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# ANALYSIS OF THE TECHNICAL POSSIBILITY OF SUBMARINE CAMOUFLAGE FROM DIRECTION FINDING MEANS

*Наводяться результати лабораторних досліджень ефективності ультразвукових технологій при вирішенні задач маскування субмарин від засобів пеленгації підкильної, занурювальної та буксируючої структури гідроакустичних станцій з антенами змінної глибини. Доведена можливість маскування субмарини за відсутності власного ходу. Проаналізовані можливості пропонуємого технічного рішення для створення маскувальної огорожі на основі геометричного резонансу штучно формуємих захисних зон каустики.*

**Ключові слова:** *аберація, хвильове співпадання, поверхня каустики, колові хвилі, згінні хвилі оболонки.*

## 1. Introduction

The submariners have a saying that says there are only two types of ships – **SUBMARINES** and **TARGETS**. These words are close to the truth, since submarines today are the most secretive and destructive fighting unit from the whole vast range of weapons of war ever created by mankind.

The Navy (US Navy) is developing an innovative power plant for advanced nuclear missile carriers. The new nuclear power plant will be almost silent and will be able to work 50 years without recharging.

The submarine, which will replace the existing underwater missile carriers of the Ohio class, will receive an entirely new nuclear power plant without a mechanical transmission. This will make the engine run quietly, and a possible combination with a pump- jet propulsion will make the submarine virtually inaudible. In addition, the reactor of the new submarine will be able to operate at one refueling station for 50 years, that is, the entire lifetime of the submarine.

The energy of the reactor in the new submarine will not come from the turbines through the transmission to the propellers, as in modern submarines. Instead, the reactor will generate electricity, which will directly flow into the submarine's electrical network. This will not only reduce noise (for the submarine it is the main detectable factor), but it will also allow taking more energy from the reactor. At present, 75–80 % of the nuclear submarine reactor power is used to provide propulsion. There will be more free power in the new submarine, which will allow using more powerful sonars, new electronics and unmanned vehicles.

Modern «Ohio» class submarines (from the Latin Submarina) at the moment are the most powerful weapon on the planet. Displacement of almost 19 thousand tons, two turbines of 30 thousand h.p., 24 Trident II (D5) ballistic missiles with a dozen warheads in each or 154 cruise missiles BGM-109 «Tomahawk» [1].

The main combat qualities of modern surface ships are a large power reserve, powerful air defense, the ability to receive unmanned and piloted aircraft aboard. Unfortunately, surface ships are vulnerable to anti-ship missiles and, moreover, are too detectable. Unlike them, submarines have a high degree of *stealth* and better *protection against missiles*. True, it has to pay for all this with a low movement velocity, «*below the periscope depth*» and the inability to use carrier-based aviation [2].

In combat conditions or in the performance of reconnaissance-sabotage tasks, one of the most important operations seems to be sufficient secrecy of the submarine.

This purpose is provided by technical means, which exclude the effectiveness of the direction finding of the submarine – the definition of distance, bearing and elevation angle.

A submarine fleet, in particular submarines, carrying carriers of various types of damage means is a powerful military pressure on the states in the presence of a conflict situation. On the one hand, one's own submarine fleet needs to be able to mask, on the other hand – it is necessary to be able to open camouflage means of enemy submarines.

In combat conditions, the presence of a towed enclosing tunnel will effectively combat the problem of deep-sea bombing by enemy destroyers, which shows the relevance of research in this direction.

## 2. The object of research and its technological audit

*The object of research* is the process of elastic interaction of an ultrasonic beam with an elastic shell and the causes of the appearance of resonance-type features in a multiphase shell structure.

Irradiation of the outer surface of a system of two coaxial shells separated by a specially selected liquid with the required characteristics of sound propagation velocity in it by an ultrasonic beam makes it possible to form a confocal shell of the caustic surface. This goal is achieved by fulfilling the required effect of aberration of sound waves in the internal inter-shell space filled with liquid. The

degree of procedure effectiveness is directly dependent on the fulfillment of the condition of a significant wave size of the shell, i. e., exceeding a unit of magnitude much larger.

The adjustment of the direction of the ultrasonic beam relative to the normal to the surface of the outer shell makes it possible to enter the zone of wave coincidence. Then local features of the mechanical system will appear in the form of transmission of the energy of ultrasonic radiation without dissipation of energy. This will serve as a significant increase in the energy activity separating the liquid shells. This phenomenon is commonly called the «acoustic transparency» of the shell.

