New optical method for studying a magnetic track from a moving object

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Abstract. A new method for detecting a magnetic track from a moving magnetic object is presented. A technique has been developed to study the nature of changes in the magnetic field in a magnetic track using ferromagnetic fluid. The results of experimental studies are presented.

1. Introduction

The study of the structure of magnetic fields and physical phenomena associated with them is one of the urgent problems of fundamental and applied physics [1–8]. Using a magnetic field, carry out various studies and measurements [6-14]. The magnetic field is associated with the formation of a number of physical phenomena [15-19]. The obtained data on the value of the magnetic field induction and its structure help to understand many physical processes and related phenomena [1–4, 7, 20–23]. One of the most difficult in this area for the study of phenomena is the magnetic track, which occurs when a magnetic object moves in different environments (a comet or meteor in space, a ship at sea, etc.). The appearance of a magnetic track is associated with a change in the structure of the magnetic field lines in the zone of movement of the magnetic object.

Of particular interest are studies of the magnetic track at a depth in the marine area. The influence of external factors (water flow, wind, etc.) on the path destruction processes is insignificant. The currently relevant methods of monitoring the situation in various areas of the water area do not allow detecting a moving object at depths of more than 500-550 m [1–4, 20, 21–23]. The only effective method for detecting objects (magnetic) at such depths is the use of magnetometers, especially quantum ones, which are highly sensitive to variations in the magnetic field [1–4, 7, 24–27]. In some cases, the position of a moving object at such depths can be determined using fiber-optic antennas [28, 29]. When using a magnetometer (by immersing it in depth), it is possible to establish the presence of a magnetic track from a moving object in a marine environment. Also, on the basis of the readings of this device, it is possible to investigate the variation of the magnetic field variations in different parts of the magnetic track. Determine the rate of its destruction.
Conducting such experiments in real conditions is a rather complicated process. Therefore, we have developed a new optical method for the study of the magnetic track in the laboratory. In addition, experiments have shown that finding a magnetic track in sea space with a single magnetometer is an extremely difficult task. A reliable detection system is required that is resistant to diving to great depths. Its development requires additional research.

2. The method of studying the magnetic track and the method of its detection

With the movement of a moving object on the surface of the water, a peculiar wave (crest) is formed. The crest is formed due to the turbulent motion of water molecules during the movement of a moving object. The formation of this ridge is described by the Bernuli equation:

\[ p + \frac{p u^2}{2} + p g h = \text{const} \]

where \( p \) - the density of the fluid, \( u \) - the flow velocity, \( h \) - the height, \( p \) - the pressure, \( g \) - the acceleration of gravity.

This wave crest on the surface of a water body is determined by radar methods [23, 30]. If a moving object is at a depth of more than 550 m, the waves caused by the turbulent motion of the fluid, attenuate at the boundary of two water layers. This boundary is located at a depth of 500 - 530 m. A wave crest with a height \( h \) when moving a moving object at a depth of 550 m and more does not form on the surface of the sea water area. In addition, it is necessary to take into account that the turbulent movement of water at the indicated depths occurs at a pressure of more than 55 atm. Therefore, the process of forming a magnetic track behind a moving magnetic object that has left a certain zone is very fast. Empty space is filled with water at high speed.

The magnetic track that we study is formed in the process of moving molecules, which in turn affect the change in the structure of the magnetic field lines. The magnetic field lines are closed on the magnetic object and open when it moves. Based on previous studies of the structure of the magnetic field lines in the interpolar space of the magnetic system [2, 4, 7, 20, 21], it was decided to create a magnetic track in an aqueous solution of single-domain magnetite nanoparticles (ferromagnetic liquid) with an average particle size of 14 nm. The concentration of the liquid was 0.025 particles per unit volume. In the role of the surface substance (surfactant) acted oleic kilot. Magnetic fluid is placed in a quartz cell [2, 4, 7, 20, 21]. The nature of the motion of a magnetic object in a ferromagnetic fluid was reproduced by a point magnetic field of the “magnetic pen” with an induction at the end of the order of 1 T. The volume of the disturbing magnetic field is 1 mm3. Laser radiation is applied to the transparent face of the cuvette. The other side of the cuvette is covered with an opaque, poorly reflective material. “Magnetic pen” was moving along this face. The ferromagnetic liquid cuvette was in a laboratory magnetic field. A speckle pattern is recorded in reflected light by a specialized video camera. The operation of the experimental setup for registration of speckle structures was considered in more detail in [2, 4, 20, 27, 31]. Laser radiation with \( \lambda = 632.8 \text{ nm} \), various photodetectors and optical systems were used to register speckle pictures [2, 4, 20, 27, 31-36].

