Application of electric explosion technologies for protection of mobile marine objects from means of detection and destruction by naval weapons

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Abstract. The article discusses the possibilities of using electric discharge technologies to create sources of acoustic waves in sonar countermeasure systems. Presented are the results of preliminary research works aimed at determining the parameters of acoustic waves generated by electric discharge technologies. The possibility of using electric discharge as a source of acoustic interference for undersea weapon guidance systems is shown. The current situation in the world, the armed conflicts and terrorist threats require ensuring the safety of maritime mobile objects (vessels, ships) from being hit by naval weapons. Today, one of the means of surface or submarine ship destruction is a torpedo weapon. The main means of protection against destruction by torpedo weapons are the ship maneuvering and its sonar countermeasures to the weapon guidance facilities [1]. The methods of sonar countermeasure are divided into passive and active ones [1 – 4]. Active methods are aimed at interfering with guidance systems, interrupting the wake, placing target simulators, etc.

Introduction
Sources of acoustic waves with various physical principles of operation can be used as jammers. The main task of the jammer is to create acoustic noise, the level of which exceeds the noise level of the protected object. One of the jamming methods is the use of explosive sound sources [1 – 4].

At present, the underwater explosion of a remote charge in the infinite medium and the spherical shock wave (SW) emitted in this case have been studied quite fully [5 – 8].

Alternative sources of SW and strong sound fields, in addition to chemical explosives, can be air guns, piezo emitters and electric discharge technologies [9 – 19]. The main advantage of using electric-discharge technologies is the ability to regulate both the pulse repetition rate and controllability of the energy input modes when generating an underwater pressure wave.

Electric discharge technologies are based on the use of the effects associated with a pulsed electric discharge in a liquid. As a result of the rapid energy release of capacitors, high temperature and pressure arise in the discharge channel. These properties of pulsed electric discharges in a liquid are widely used in the development of new technological procedures for processing various materials, in drilling wells, cutting rock formations, in construction, in medicine, in seismic exploration, etc.
Applied use and theoretical support of pulsed electric discharges in a liquid is continuously expanding [14 – 19].

Methods for initiating an electric discharge in the liquid, the properties of the liquid, the shape of electrodes, the water hammer direction, the duration and frequency of pulses, and many other factors affecting the efficiency of the acoustic interference are subject to study.

An electric discharge in water is an effective source of impulses of acoustic and shock waves of high and super high pressure [9 – 13]. The characteristics of the pressure pulse (wave) (amplitude, propagation velocity, length of the compression zone) are determined by the set of parameters of the electric discharge and the discharge circuit: stored energy, maximum rate of energy input into the discharge, voltage at the discharge gap, length of the discharge gap, and the shape of electrodes. Thus, a sufficiently large number of factors affect the characteristics of the wave created by an electric discharge in water, as well as the effects accompanying it.

The main advantages of the electric discharge technology over chemical explosives [9 – 13] are that there is no need to store explosives and that it is possible to operate in a periodic mode. The main advantage over pneumatic systems is the absence of moving mechanical parts - the pneumatic valve, and the speed of energy storage and input; over piezodynamic systems - no restriction on the radiated sound power (the power of the piezo-emitter is limited from above by the ultimate strength of the medium, beyond which the piezo-emitter is destroyed by cavitation).

**Description of experimental results**

This article considers the possibility of using an electric discharge as a source of acoustic waves for application in naval weapon countermeasure systems.

Figure 1 shows the general diagram of electric discharge in a liquid.

![Fig. 1. General diagram of electric discharge in a liquid. Inductance and resistance of the discharge circuit.](image)

The general principle of operation of the circuit shown in Fig. 1 consists in the fact that the storage capacity C1 is charged to a predetermined voltage level U0, and after that S1 switches to the discharge gap placed in the liquid.

The characteristics of an underwater shock wave are determined by the set of parameters of electric discharge and the discharge circuit (Fig. 1): the stored energy, the maximum speed of energy input into discharge, voltage at the discharge gap, the length of the discharge gap and the shape of the electrodes [9, 13, 14 – 19].

Table 1 shows the comparative specific energy characteristics for electric discharge and conventional explosives. As can be noted, as regards the density of stored energy (the dimensions of the installation) an electric discharge loses out to chemical explosion by three orders of magnitude. However, the short energy input time and the small dimensions of the plasma channel make it possible
to attain the energy density in the discharge channel by an order of magnitude higher. Besides, the electrical discharge can be reused.

Table 1 – Specific energy characteristics of chemical explosives and electrical discharge.

| Energy conversion method | Specific energy | Typical energy input time |
|--------------------------|----------------|--------------------------|
|                          | Stored energy  | Energy density           |                         |
|                          | \( W, \text{kJ/cm}^2 \) | \( W_0, \text{kJ/g} \) | \( W_e, \text{kJ/cm}^2 \) | \( \tau, \text{s} \) |
| Chemical explosive       | 5–7           | 4.2–4.6                  | 5–7                     | \( 10^{-6} – 10^{-3} \) |
| Electric explosion       | \((0.3–0.5)\times10^{-3}\) | \((1–10)\times10^{-3}\) | 50–100                  | \( 10^{-5} – 10^{-4} \) |

\( W \) – energy volumetric density; \( W_0 \) – energy mass density; \( W_e \) – explosion energy density

The pressure amplitude in the discharge channel depends on two interrelated processes: the time of energy input and the rate of the channel expansion. The pressure in the discharge channel can be roughly estimated as

\[
p_k = \rho_0 \frac{R_k^2}{\tau^2}
\]

where \( \rho_0 \) – density of the environment, \( \tau \) – the characteristic discharge time, \( R_k \) – the characteristic radius of the discharge channel.

