Development of optical imaging formation system for research of magnetic track parameters from moving object

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Abstract. The necessity of the magnetic track research from the moving object is substantiated. An optical system has been developed to detect a magnetic track at sea depth from the moving magnetic object. A method of processing and decoding optical images formed using a ferrofluid cell and laser radiation is proposed. The results of experimental studies are presented.

1. Introduction

Research of physical phenomena that are formed as a result of interaction of a magnetic field with matter is one of the most difficult tasks of both fundamental and applied physics [1-8]. There have been countless researches that show that a large amount of information is embedded in the variations of the magnetic and electromagnetic fields after its interaction with the substance [8-15]. There is new knowledge about the structure of matter, various physical processes, the dynamics of their development when this information decipher. This information will help to more fully describe the various phenomena, determine the parameters and develop methods for measuring them in practical use.

The using of magnetic field variations allows to realize the investigations of the magnetic tracks. This phenomenon is formed during a movement of the magnetic object in the different media. The most striking example of magnetic tracks is the movement of a comet or meteorite in airspace, a ship at sea, etc. The appearance of the magnetic track is associated with a change in the structure of the magnetic field lines in the movement zone of the magnetic object.

Research the magnetic track at the depth of the sea with high pressure of water layers is one of the complex issues. In this case, the influence of various external factors that are present during the formation of the magnetic track in other conditions (for example, the flow of water, wind, etc.) on the processes of destruction of the track are insignificant. Currently of most methods which are used for monitoring the situation control in various sectors of the water area do not allow detecting a moving magnetic object at depths of more than 500-530 m [15-24]. The only effective method of detecting magnetic objects at such depths is the use of high-precision magnetometers, especially quantum, with high sensitivity. High sensitivity makes it possible to measure small variations in the magnetic field.
[10, 25–27]. Information about them change allows to determine the presence of a magnetic object in a given area, both mobile and stationary. By immersing the magnetometer to a depth, it is possible to establish the presence in the marine environment of a magnetic track from a moving object. Also, based on the readings of this device, it is possible to investigate the change in magnetic field variations in various parts of the magnetic track and determine the rate of its destruction.

Carrying out such experiments in real conditions is a rather complicated process. In addition, to search for a magnetic track in a large sector of the sea depth, it is necessary to use more than 10 magnetometers and special vessels for them maintenance. This is extremely difficult to implement. Therefore, for getting the necessary information for the preparation and conduct of experiments at sea depths, we developed an experimental stand and an optical method for studying the magnetic track in the laboratory. The particular attention in this method was paid to the formation of optical images during the movement of a magnetic object. In addition, it should be noted that for detecting a magnetic track is necessary the reliable system which is steady to immersion of the great depths. This system should provide a process for measuring variations in the magnetic field in a large plane and be easily moved at depth. Its development requires additional research.

2. Methods of magnetic track detection and experimental setup

The magnetic track of investigation by us is formed in the process of closing and opening the lines of force of a magnetic field on a magnetic object during its movement. It should be noted that molecules located next to a magnetic object are magnetized (the magnetic field of a moving magnetic object can be 20-30 times greater than the Earth’s magnetic field). In addition, an empty space is formed behind the departed moving magnetic object at a depth. This space is filled with great speed, since the pressure at such depths is more than 55 atm. At a high speed of a moving object, the process of magnetic track formation becomes very fast. Turbulent flows play the main role in this process.

Based on the completed investigations of the structure of magnetic field lines under the influence of perturbing magnetic fields [13, 28–29], it was decided to create a magnetic track in an aqueous solution of single-domain magnetite nanoparticles (ferromagnetic fluid), the average particle size of which is 12 nm. The volume concentration of magnetite particles is 0.025. The oleic acid acted as a surface substance (surfactant). The magnetic fluid is placed in a quartz cuvette. The nature of the motion of a magnetic object in a ferromagnetic fluid was reproduced by a point magnetic field of a “magnetic pen” with induction at the end of the order of 1 T. The scope of the perturbing magnetic field that was moving was 1 mm3. The laser radiation with $\lambda = 632.8$ nm was applied to the transparent face of the cell. A material opaque to laser radiation was deposited on the other side of the cell. A “magnetic pen” moved along this face. A cell with ferromagnetic fluid was in the laboratory magnetic field of the Earth. In the reflected light, a speckle pattern is recorded by a specialized video camera. For the formation and the focusing of images as well as the transformation of laser radiation are used the various optical elements and techniques [30-40].

Figure 1. The diffraction pattern of laser radiation in the case of the placement of a magnetic fluid: (a) in the Earth's magnetic field; (b) in a magnetic field when a magnetic pen is moving.
In fig. 1 shows optical images in reflected laser radiation without the influence of a “magnetic pen” on a ferromagnetic fluid and when it moves along an opaque face of a quartz cell. In the zone of action of the “magnetic pen”, nanoparticles are placed on the lines of force of the magnetic field (fig. 1.b). The agglomerates (speckle structures) are formed. It should be noted that at a high speed of movement of the “magnetic pen” along the wall, a wave appears on the surface of the magnetic fluid. This is due to the fact that under the influence of a strong alternating magnetic field, turbulent motion of magnetite particles in a ferrofluid liquid occurs due to a sharp change in energy with increasing magnetic field induction. This process reproduces the turbulent motion of water molecules with magnetization at a depth during moving a magnetic object.

The obtained experimental results, as well as data obtained as a result of previous studies [13, 28, 29] allowed us to develop an experimental setup for studying the magnetic track. Its structural diagram is presented in fig. 2.