In Figure 1 shows the data of the pattern without the influence of the magnetic pen on the ferromagnetic fluid and when it moves along the opaque face of the cuvette. The movement of a moving magnetic object in a magnetic fluid is simulated by moving along an opaque cell wall of a one-sided magnetic needle system with an induction on the tip of the order of 1 T. In the area of a magnetic needle, nanoparticles are placed on the magnetic field lines of its magnetic field (fig. 1.b). Formed agglomerates (speckle structure). It should be noted that at a high speed of movement of the magnetic “needle” along the wall, a wave arises on the surface of the magnetic fluid. This is due to the fact that under the action of a strong alternating magnetic field, particles quickly tend to occupy a certain position in space.
Figure 1 (a, b). The diffraction pattern of the laser radiation in the case of the magnetic liquid placing: (a) in magnetic field Земли; (b) in field movable magnetic needle.

The experimental results obtained, as well as the data in previous studies [2, 4, 20, 27, 31], allowed us to develop a new method for determining the presence of a magnetic track in the marine water area. For the practical implementation of our proposed method, it is proposed to place optical sensors based on ferrofluidic cells [2, 4, 20, 27, 31] developed earlier in a construction in the form of squares with a side of 8-10 m. To confirm the possibilities of determining the presence of a magnetic track in a water area with the use of an optical sensor, we have developed and assembled an experimental setup. Its structural diagram is presented in figure 2.

Figure 2. Structural scheme of experimental setup: 1 - power supply; 2 – solenoid; 3 - rectangular vessel; 4 – water; 5 - non-magnetic material; 6 - ferrofluid cell; 7 – the body; 8 – the laser; 9 - diaphragm; 10 – the lens; 11 - photosensitive element; 12 - polarizer; 13 - processing device;
Magnetic fluid (an aqueous solution of magnetite nanoparticles with a concentration of 0.03 - surfactant - oleic acid) is placed on a stand made of non-magnetic material 5 in a ferrofluid cell 6. The cell is placed in a magnetic field of a solenoid 2. The induction of a magnetic field B1 in the cell area of 6.8 mT. Between the solenoid and the ferrofluid cell is a rectangular vessel 3 with a liquid medium 4 (water). The length of the vessel 3 moves the body 7, made of permalloy. To register the reflected laser radiation from speckle structures, the same registration system is used as in figure 1. In figure 3.a shows the recorded image of the camera 11 of the reflected laser radiation from speckle structures formed by nanoparticles on the magnetic field lines of the solenoid.

![Figure 3 (a, b, c). The diffraction pattern of the laser radiation in the case of the magnetic liquid placing: (a) in a uniform magnetic field; (b) a magnetic field force lines are closed on the body; (c) 2 minutes passed after the closure of all the magnetic field lines on the body.](image)

When the body 7 moves through the vessel, the magnetic field lines of the solenoid close to 7. The agglomerates that were formed in the magnetic field begin to collapse under the action of thermal motion, and the recorded speckle pattern changes. Fig. 3.b shows the image of the reflected radiation from the speckle pattern of nanoparticles 120 seconds after the magnetic field lines of the solenoid close to the body. This is the average transit time of a moving magnetic object through a point in space at a depth in the zone of formation of a magnetic track.

Analysis of the results shows the possibility of registering changes in field variations in a magnetic track with an optical sensor. By processing images from optical sensors spaced at equal distances, it is possible to construct diagrams of variations in the magnetic field at a depth of the water area. Experiments have shown that according to these diagrams, it is possible to establish the presence of a magnetic track at the depth of the water area.

3. Conclusion
The results obtained confirm the possibility of studying the magnetic track with optical sensors. The data obtained using the developed system using optical sensors allows us to establish the presence of a magnetic track in the marine area. Experimental data using the developed system in a specialized pool coincided with measurements performed by quantum magnetometers.

The experiments have shown that the data on the amplitude of magnetic variations, taking into account their nature of changes in the track volume, allow determining the time of its formation and the direction of movement of the magnetic object with an error of no more than 30%. The accuracy of the definition of this information meets the requirements for carrying out activities to control the water area.

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