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**DETECTION METHOD FOR UNDERWATER ROBOTS AND DRONES AND
DEVICE SUITABLE FOR ITS IMPLEMENTATION**

20 The invention relates to a detection method for search objects and a device for detecting search objects, such as underwater robots and drones.

The invention pertains to the field of detecting ferromagnetic underwater objects and other objects of artificial origin, particularly the detection of underwater robots and drones, which are widespread in the modern world.

25 The most difficult problem is the detection of stationary objects. These are so-called underwater "bookmarks" - robot capsules that are deployed underwater for many weeks, months or years, are activated by a signal, and after surfacing underwater or above water, operate and activate one function or another.

The detection of such underwater robot capsules is an extremely urgent task to ensure the security of sea and river ports, ships, and coastal infrastructure facilities.

30

State of the Art

There is a known hydroacoustic method for detecting objects in an aquatic environment. It is based on recording a hydroacoustic signal reflected from an underwater object [1].

5 The disadvantage of this method is the practical impossibility of detecting a stationary underwater object against the background of interference, especially due to bottom irregularities.

For the detection of ferromagnetic (and non-ferromagnetic) metal objects, an induction method is known [2].

10 The disadvantage of this method is the small detection range, comparable to the size of the search element (frame antenna).

The closest to the claimed invention is the magnetometric detection method, which allows for the detection of ferromagnetic objects in various environments, including in water [3].

15 It is known that the magnetometric method allows for recording spatial distortions of the Earth's magnetic field created by a ferromagnetic search object. The detection of objects whose construction includes ferromagnetic elements (body, mechanical and electrical parts) is possible in any natural environment: sea and fresh water, clay and sandy soils at great depths, ice, etc. The strength of the Earth's magnetic field is 0.34 Oersted at the magnetic equator, 0.66 Oersted at the magnetic poles, and 0.57 Oersted at middle latitudes (about 40 A/m in the SI system).

Magnetometers are most commonly used in this field. Using two magnetic receivers, a device is created to measure the difference in magnetic field induction at two points in space. In this case, the device is called a magnetic gradiometer.

25 The disadvantage of this method is the insufficient detection range of local ferromagnetic objects of no more than 6-8 meters. The characteristic dimensions of such objects are decimeters ... units of meters.

US 6,335,624 B1 discloses a detection of electrically conductive objects hidden near the surface in the seabed, such as mines laid near the coast.

DE 10 2016 112 524 A1 discloses a method for electromagnetic detection and investigation of a water surface for metallic foreign objects hidden under a bottom surface,
5 particularly for searching for unexploded ordnance.

US 5,598,152 discloses detecting submerged objects by creating electric or magnetic fields and measuring their deviations and changes. Magnetic objects cause a change due to their magnetization based on emitted electric or magnetic fields. Non-metallic objects submerged in seawater cause deviations of created electric or magnetic
10 fields by producing a "hole" in the conductivity pattern of the seawater.

AU 632320 B2 discloses detecting objects submerged in brine or salt water by creating magnetic fields and measuring their deviations and changes. The creation of magnetic fields occurs in a pulse-like manner with abrupt transitions from one essentially stationary voltage to at least one other essentially stationary voltage.

15 RU 2 444 765 C2 discloses detecting submerged objects by generating mechanical vibrations of the search object using a pulse-like magnetic field, which vibrations are then detected hydroacoustically.

US 6,215,734 B1 discloses a projector for generating electrohydraulic sound and pressure waves. This includes an energy source, such as a capacitor, arranged with-
20 in a radius of about one meter of an electrode arrangement. Larger projectors can be formed by arranging multiple projectors, and even larger projectors can be formed by arranging them in a row.

Disclosure of the Invention

One of the objectives underlying the invention is to increase the detection range of
25 ferromagnetic underwater objects and other objects such as underwater robots and drones that have a complex and heterogeneous structure.

The objective is achieved by the features of the independent claim. Advantageous developments result from the dependent claims.

5 The detection of ferromagnetic underwater objects is accomplished by the additional introduction of a shock-pulsed magnetic field channel. This channel magnetizes the ferromagnetic elements of the detected object, while the change (increase) in the magnetic field of the object occurs due to the residual magnetization, which is recorded by a magnetometric receiver.

10 The detection of ferromagnetic (and non-ferromagnetic) underwater objects is based on additional pulsed mechanical force impact by electrohydraulic shock and informational influence by a harmonic magnetic field from a magnetic frame antenna on the detected object with registration of the parametric modulation ("burst") of the reflected harmonic magnetic field.

15 The mechanical force impact of an electrohydraulic shock on a detected metal object causes a short-term (pulse) change in the distances (r and h) between the search object, magnetic loop antenna, and receiver.

This results in a parametric amplitude modulation ("burst") of the reflected signal of the investigating harmonic magnetic field, which is registered as an additional information feature with a magnetometric receiver.

This improves the search performance.

20 Most hulls (bodies) of underwater robots and drones are made of ferromagnetic materials. However, the possibility of manufacturing them from other materials that do not exhibit magnetic properties, such as titanium, bronze, brass, and others, must be considered. A hydroacoustic shock wave generates a pulsed overpressure and penetrates the ferromagnetic or non-ferromagnetic hull of the detected object.