![Figure 2](image)

**Figure 2.** The block diagram of the experimental setup: 1 - power supply; 2 - solenoid; 3 - rectangular vessel; 4 - water; 5 - non-magnetic material; 6 - ferrofluid cell; 7 - case; 8 - laser; 9 - aperture; 10 - lens; 11 - photosensitive element; 12 - polarizer; 13 - processing device.

The magnetic fluid (an aqueous solution of magnetite nanoparticles with a concentration of 0.03 - surfactant - oleic acid) is placed on a support of non-magnetic material 5 in a ferrofluid cell 6. The cell is placed in the magnetic field of the solenoid 2. Induction of the magnetic field B1 in the cell placement area of 6.8 mT. A rectangular vessel 3 with a liquid medium 4 (water) is located between the solenoid and the ferrofluid cell. Along the length of the vessel 3 moves the body 7, made of permalloy [41-44]. For image registration of the reflected laser radiation from speckle structures is using the special optical system developed by us. In fig. 3.a shows the image of the reflected laser radiation from speckle structures formed by nanoparticles on the lines of force of the magnetic field of the solenoid recorded by photosensitive element 11 (fig. 2).

The movement of the body 7 through the vessel closes the force lines of the magnetic field of the solenoid to 7. The agglomerates that are formed in the magnetic field begin to collapse under the action of thermal motion, and the recorded speckle pattern changes. In fig. 3.b shows the image of reflected radiation from the speckle pattern of nanoparticles through tz = 20 s after the magnetic field lines of the solenoid are shorted to the body and at tz = 120 s - fig. 3.c. The movement of the body 7 through the vessel closes the force lines of the magnetic field of the solenoid to 7.

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lines of the solenoid are shorted to the body and at tz = 120 s - fig. 3.c. The value tz = 120 s is the average travel time of a moving magnetic object through a space point at a depth in the zone of formation of the magnetic track. The longitudinal relaxation time T1, which determines the process of magnetization of the substance, for water at a depth of less than 1 s. For the complete magnetization of a liquid medium, 3T1 time is required [1, 2, 25-27, 45].

**Figure 3.** The diffraction pattern of laser radiation in the case of magnetic fluid: (a) in a uniform magnetic field; (b) - magnetic field lines are closed on the body; (c) - 2 minutes have passed after the closure of all the lines of force of the magnetic field on the body.

3. The results of experimental research and their discussion

It should be noted that the process of the magnetic track formation depends both on the speed of movement and on the magnitude of the induction B of the magnetic field of the moving object. As an example, in fig. 4 shows images of reflected radiation from the speckle pattern of nanoparticles through tz = 5 s (fig. 4.b) after the field lines of the magnetic field of the solenoid are closed to the body and at tz = 30 s - fig. 4.c.

**Figure 4.** The diffraction pattern of laser radiation in the case of a magnetic fluid: (a) in a uniform magnetic field; (b) - magnetic field lines are closed on the body; (c) - 2 minutes have passed after the closure of all magnetic field lines on the object.

The obtained result of a change in the structure of the recorded optical image, which was formed from the movement of a moving object from a material with a low value of B0 = 153 μT at atmospheric pressure, confirms the influence of the speed of the object on the process of formation of the magnetic track. With increasing pressure of the water layer and the volume of the moving object, this process will be more pronounced.

As an example, in fig. 5 shows the images of reflected radiation from the speckle pattern of nanoparticles through tz = 5 s (fig. 5.b) after the magnetic field lines of the solenoid are closed to a moving object with induction B0 = 1.7 mT (previously used permalloy), and at tz = 30 s - fig. 5.c. A
magnet made of a samarium-cobalt alloy was used as a moving object. The direction of the lines of force of the magnetic field of the solenoid and magnet coincide.

![Figure 5.](image)

**Figure 5.** The diffraction pattern of laser radiation in the case of a magnetic fluid: (a) in a uniform magnetic field; (b) - magnetic field lines are closed on the body; (c) - 2 minutes have passed after the closure of all magnetic field lines on the object.

Analysis of the obtained results in fig. 4 and 5 show a change in the nature of the optical image from speckle structures after the field lines are closed to a magnetic object. The process of the speckle structures destruction depends from the object speed in all directions of the recorded image.

It shows the possibility of the changes detecting in magnetic field variations by optical sensor. By processing images from optical sensors spaced at equal distances, it is possible to construct the diagrams of magnetic field variations changes and to establish the presence of the magnetic track on the depth of the water area.

![Figure 6.](image)

**Figure 6.** (a, b). The dependence of the intensity I on the distance between the force lines of the magnetic field: a) in a homogeneous field $B_0$; b) the magnetic field from the mobile object.

4. Conclusion

The research results allowed to develop a device in the squares form with the side of 8-10 m in the corners of which there are optical sensors based on ferrofluid cells for detecting a magnetic track at a depth of the sea. The data of experiments on the magnetic track detection from moving magnetic objects in the specialized pool with the using developed by us the sensor system confirms the measurements are made by proton immersion magnetometer.

The completed experiments showed that for determination of the magnetic track formation time and the direction of the magnetic object movement at amplitude change of the magnetic field
variations, it is more advisable to use a magnetometer. The sensitivity of the developed optical sensors in some cases is not enough to obtain a reliable result.

In figure 6, as an example, presents the distribution data in the diffraction pattern for the laser radiation transmitted through the ferrofluid cell.

5. References
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