The artificially formed turbulence of the caustic zone in the studied technical implementation of the biaxial shell structure serves as an artificially created obstacle for the direction finding means of the submarine by hydroacoustic stations with variable depth antennas (HASs with VDAs). It is assumed that the insulating tunnel of two coaxial shells separated by a liquid is in a stationary position. The submarine comes inside it and is in it also in a fixed state, with complete lack of propulsion.

On the screens of the sensors of the enemy's location systems, thus, there will be a blurred spot absorbing the contours and features of the submarine surface. Thus, the misinformation of the true picture substantially reduces the danger of depth bombing by the results of the direction finding of HASs with VDAs by the enemy submarines. This achieves a higher degree of survivability of the underwater vehicle and the effectiveness of its combat capabilities, transmitting false images of the underwater situation.

## 3. The aim and objectives of research

*The aim* of the laboratory researches of the model is to confirm the technical possibility of camouflage and limited visibility of the submarine from the enemy direction finding equipment, as well as the choice of the necessary camouflage regime and the intensity of the caustic zones.

The objectives of research are:

1. Development of a calculation analytical model of the selected technical solution in the form of two coaxial shells separated by a liquid and irradiated externally with an ultrasonic beam.

2. Justification of the need to fulfill the condition of large wave size of the outer shell surface.

3. Clarification of the conditions for the required degree of aberration of the outer shell of sound waves emitted into the liquid by the circumferential wave and the formation of the caustic surface.

4. Determination of the ultrasonic beam incidence angle on the outer shell surface necessary for the formation of a resonant situation in the mechanical system – wave coincidence (geometric resonance).

## 4. Research of existing solutions of the problem

The advanced maritime states of NATO possess all sorts of reconnaissance complexes (space, aviation, ship, stationary coastal and underwater) equipped with radio engineering, hydroacoustic, photographic and magnetometric means in various combinations. This allows to solve problems of intelligence constantly, at any time of the day and regardless of weather conditions. Not enough attention is paid to the problems of concealment and imitation – methods of camouflage, which play an important role in eliminating and weakening the detectable features of the fleet forces preparation to combat support. Concealment, as is known, is the elimination or weakening of the detectable features of the location and activity of forces and various objects. Imitation consists in simulation of the detectable features inherent in forces and objects, by their designating using false constructions, mock-ups, light and radio imitation, and other means [3].

Optical camouflage is the earliest (but not lost its relevance to the present time). However, before the advent of optoelectronic reconnaissance (television, night vision devices, thermal imagers, thermal locator, etc.), it was reduced only to a decrease in the visibility of the ships themselves and their specific characteristics from visual observation. Optical camouflage relies mainly on the use of conditions of reduced visibility, masks, painting of the above-water surfaces of ships with paints that are non-contrast with respect to the optical background of the action area, and on camouflage. Smoke camouflage and blackout were also widely used.

The use of optoelectronic camouflage is reduced to concealment from the optoelectronic means of reconnaissance of enemy combat equipment and objects. This is achieved through the use of camouflage properties of the environment, the dark time of the day, weather conditions that limit the capabilities of these tools, artificial masks, fumes, aerosols, as well as carrying out measures for blackout, installation of mock-ups.

Thermal camouflage limits the detection of forces by means of thermal reconnaissance and destruction by ammunition with thermal homing heads (THH). It is achieved with the help of concealing properties of the environment, special coatings, paints, screening of heated surfaces with opaque barriers for IR radiation, using false thermal targets. To reduce the thermal visibility of the ship, devices spraying seawater jets, camouflage coatings with diffuse reflection of infrared radiation, aerosol formations obtained from various foaming high molecular substances, as well as infra-red false targets are used. Thermal camouflage provides, on the one hand, the concealment of the actions of forces, and on the other hand, their protection from the means of destruction equipped with infrared homing heads. Thermal camouflage means are usually used in combination with radar, because the same reconnaissance systems and weapons can be equipped with both infrared and radar equipment.

Radar camouflage is a set of measures aimed at concealment of military equipment and objects from enemy radar detection. It found its spread already in the years of the Second World War in connection with the introduction of radar technology on ships and aircraft of the Navy warring parties. At that time, such methods of concealment of forces and objects from radar surveillance were developed, such as:

– use of conditions that reduce the range of target detection using radar means;
– creation of radar jammers and masks;
– use of angle reflectors to simulate false objects.

During the past wars and military conflicts, two methods of radio camouflage have developed – passive and active.

For the first time metallized tapes for creating passive interference of the air defense radar were used by the

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British in July 1943 when the air force flew to Hamburg. Since October 1943, the transmitters of active interference «Karpet» have become widely used on American aircraft. The losses of aviation have sharply decreased. A combined use of passive and active radar interference has reduced the effectiveness of enemy air defenses in 4–5 times.