25 Inside the housing shell are movable and stationary parts of the object (robot or drone): electric motor, battery, electromechanical drives of manipulators, mechanical

elements of execution modules, devices of the control system. Their positions within the housing shell are connected by fastening elements, pulleys, hinges, and springs.

The overpressure pulse of the electrohydraulic shock penetrates the shell and causes a resonant "splashing", the object "trembles".

- 5 The presence of deeply penetrating properties of pulsed magnetic and mechanical shock fields through the body shell of the detected object leads to a partial disruption of the function of electronic circuits inside the object, which changes their operating mode and leads to a change in the level of the reflected signal in the form of a characteristic "burst".
- 10 Thus, due to even partial damage to the electronic circuits (electromechanical elements) of the underwater robot and drone, additional information about the object appears.

An important direction in increasing the maximum detection depth is to create conditions under which the search object distorts the Earth's magnetic field more strongly.

- 15 This is achieved by the method of remote parametric magnetization, which is a special case of parametric location in semiconducting media.

In a first approximation, the locally detected object can be replaced by a solid ferromagnetic sphere. A ferromagnetic sphere in a uniform magnetic field of the Earth acts like a magnetic dipole with a moment determined by the formula:

- 20 (1)

$$\vec{M}_{sp} = 4\pi R_{sp}^3 \frac{\mu_1 - \mu_0}{\mu_1 + 2\mu_0} \mu_0 \vec{H}_0$$

where

R_{sp} – radius of the ferromagnetic sphere (search object):

μ_1 – magnetic permeability of the sphere material,

μ_0 – magnetic permeability of the surrounding natural environment

(water, soil) and

H_0 is the constant magnetic field of the Earth.

- 5 In practice, when searching for local ferromagnetic objects, usually not the absolute value of the anomalous magnetic field is measured, but its gradient.

The maximum detection range of a ferromagnetic sphere with a magnetic gradiometer can be estimated with the formula:

(2)

$$10 \quad r_{det} = \sqrt[4]{\frac{6R_{sp}^3 \mu_0 H_0}{\frac{\partial B}{\partial r}^{min}}}, m$$

where min is the field sensitivity of the gradiometer T/m (distortion of the magnetic field in space per unit length, where B is the magnetic induction).

Real

- 15 The sensitivity of modern portable magnetic gradiometers is $10^{-7} \dots 10^{-8}$ T/m. With a ferromagnetic sphere radius of 0.3 ... 0.5 m, its detection range at a sensitivity of 10^{-8} T/m is 6 ... 8 m.

The vast majority of bodies of underwater robots located in the water column are made of polycrystalline ferromagnetic materials, mainly steel.

- 20 Depending on the chemical composition of the alloy and the geometric shape of the object, various structural and phase changes of its physical and mechanical properties occur during magnetization (Fig. 2). These changes generally lead to a qualita-

tive increase in the efficiency of devices for detecting search objects such as under-water robots and drones comprising search equipment, regardless of the principles of their construction.

Therefore, phase changes generally lead to an increase in the intrinsic magnetic field
5 due to a stronger alignment of the magnetic moments of the domains.

The detection range of a magnetized ferromagnetic sphere can be estimated with the following expression:

(3)

$$r_{det} = \sqrt{\frac{6R_{sp}^3 \mu_0 (H_0 + K_{dem} H_{ext})}{\frac{\partial B}{\partial r}^{min}}}, \text{ m}$$

10

where K_{dem} - is the demagnetization coefficient (for a sphere it is 0.33).

H_{ext} - is the amplitude of external magnetization, A/m.

From expression (3) it follows that magnetization of the sphere by a pulsed magnetic field with an amplitude of 1 kA/m increases the detection range by about 80%.

15 It should be noted that the duration of the magnetization pulse can be quite short. For a wall thickness of the search object of 1 ... 10 mm, it is only tenths ... hundredths of a second. It is determined by the thickness of the "skin layer" for steel, based on the shielding theory [4, 5]. The short duration of the pulses with a long pause (units ...
20 tens of seconds) ensures low power consumption in the technical implementation of the method.

To test the most complex component of the proposed method, a field experiment was conducted.

The detection range of ferromagnetic objects in fresh and sea water is the same as in soil. Moreover, in the latter case, soil moisture has no effect on the detection range. When searching in water, the magnetometer was mounted on a non-magnetic floating vehicle (rubber boat). The vehicle did not contain any ferromagnetic elements (brackets, nails, staples, etc.) in its construction.

The experimental setup generated an amplitude of a pulsed magnetic field of 500 ... 700 A/m with a duration of 20 ms at the location of the search objects. The search objects were:

- Steel balls with a diameter of 5 cm and 10 cm (reference search objects);
- A steel pipe with a diameter of 10 cm and a length of 30 cm (model of an underwater robot).

A portable magnetometer MBI-2 with a sensitivity of up to 10^{-7} T/m was used as the search instrument.

