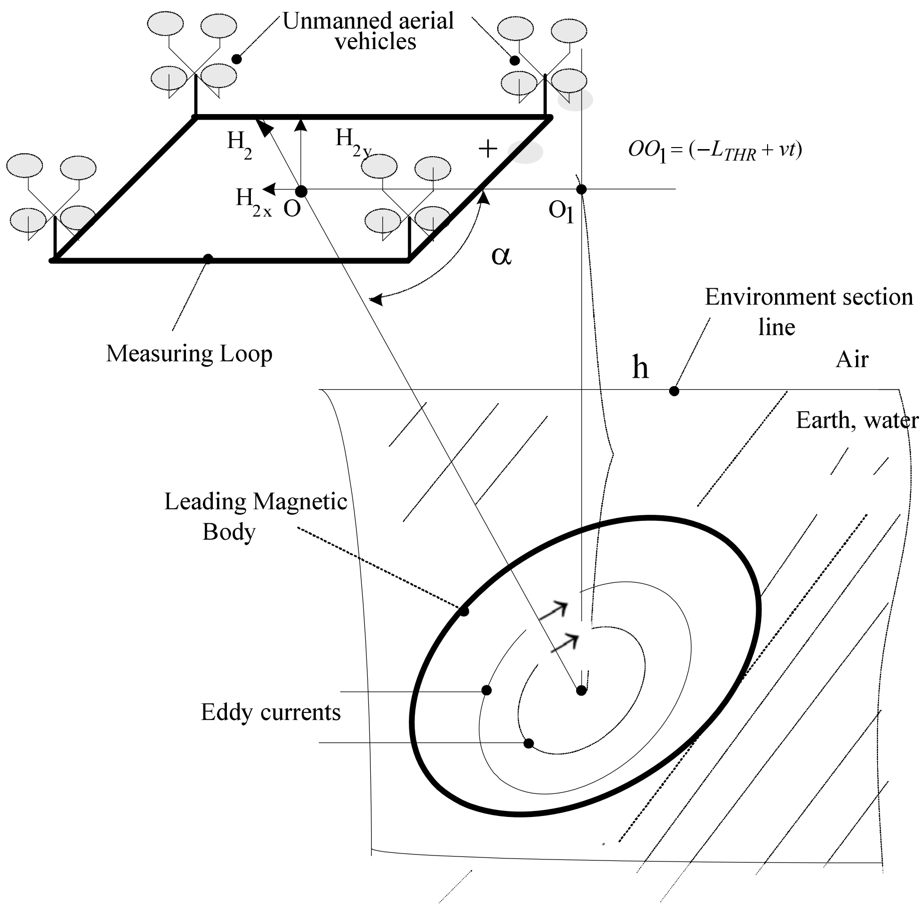

Fig.3 To substantiate the signal from bodies with ferromagnetic properties

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

$$e_{2y} = -\frac{d\Phi_{2y}(t)}{dt} = -WS\frac{dH_{2y}(t)}{dt} =$$

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

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

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

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.

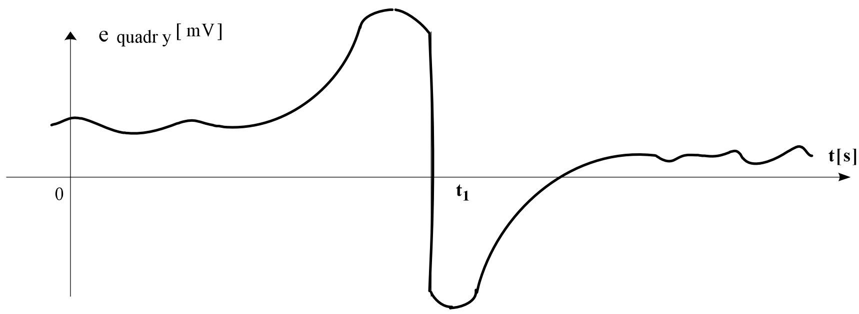

Fig.5. The signal which appearances from a body with ferromagnetic properties

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 аеробортова вихрострумова система з генерувальною та приймальною петлями для пошуку провідних підземних та підводних об'єктів. Створена динамічна модель такої системи. Модель обгрунтовує можливість використання системи для пошуку провідних об'єктів з немагнітними та магнітними властивостями. Глибина пошуку може складати сотні метрів.

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

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