The hydroacoustic camouflage is a significant influence on the elimination or weakening of the unmasking features of ships. It is carried out in order to conceal submarines and surface ships from the hydroacoustic means. Hydroacoustic camouflage is achieved by:

– the use of sound-proof and sound-absorbing devices and materials;
– the possibility of using low noise velocities of the submarine and covering it under the jump layer (a layer of water sharply reducing the capabilities of sonar for detecting submarines);
– shutdown of heavily noisy auxiliary mechanisms, as well as the use of noise simulators.

Species, methods and means of camouflage that are aimed at eliminating or weakening of detectable features are developed as the means of reconnaissance and maritime weapon systems improvement

The miniature device «Вист-2» («Vist-2») serves as an acoustic interference and silences the homing heads of torpedoes and submarine sonars [4].

Methods of underwater vehicle camouflage by changing the water density in the underwater vehicle wake are known. This is achieved by increasing its salinity and by cooling the power plant with more salt water than the seawater, and dumping it into the wake. Thus, a decrease in the discernibility of the ship's wake is achieved [5].

The means of imitation of submarines are also used [6].

Concealment of the submarines is considered in [7–9]. Here, it is possible to create a marine combat mobile complex in the form of a surface ship and a submarine connected to it by disconnection. The connecting element is made detachable from the submarine, and has positive buoyancy and lines for air exchange and observation of the above-water situation, connected to the corresponding lines of the surface ship. The elements of negative buoyancy, which compensates for the positive buoyancy of the submarine, are also connected to the submarine cables with actuators. In this case, the submarine can move along the cables, changing its depth [10].

The known ways to solve the problems of camouflage and limited visibility of submarine contours, based on passive methods, allow to conclude that the most promising are still the means based on resonance phenomena of a different physical nature. The authors' research on camouflage means using artificially formed enclosing surfaces in the form of caustic zones presented in the material is quite simple and effective for achieving the stated goal.

In [11], acoustics of conformal transformation are used to create camouflage devices with layered homogeneous structures that can acoustically generate illusions of objects. In [12], using optical transformation, it is offered to use a camouflage cover that can mask an arbitrary object, simulating the electromagnetic scattering of an empty V-shaped cavity under a metal surface. Such camouflage device will be misleading and confuse detectors and observers, and therefore any object that is concealed under this camouflage cover can't be perceived. As an example of complex joint missions, the creation of a coherent phantom wake through the control of several electronic combat vehicles is an area of great interest to the defense department with the aim of deceiving the radar network [13]. In [14], an optimizing procedure for the microwave absorber is proposed, based on the absorbing mechanism of a single-layer microwave absorber. The amplitude-frequency characteristic of the material is obtained with the optimal adjustable electromagnetic parameters together with the use of the optimization method. Researches [15] consider the achievements in the field of bioinduced photonic materials with different structural colors, including various easy and effective ways of nanostructures construction and development of artificial variables of structural colored photonic materials.

## 5. Methods of research

As already noted, the undisputed advantage of the submarine, as an object of military operations, is its concealment. On the other hand, the most significant drawbacks include «blindness» and noisiness of the underwater vehicle. The first defect disappears only when the submarine leaves the periscope depth, the second – only in the absence of its own propulsion.

HASs with VDAs listen to a given area of the water area for the purpose of detecting an underwater target. Information on the main parameters of the submarine, namely, bearing, elevation angle, distance is communicated to the dispatcher of the military unit and from there goes to the destroyer, which is sent to the location of the boat to carry out deep-seated bombing.

In this paper, one of the options for a technical solution is proposed to ensure sufficient masking of the submarine (with the obligatory observance of the absence of one's own propulsion). This technical solution is the creation of a kind of hole in the form of a cylindrical tunnel in which the boat will be anchored. The surface of the tunnel is two coaxial shells filled with liquid and irradiated externally with an ultrasonic beam. The latter forms a caustic zone, under certain conditions, in the liquid of the tunnel shell, which serves as an obstruction to the direction-finding systems.

The presented technical solution in the laboratory conditions repeats the original ideology. In the laboratory, the layout assesses the principal possibility of achieving the desired goal of providing camouflage and a limited visibility of the submarine at any depth. An external ultrasonic beam generator with a frequency of 36 kHz and a power of 650 W (Fig. 1) is used as an external irradiator [11].