The measurements were also carried out in fresh water ($\epsilon=80$, $n=10^{-2}$ S/m) in a 2.5 m deep pond. The detection range of objects was the same as in air. The MBI-2 magnetometer was placed on a rubber boat.

Ferromagnetic search objects exposed to remote magnetization at $H_{ext} \approx 500 \dots 700$ A/m were detected at distances 1.5 ... 2 times higher than the limit capabilities of the MBI-2 magnetometer.

As mentioned above, the invention proposed a method of remote parametric magnetization of the search object to increase the detection range of ferromagnetic objects using the magnetometric method. However, this method only detects ferromagnetic objects.

New in the invention (the method according to claim 2) is the increase in detection range not only of a ferromagnetic underwater object, but also of any metallic search

object. It also becomes possible to perform recognition and determine the recognition range.

The claimed method additionally includes two channels: The first is a channel of pulsed mechanical force impact by electrohydraulic shock, and the second is a channel of informational influence by a harmonic magnetic field from a magnetic loop antenna on a detected object with registration of the parametric modulation ("splash") of the reflected harmonic magnetic field.

The search object is irradiated with a probing low-frequency magnetic field, and the field reflected from the object surface is recorded. Additionally, a pulsed mechanical force impact is exerted from an electrohydraulic shock installation (EHU).

The search object has a rather complex structure, so the reflection diagram of the secondary magnetic field from the real object also has a complex needle shape. This enhances the effect of amplitude parametric modulation of the signal during back-reflection, as the phase in the reflected harmonic field also changes. Therefore, when using a phase-sensitive receiver, the effect of parametric modulation is significantly enhanced.

Considering the above, the secondary (reflected) magnetic field of the search object is determined by the expression:

(4)

20

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{\ddot{\vec{M}}}{r^3} - \frac{1}{4\pi\epsilon_0} \frac{\ddot{\vec{p}}}{r^3}$$

where

M is the magnetic moment of the radiating frame antenna

$$0 = 4\pi \cdot 10^{-7} \text{ H/m}$$

rsf is the radius of the search object (sphere), m

h is the distance between the search object and the magnetic loop antenna, m

r is the distance between the search object and the receiver of the reflected magnetic
5 field, m

D is a function describing the anomalous low-frequency magnetic field on the surface
of an object [6].

Since the distances to the detected object are not large and the frequencies used are
rather low (hundreds of Hz - units of kHz), the losses of the harmonic LF magnetic
10 field in seawater ($\epsilon=80$, $n = 4 \text{ S/m}$) are insignificant.

Under the influence of a hydroacoustic shock from the EHU installation, there is a
short-term (pulse) change in the distances (r and h) between the search object, mag-
netic frame antenna, and receiver. This leads to a parametric amplitude modulation
("burst") of the reflected signal. At the same time, characteristic resonance oscilla-
15 tions also occur. Each object type has its own vibration spectrum, which allows it to
be recognized. In addition, optimal filtering of the received signal is possible, which
increases the sensitivity of the receiver and thus the detection range.

By measuring the transit time of a hydroacoustic shock from the EHU installation to
the search object, it is possible to estimate the distance to this object [7]. In this case,
20 the impact velocity in water is known to be at a stable value of 1485 m/s.

Practice shows that stationary robots - "bookmarks" in sleep mode - can hide against
the background of the seabed topography in layers of silt and bottom sediments,
making their search extremely difficult. The passage of mechanical vibrations in the
form of hydroacoustic waves through these layers is accompanied by significant
25 losses.

In the claimed invention (the method according to claim 3), it is proposed to use the deeply penetrating properties of the magnetic field (which propagates equally in both soil and seawater) and, as a mechanical effect, the force of shock waves.

5 The presence of deeply penetrating properties of pulsed magnetic and mechanical shock fields through the body shell of the object to be detected leads to a partial malfunction of the electronic circuits inside the object, which leads to a change in the reflected signal in the form of a characteristic "burst". Thus, in connection with even partial damage to the electronic circuits of the underwater robot and drone, an additional information sign appears. The required parameters of the pulsed magnetic field
10 are listed below:

In a first approximation, these local search objects can be represented as a hollow sphere or elongated spheroid with electronic elements inside. It is known that the malfunction of typical radio circuits caused by induced voltages begins to become noticeable at a pulsed magnetic field strength of more than 100 A/m [8,9]. The amplitudes of the voltages induced in the circuits and their shape are mainly determined
15 by the following factors:

- Magnetic field strength, rise and fall time;
- geometric dimensions of the circuit contours;
- designations of the components;
- 20 • mutual alignment of circuits and magnetic field vector;
- electrical mode (supply voltage, sensitivity to polarity reversal of input signals);
- constructive arrangement of the circuit mounting relative to the metal housing of the device.

The penetration of the pulsed magnetic field into the shielding structures occurs through two mechanisms: field diffusion through the walls due to the non-ideal conductivity of the latter, field penetration through holes.

As is known, a pulse signal can be represented as a sum of harmonic components.