**Fig. 1.** Appearance of the laboratory unit

The submersible unit of ultrasonic radiators consists of a block of ultrasonic radiators, which are made of stainless steel and an ultrasonic generator. On the cover of the unit inside the case there are ultrasonic radiators, which convert electric energy into ultrasonic vibrations. On the back panel there is the output of the network cable. The immersion unit is connected to an ultrasonic generator. In addition, the ultrasonic unit is lowered into the liquid.

## 6. Research results

In the absence of irradiation with an ultrasonic beam of the outer shell of the tunnel, clear images of the submarine appear on the screen of the direction finder (Fig. 2, *a*). To obtain the desired camouflage effect under the protection of the surface of the caustic zone, it is necessary to fulfill two conditions – a significant wave size of the outer shell of the tunnel and the choice of the beam coincidence angle of the ultrasonic generator.

The first condition allows to consider the element of the outer shell of the tunnel as a plate at a considerable wave size, i. e., larger than a few units, as a plate that emits a sound wave into the inter-shell liquid. The phenomenon of aberration can be regulated by appropriate selection of the material of the outer shell and liquid in such way that the ratio of the sound propagation velocities in them makes it possible to construct caustic zones in the form of a confocal surface of the tunnel shell of a given radius. Obviously, with an insignificant wave size, the mechanism for constructing an insulating surface will not work. In Fig. 2, *b*, the initial change in the visibility of the contours of the underwater vehicle body is demonstrated. These changes, as can be seen, are not yet of a fundamental nature, but they also take place.

Selection of the ultrasonic beam incidence angle on the outer shell surface of the tunnel to the values of the incidence angle, that is, before the onset of geometric resonance in the form of wave coincidence. This allows further develop the distortion of the body on the screen of the direction finder of the submarine (Fig. 2, *c*). This is achieved due to the fact that the turbulence and energy activity of the inter-shell liquid under resonance conditions reaches a level where the visibility of the contours practically is disappear. Thus, a satisfactory camouflage of the submarine from the direction finding equipment is ensured. The mechanism of this phenomenon is caused by a sharp increase in the power of the ultrasonic beam, which has passed inside and sound waves generated by it due to the onset of the so-called «acoustic transparency» of the outer shell of the tunnel [12, 13].

Thus, the «acoustic transparency» of the outer shell creates the prerequisites for a sharp increase in the energy state of the initially stationary inter-shell liquid. At the same time, «acoustic transparency» transforms the inter-shell liquid into a turbulent structure with the existing temperature gradient over the entire volume, cavitation appearance and, naturally, a stochastic distribution of the amplitude of liquid oscillations.

It is obviously that the proposed technical implementation, providing for «acoustic transparency» of the outer shell, turns the inter-shell liquid into a high-energy turbulent screen, which is the only concealing element.

*a*

*b*

*c*

**Fig. 2.** Image of the test sample of the submarine: *a* – the starting position, there is no ultrasonic beam irradiation of the isolating tunnel; *b* – external artificial acoustic radiation of the shell of the tunnel (outside the resonance zone); *c* – on the screen of the direction finder sensor when there is a resonant situation in the inter-shell space – wave coincidence

## 7. SWOT analysis of research results

*Strengths*. The original side of the obtained results of laboratory studies is the confirmation of the theoretical prerequisites for the technical implementation of the artificial formation of enclosing surfaces in the form of caustic zones for camouflage and concealment of a military underwater product. An obvious advantage of this method is the ability to remotely control the submarine

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camouflage on the part of the dispatcher (unit commander), as well as the speed of transition to active actions in force majeure.

*Weaknesses*. The proposed technical implementation is not the only possible to achieve the goal of submarine camouflage, its imperfection can be classified as a low-mobility enclosing surface, assuming a stationary state of the enclosing tunnel. At the same time, it is possible to make a fencing tunnel capable of changing its underwater dislocation both in depth and in azimuth.

The weaknesses of the proposed technical solution include stationary, at the anchorage, location of the enclosing tunnel and the essential dependence of the speed and quality of the installation of the enclosing tunnel on the topography of the seabed. A promising solution to this disadvantage is to work out the possibilities of towing a fencing tunnel to a new location in a given part of the water area.

Naturally, the main disadvantage of entering the submarine into the enclosing tunnel is its «blindness», which creates a lot of difficulties for fulfilling all conditions of camouflage.

*Opportunities*. In combat conditions, the presence of a towed enclosing tunnel will effectively combat the problem of deep-sea bombing by enemy destroyers.

It should be noted that the masking tunnel can, in the absence of a submarine, perform the role of camouflage, reproducing the noise effects and cavitation phenomena of the underwater vehicle during towing. Thus, it will take over, like a small or large a ship-target.