- 5 In a rigorous environment, to determine the penetration of harmonic electromagnetic fields that penetrate into the interior of solid conductive shields, a boundary problem is posed: Maxwell's equations are considered in three regions (in the outer, in the walls of the shield and in the inner). For shields (cases) of the simplest configurations, analytical expressions for transfer functions are obtained, i.e. the ratio of the
10 field that penetrated the shield to the external field [10]. From the transfer function, the impulse response of the screen can be determined by an inverse Fourier transform. However, the frequency dependence of the transfer functions of even the simplest screens is still quite complicated, and it will not be possible to obtain an expression for the impulse response of the screens in analytical form with a finite number of
15 terms [11].

With a simplified solution to the problem of penetration of a pulsed magnetic field through the metal shell of the screen, it is possible to use the average frequency of the video pulse spectrum. This makes it possible to apply the mature insights of the theory of propagation of harmonic electromagnetic fields through conductive media.

- 20 The propagation process of a harmonic magnetic field in a conductor is described by the expressions:

(5)

$$H_f = H_1 e^{-\alpha h}, k_\alpha = \frac{H_f}{H_1}$$

(6)

25

$$\alpha = \sqrt{\frac{\gamma \mu_{rel} \mu_0 \omega_{sur}}{2}}$$

h - is the penetration depth of the field into the metal, m

$\mu_0 = 4\pi \cdot 10^{-7}$ - magnetic permeability in vacuum, H/m

The average frequency of the video pulse spectrum is:

(7)

$$F_{avg} = \frac{1}{2\Delta T}, \text{ Hz}$$

where ΔT is the pulse duration of the magnetic field.

In turn:

(8)

$$\omega_{sur} = 2\pi F_{sur}, \text{ Hz}$$

10

The attenuation coefficient K_a - is the ratio of the amplitude of the magnetic field H_f in the thickness of the conductor (metal) to the amplitude of this field at its surface (before penetration into the metal) H_1 .

15 Currently, the housings (shells) of small underwater devices (robots and drones) are often made of titanium instead of steel. This is due to two factors:

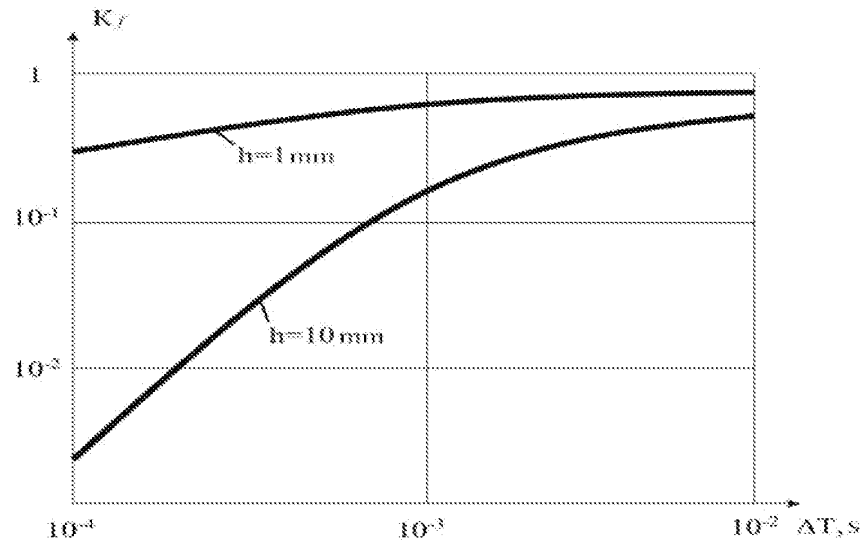
- higher strength of titanium compared to steel;
- lack of magnetic demasking properties, which makes their detection more difficult.

The wall thickness of the shell is usually a few millimeters, i.e. from 1 to 10 mm.

20 Graph 1 shows the dependencies of the attenuation coefficient of the pulsed magnetic field on the duration of these pulses. A reduction in duration increases the average frequency of the spectrum, which leads to an increase in field attenuation in the thickness of the metal (titanium).

Properties of titanium in the calculations:

- electrical conductivity $\gamma = 2 \cdot 10^7$ S/m,



Graph 1 Dependencies of the attenuation coefficient of a pulsed magnetic field in a metal on the pulse duration. Housing material (screen) – titanium.

- The relative magnetic permeability is equal to 1 (paramagnetic).

Graph 1 shows that with a magnetic field pulse duration of more than 1 ms and a titanium shell thickness of 1 mm to 10 mm, the losses are insignificant, as the field penetrates into the screen. This allows the use of a pulsed magnetic field to deactivate the internal modules of various underwater devices that contain electronic components in their design.

By incorporating an electrohydraulic shock or an electrohydraulic installation (EHU) or device generating an electrohydraulic shock pulse, an intensity of the pulsed magnetic field of 100 A/m and more can be generated. However, in this case, the battery

of high-voltage capacitors is not connected to the spark gap, but to a frame antenna with a large diameter (several meters).

The pulse-like mechanical force impact by electrohydraulic shock also has a high penetrating ability, both through the ferromagnetic shell and through the walls of the object body made of other materials.

It is known that most hulls (bodies) of underwater robots and drones are made of ferromagnetic materials. However, the possibility of manufacturing them from other materials that do not exhibit magnetic properties, such as titanium, bronze, brass, and others, must be considered.

10 A hydroacoustic shock wave generates a pulsed overpressure and penetrates through the non-ferromagnetic hull of the object to be detected.

Movable and stationary parts of the object (robot or drone) are housed within the body shell: electric motor, battery, electromechanical drives of manipulators, mechanical elements of control modules, control system devices. Their positions within the body shell are connected by fastening elements, pulleys, hinges, and springs.

An overpressure pulse from an electrohydraulic shock penetrates the interior of the shell and causes a resonant "splashing", the object "trembles".

The electronics of underwater robots and drones can be disabled by shock waves [12–14]. Such a strike is possible with an electrohydraulic shock. A peculiarity of this process is that the conversion of electrical energy into mechanical energy occurs without intermediate links. The pressure in the discharge channel between high-voltage electrodes (characteristic distances of units ... tens of centimeters) can reach tens of thousands of atmospheres. The voltage value is usually in the range of 10 kV to 100 kV. In this case, the time of the electrical discharge itself is usually units ... tens of microseconds. Such times are typical for explosions of small charges (tens of grams - units of kilograms) of ordinary TNT.

The expression for estimating the pressure at the shock wave front in water generated by an electrohydraulic unit (EHU) has the form:

(9)

$$\Delta P = 1.2(\sqrt[3]{\eta C U^2})/R, \text{ atm}$$

5 (10)

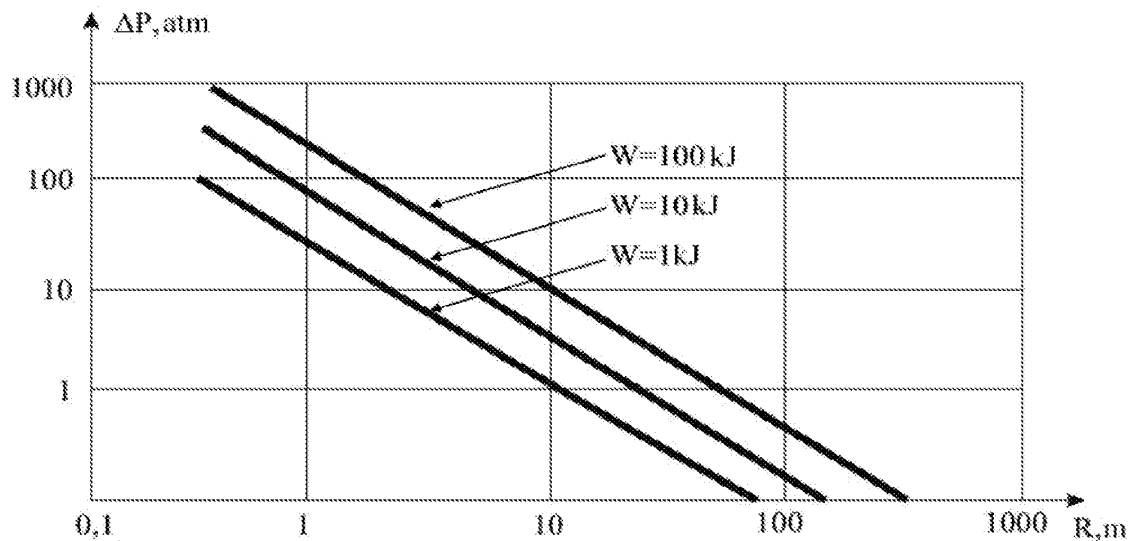
$$W = \frac{C U^2}{2}, \text{ J}$$

where C - is the capacitance of the capacitor bank, F

U – is the voltage on capacitors, V

10 η - is the conversion coefficient of the electrical energy of the discharge into the mechanical energy of the shock wave ($0 < \eta < 0.35$).

Graph 2 shows the dependence of the pressure at the front of the shock wave generated by the EHU installation on the distance (at $\eta = 0.25$).



15 **Graph 2** Dependencies of the pressure at the front of the wave generated by the EHU installation on the distance

The deactivation of underwater objects is likely in two cases:

- Destruction of the metal housing (titanium, steel);
- Deactivation of various electronic devices in the hull.

In the first case, the pulse pressures should be hundreds of atm, in the second case
5 tens of atm (approximately).

An analysis of modern underwater robots and drones shows the presence of hydroacoustic sensors of various configurations in their orientation and targeting systems. Basically, sensitive hydroacoustic sensors are used, which are manufactured as one piece with the hull shell.

- 10 The failure of a vulnerable hydroacoustic receiving sensor is possible when the operation of the input-sensitive amplifier is interrupted due to the effect of a large pulse voltage generated by the piezoelectric sensor.

In the case of exposure to a regular object - a robot capsule - by an electrohydraulic force impulse and a pulsed magnetic field to deactivate the hydroacoustic and magnetic orientation and targeting sensors, it must be clear, however, that in sleep mode
15 the sensitive sensors are inactive and the electronic circuits are switched off, and there are protective devices for environmental contact sensors and electronics. In this regard, a failure of the hydroacoustic and magnetic orientation sensors of the robot capsule's targeting is unlikely.