*Threats*. Additional costs for using the camouflage tunnel are associated with the need for towing by underwater or surface water, mooring at a certain depth in the anchorage, as well as electromechanical and energy support for the technical realization of this idea.

In the open press on the issues of camouflage and the limited visibility of such technical solution, information is not provided.

## 8. Conclusions

1. The calculation model of the chosen technical solution is developed. This model allows to adequately analyze the nature of studied phenomenon and develop recommendations for improving its functioning.

2. The necessity of fulfilling the condition of a large value of the wave size, which is a product of the representation of the outer shell elements of the tunnel in the form of a set of planar elements, is justified. This is achieved either by increasing the radius of the outer shell, or by changing the corresponding velocities of sound into the shells and separating the shell of the liquid, or of both factors simultaneously. In this case, irradiation is now provided in the plane element of the shell inside the liquid and sound waves with a defined degree of aberration.

3. The conditions for the necessary degree of change in the composition of the physical properties of the separating liquid and the material of the outer shell of the tunnel are determined, which determine the required degree of aberration as a ratio $\sin \alpha = c/V$.

4. It is found that in a laboratory unit for conducting semi-detailed studies for a radiation frequency of 36 kHz for the resonance of circumferential waves, an angle of incidence must be ensured equal to 10 degrees from the outer normal.

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**АНАЛИЗ ТЕХНИЧЕСКОЙ ВОЗМОЖНОСТИ МАСКИРОВКИ СУБМАРИНЫ ОТ СРЕДСТВ ПЕЛЕНГАЦИИ**

Приводятся результаты лабораторных исследований эффективности ультразвуковых технологий при решении задач маскировки субмарин от средств пеленгации подкильной, опускаемой и буксируемой структуры гидроакустических станций с антеннами переменной глубины. Доказана возможность маскировки субмарины при отсутствии собственного хода. Проанализированы возможности предлагаемого технического решения для создания маскирующего ограждения на основе геометрического резонанса искусственно формируемых ограждающих зон каустики.

**Ключевые слова:** аберрация, волновое совпадение, поверхность каустики, окружные волны, изгибные волны оболочки.

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# DEVELOPMENT OF METHODS AND MODELS OF COMPLEX OF SECURITY TECHNOLOGIES FOR PRINTING PRODUCTS

*Проведено аналіз існуючої технології опису рівня захищеності поліграфічного виробу від фальсифікації з наступним виявленням її недоліків. Розроблена математична модель, що дозволяє обчислити інтегрований показник захищеності виробу. Особливістю моделі є використання поняття «технологічний ряд», щоб виключити застосування однотипних захисних елементів. Результатами проведеного дослідження є рекомендації з оптимізації вибору захисного комплексу.*

**Ключові слова:** *захищеність поліграфічного виробу від фальсифікації, технологічний ряд, захисний комплекс, захисний елемент.*

## 1. Introduction

Currently, in Ukraine and most countries of the world there is an objective need to counter falsification of printing products. The urgency of this problem is largely due to the development of printing technology and its widespread use.

With all the variety of currently available technical security methods, there is a certain gap in the field of security of products of wide distribution, such as labels and packaging. The issue of security of the printing design is especially acute in connection with development of reproductive and digital equipment, which makes it possible to easily reproduce the original packaging that does not have security. Unlike traditional objects of application of security equipment, packaging and label products have certain limitations. These restrictions primarily concern the cost of protected products, the nature of the design and the used materials.

Given the cost constraints imposed on the security elements of label and packaging products, the applicability of most of them is low, as well as economic efficiency. For these reasons, it is necessary to create an effective integrated product suitable for the security of labels and packaging products.

Thus, there is a need to develop methods and models for assessing the level of security of a printed product, which will make it possible to comprehensively solve the problem of choice and minimize the cost and time costs for developing the original layout of a protected product.

## 2. The object of research and its technological audit

*The object of research* is the process of selection of the elements that make up a complex of security printing technologies to counter the fabrication of a printing product.

The subject of research is optimization methods in the problems of selecting a complex of security printing technologies, information technology of pre-press preparation of publications.

One of the most problematic places is the process of deciding whether to incorporate into the design of a printed product some or other elements that protect the product from falsification. At large and well-known enterprises, such as Ukrspetspoliprografia (Ukraine) or Goznak (Russia), such decisions are made on the basis of collective analysis in the relevant departments. Secured printing products number dozens (securities, documents) and even hundreds (money banknotes) of security elements