- 20 Therefore, an important case for practice is the penetration of a hydroacoustic shock wave through the metal shell of the body.

Practically considered is a metal plate located in water. It is known that the pressure in an incident wave changes exponentially. Taking into account some simplifications (it is assumed that the shock wave propagates along the hull shell and structural el-

ements), the pressure behind the metal plate can be determined using equations [12-14]:

(11)

$$P_2(t) = \frac{2P_1}{2\gamma-1} \left[e^{-\frac{t}{\delta}} + e^{-2\gamma\frac{t}{\delta}} \right];$$

5 (12)

$$\gamma = \frac{\rho_0 c_0 \theta}{\rho \delta} ;$$

(13)

$$\theta = 1,5 \frac{R_0}{c_0} \left(\frac{R}{R_0} \right)^{1,18}$$

10

where P - density of the plate material,

δ - the plate thickness;

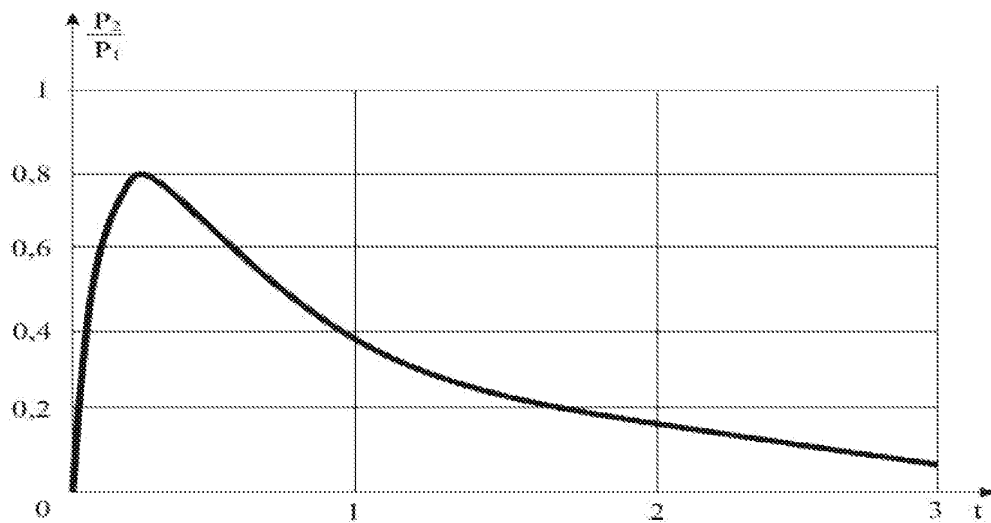
γ - the complex parametric coefficient;

ρ_0 the density of water;

15 c_0 the speed of sound in still water;

$\frac{R}{R_0}$ is the reduced distance.

From Graph 3 it can be seen that the protective properties of the metal plate, when placed in water, are insignificant. The maximum pressure behind the barrier is reduced by no more than 20%.



Graph 3 Pressure in a passing shock wave behind a metal plate as a function of time

Thus, almost all the energy of the mechanical force generated by the electrohydraulic shock is exerted on the shell and internal structure of the object to be detected.

5 It can be concluded as follows.

The above enables the detection of both ferromagnetic objects and objects whose shell is made of a non-magnetic material - a paramagnet (titanium, aluminum), to recognize them (according to the spectrum of mechanical resonance oscillations) and their range - according to the time - namely the passage of a hydroacoustic shock wave. Furthermore, there is the possibility of detecting stationary objects hidden under a layer of sludge and soil, due to the deep penetrating properties of pulsed magnetic and mechanical shock fields penetrating through the metal shell of the housing.

In this case, a magnetic frame antenna is used (alternately) in two modes: firstly, the mode of shock magnetization of the object, secondly, induction with the registration of parametric modulation.

In the first case, a force magnetic field is generated to magnetize the detected object; in the second case, the information-capturing parametric magnetic field.

The invention (method and apparatus) can be characterized by at least one of the following features in any combination:

- 5 - Residual magnetization of the search object
- parametric modulation of the reflected harmonic magnetic field
- penetrating properties of a pulsed magnetic field through a metal shell
- penetrating properties of electro-hydraulic impact through a metal shell
- partial micro-displacement of the search object.
- 10 At the same time, a dedicated electrohydraulic unit (EHU) is used as a powerful underwater source of electrical energy, which has as its load:
 - 1 - in the case of generating a shock-pulsed magnetic field - a radiating magnetic frame antenna with vibration-resistant construction (operation in search object magnetization mode);
 - 15 2 - in the case of generating a harmonic magnetic field - a radiating magnetic loop antenna forming an induction channel (informational influence with registration of parametric modulation);
 - 3 - for mechanical force impact, an electrohydraulic discharger that generates an overpressure pulse (hydroacoustic shock wave).

20 Implementation of the Invention

The invention can be advantageously realized through a method for detecting search objects such as underwater robots and drones, using search equipment suitable for magnetometric search of ferromagnetic objects. Using a powerful underwater electri-

cal energy source and a radiating magnetic loop antenna, a shock-pulsed magnetic field is generated. The shock-pulsed magnetic field magnetizes the ferromagnetic elements of a ferromagnetic search object, causing the magnetic field of the search object to change (increase) due to residual magnetization. This change or increase in the magnetic field of the search object is recorded by a magnetometric receiver.

The method is advantageously characterized in that additionally a mechanical force impact is exerted by an electrohydraulic shock pulse, briefly referred to as electrohydraulic shock, electrohydraulic impact, electrohydraulic strike, electrohydraulic shock or physical shock, in the form of a single overpressure pulse, whose impact results in altered physical properties, for example of the magnetic field of the search object and/or as well as special properties ("burst"), such as a malfunction of the electronic circuits of the search object. By exerting the electrohydraulic shock pulse, the parameters of reflected probing signals of the search equipment change. Parametric effects or parametric modulation hereinafter refers to a change in the parameters of reflected probing signals of the search equipment as a result of exposing the search object to the electrohydraulic shock pulse.

The probing signals include, in addition to the shock-pulsed magnetic field, an informational influence by a defined, harmonic magnetic field.

The informational influence by the harmonic magnetic field of the magnetic loop antenna on a detected (metal) search object for the detection of underwater robots and drones is performed with registration of the parametric modulation - briefly: parametric effects - of the reflected defined harmonic magnetic field.

A pulsed exciting magnetic field magnetizes the ferromagnetic elements of an underwater robot or underwater drone. Due to the presence of a so-called hysteresis loop in ferromagnets - a known phenomenon of the remaining alignment of a part of the magnetic domains after removing the magnetic field - this leads to an increase in its own magnetic properties due to residual magnetization, which is recorded by the magnetometric receiver. That is, the search object's own magnetic field increases.

The impact of an additional excitation field on the search object is referred to as parametric; it aims to change the properties of the search object itself (reflective, magnetic, nonlinear and other physical properties). In this case, the parametric field changes the properties of the search object itself, thereby increasing its magnetic properties, i.e. making it physically more noticeable to the magnetometric receiver.

Parametric effects refer to properties of the search object induced by the electrohydraulic shock pulse and altered physical properties of both the search object and the probing signals reflected by the search object, which change the parameters of the reflected probing signals of the search equipment.

10 Probing a search object with, for example, a low-frequency harmonic magnetic field while recording the reflected magnetic field is commonly referred to as an "inductive search method".

If the search object is simultaneously exposed to an additional exciting parametric physical field, parametric effects can occur due to changes in the properties of the object itself and, consequently, the parameters of the reflected magnetic field.

When probing with low-frequency harmonic magnetic search object field. The magnetic field reflected by the object contains changes due to altered parameters of the search object's signal (amplitude, frequency, phase), i.e. it exhibits, for example, a parametric modulation or a so-called "burst" of the harmonic magnetic field at the moment when the search object is subjected to an electrohydraulic shock.

The shock wave caused by electrohydraulic shock in the proposed invention is a pulse of a parametric excitation field that acts on the search object and causes a change in its parameters. In this case, the shock wave against a detected metal object leads to a short-term change in the distances (r and h) between the search object, the magnetic frame antenna and the receiver.

This results in a spatial micro-displacement of at least parts of the search object relative to the magnetic loop antenna and the receiving device. The reflected signal of

the probing field will naturally change. Its modulation differences carry information about the search object.

This results in a parametric amplitude modulation ("burst") of the reflected harmonic magnetic field.

- 5 This parametric modulation of the reflected signal is physically caused by two factors: a change in the directional pattern of the reflected signal and a spatial micro-displacement of the search object at the moment of a "burst" of the magnetic field, also referred to as an "outbreak", due to pulsed overpressure on the search object during an electrohydraulic shock.
- 10 It is important to emphasize at this point that, in contrast to an electrohydraulic shock pulse, underwater sonar also briefly referred to as "sonar", "echo sounder" or described as "underwater sound waves generated electrodynamically" uses harmonic signals with frequencies of several tens to hundreds of kHz, the use of which serves the transmission and reception of information. The current state of the art includes in
- 15 particular sonar systems for detecting underwater objects.

In contrast, the electrohydraulic shock is equivalent to an electrical explosion underwater with similar parameters to a TNT explosion, causing a shock excitation of the water environment, a single overpressure pulse with a duration of several tens of microseconds.

- 20 The shock wave caused by electrohydraulic shock in the proposed invention is a pulse of a parametric excitation field that acts on the search object and causes a change in its parameters.

- The physical basis of the electrohydraulic shock is the conversion of electrical energy into mechanical energy without intermediate links with high efficiency. The electrohy-
- 25 draulic effect is a pulsed electrical discharge in a liquid, where a rapid, almost instantaneous energy release occurs in the discharge channel. As a result, the pressure in

the outlet channel significantly exceeds the external pressure, the channel expands rapidly, which leads to the occurrence of a shock wave.

The shock wave caused by electrohydraulic shock in the proposed invention is a pulse of a parametric excitation field that acts on the search object and causes a
5 change in its parameters: reflective, nonlinear, magnetic and other properties.

At the same time, the search object is probed with a low-frequency harmonic magnetic field. The magnetic field reflected by the object "contains traces" of altered parameters of the search object's signal (amplitude, frequency, phase), i.e. it currently exhibits a parametric modulation or a "burst" of the harmonic magnetic field when the
10 object is subjected to an electrohydraulic shock.

Advantageously, when executing the method, the deeply penetrating properties of pulsed magnetic and mechanical shock physics fields, comprising the shock-pulse magnetic field and the electrohydraulic shock pulse, can be utilized through the metal shell of the body of the detected object. The exposure of the search object to the
15 magnetic and mechanical shock physics fields leads to malfunctions of the localized electronic circuits inside the search object. A resulting change in the operating mode as well as the level change of the reflected signal in the form of a characteristic "burst" are recorded as an additional information feature.

A device suitable for carrying out a method described above and shown in whole or
20 in part in Fig. 1 for detecting search objects such as underwater robots and drones is advantageously equipped with a magnetometric receiver 8 and a unit for recording the results of measurements of the magnetic field distortion from the search object 6. The device is characterized by:

- an electrical energy source 1,
- 25 - a magnetic shock pulse field generator 2,
- a harmonic signal generator 3,

- a source of pulsed mechanical force impact 4,
 - a radiating magnetic frame antenna 5,
 - a receiver for reflected magnetic fields 7,
 - an object distance meter 9, and
- 5 - a control module 10.

Fig. 1 shows a block diagram of a device that implements the proposed method for detecting underwater robots and drones on the seabed.

In search mode, generator 2 emits a shock-pulsed magnetic field into the aquatic environment via the magnetic loop antenna 5, which magnetizes the search object 6, 10
distorting the Earth's magnetic field due to residual magnetization, but increasing the range of its detection by the magnetometric receiver 8 (parametric magnetization mode).

The harmonic signal generator 3 periodically emits a low-frequency harmonic magnetic field into the aquatic environment via the magnetic loop antenna 5. At the same 15
time, the pulsed mechanical force source 4 generates a hydroacoustic shock wave that acts on the search object and causes a parametric modulation of the reflected harmonic magnetic field. Upon entering the detection range, the search object 6 reflects the low-frequency magnetic field, which is recorded by receiver 7 (search mode). Simultaneously, due to the high penetrating power of the pulsed magnetic 20
and mechanical shock fields through the body shell, a malfunction of the electronic circuits of the detected object is captured as an additional information sign.

The operation of the shock generator for pulsed magnetic fields 2 and the generator for pulsed mechanical force impact 4 is carried out via a dedicated electrohydraulic unit (EHU) 1. For pulsed parametric shock magnetization, the output of EHU 1 is

connected to an emitter. This is a magnetic frame antenna with a large diameter (several meters) and mechanical strength.

Under force influence, the output of EHU 1 is switched by a control module 10 to a different load (electrode system), creating an electrohydraulic shock pulse also referred to as a hydroacoustic shock wave, among other things.

The control module 10 ensures switching of the operating modes of EHU 1 and generators 2-4, power supply to all modules of the installation, and control of the operation of the harmonic magnetic field receiver 7, magnetometric receiver 8, object distance meter 9, data processing and storage, as well as information display.

10 Fig. 3 shows a more detailed view of Fig. 1.

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Claims

1. A method for detecting underwater robots and drones, using search equipment suitable for magnetometric search of ferromagnetic objects, wherein a shock-pulsed magnetic field is generated which magnetizes the ferromagnetic elements of a search object, causing the magnetic field of the search object to change (increase) due to residual magnetization, which is recorded by a magnetometric receiver, characterized in that additionally a mechanical force impact is exerted by an electrohydraulic shock pulse in the form of a single overpressure pulse, whose impact results in altered physical properties and characteristics of the search object, whereby the parameters of reflected probing signals of the search equipment change, referred to as parametric effects, the probing signals include, in addition to the shock-pulsed magnetic field, a harmonic magnetic field, and the detection of underwater robots and drones is performed with registration of the parametric effects of the reflected harmonic magnetic field.
2. The method according to claim 1, characterized in that the deeply penetrating properties of pulsed magnetic and mechanical shock physics fields are utilized through the metal shell of the body of the detected object, which leads to malfunctions of the localized electronic circuits inside the object, and that the operating mode as well as the level change of the reflected signal in the form of a characteristic "burst" are recorded as an additional information feature.
3. A device for detecting search objects such as underwater robots and drones, with a magnetometric receiver (8) and a unit for recording the results of measurements of the magnetic field distortion from the search object (6), of residual magnetization characterized by:

an electrical energy source (1), a magnetic shock pulse field generator (2), a harmonic signal generator (3), a source of pulsed mechanical force impact (4), a radiating magnetic frame antenna (5), a receiver configured to receive paramagnetically modulated, reflected harmonic magnetic fields (7), an object distance meter (9) as well as
5 a control module (10).