The characteristic discharge time for a generator with the given electrical parameters of the RLC circuit (Fig. 1) can be taken equal to half the oscillation period: \( \tau = \pi \sqrt{\frac{L}{C}} \).

The two main ways to initiate discharge in a liquid are known: initiation by explosion of a conductor and the high-voltage breakdown. Figure 2 shows the schematic diagrams typical for different methods of initiation.

![Figure 2](image)

**Fig. 2.** Methods of electric discharge initiation A – high-voltage breakdown; B – conductor explosion.

The choice of the conductor as a discharge initiator allows us to use relatively low levels of charging voltage (about 5 kV). In this case, the characteristic lengths of the discharge gap can be up to 0.5 m. For high-voltage breakdown, it is necessary to ensure the electric field strength at the discharge gap of the order of 3 kV/mm. Thus, to break through the 10 cm gap, a voltage of \(~300\) kV is required.

Each of the methods of initiating the discharge has its own advantages and disadvantages. The main disadvantage of using a conductor is the need to recharge the conductor. The disadvantage of high-voltage breakdown, as an initiator, is the need to use high voltage (tens of kilovolts).
As a result of the set of works, a number of experimental facilities were created that allow us to investigate generation of an underwater pressure wave with various methods of initiation. The power reserve of the facilities ranged from a few joules to tens of kilojoules.

As a result of the experimental work, studies were carried out on the formation of an electric discharge by initiating a conductor of both rectilinear and curvilinear shapes.

Figure 3 shows an image of a discharge chamber with a complex-shaped conductor and the result of the discharge initiation by the conductor explosion.

From the data presented in Figure 3 it follows that the shape of the discharge channel repeats the shape of the initiating conductor in task geometry.

Figure 4 shows the design of the emitting system for generating an underwater shock wave by the electric discharge initiated by a linear conductor. Two parallel-connected aluminum foils with geometric dimensions of 10 × 240 mm and a thickness of 30 μm were used as an exploding conductor.

Figure 5 shows the general view of the mounted emitting system on the underwater research bench.
Fig. 5. A mounted emitting system for generating a shock wave by a linear initiating conductor on an underwater research bench: 1 – an emitting system, 2 – a low-inductance cable line mounted on a cable collector of the emitter, 3 – piezoelectric pressure sensors.

Figure 6 shows the frames of high-speed shooting of the plasma channel dynamics.

Fig. 6. Frames of high-speed shooting of the plasma channel dynamics (vapor-gas cavity), obtained with the emitting system with a linear initiating conductor.
The frames of high-speed shooting show that in the process of expansion, the channel cools and passes from the plasma state to the gas cavity. Due to the non-uniformity of parameters along the plasma channel, its expansion is not uniform. Plasma stratification occurs in the form of constrictions and luminous localized areas. When the discharge current drops, due to a decrease in conductivity, the integrity of the conducting channel at the constriction points is violated, which leads to a break in the conducting channel in several points (which is now a series-connected alternately conducting and poorly conducting inclusions along the plasma channel). The residual voltage of the capacitor bank remains in the discharge gap, which leads to a repeated thermal breakdown after a significant period of time.

The repeated breakdown on the pressure oscillogram corresponds to the second pressure peak following immediately after the first one after a time interval of about 3 ms (Fig. 7). We can also observe the delay of the repeated breakdown on the oscillograms of current and voltage (Fig. 8).

Fig. 7. Oscillogram of the excess pressure profile measured at a distance of \( l = 2.7 \) m to the plasma channel (vapor-gas cavity) formed by the emitting system with a linear initiating conductor.

Fig. 8. Oscillogram of voltage (channel 1) and current (channel 2) obtained for frames of high-speed shooting shown in figure 10 and for the pressure profile shown in figure 11.
Figure 7 shows an oscillogram of the pressure profile taken by a piezoelectric pressure sensor, located under water at a depth of 0.5 m from the water surface and at a distance of 2.5 m from the emitter. On the oscillogram, the following features can be distinguished: two successive pressure pulses from the main discharge and repeated breakdown, a prolonged discharge wave and pulses reflected from the bottom of the test tank.

Figure 9 shows the image and the schematic diagram of an acoustic wave generator with energy storage of up to 150 J.

![Figure 9. Pressure wave generator with energy storage up to 150 J. A – dimensions; B – generator in the test tank; C – schematic diagram of the generator.](image)

Figure 10 shows typical pressure pulses generated by an electric discharge generator (EDG is shown in Fig. 9). The corresponding oscillograms for voltage and current pulses are shown in Figure 11.

![Figure 10. Typical pressure pulses generated with a 150 J electric discharge generator.](image)
Fig. 11. Oscillograms of voltage and current pulses.

Figure 12 shows the oscillograms of pressure pulses at a distance of 2 and 3 meters from the emitter, obtained with an energy input into the discharge channel of the order of $10^{-12}$ kJ.

Conclusions

As a result of the scientific research, a complex of electric discharge facilities with the energy storage of 5 J to 100 kJ was designed, allowing us to study the effect of acoustic waves generated by electric discharge facilities in order to solve the problem of undersea weapon countermeasures.

The obtained technical solutions make it possible to create generators that form a pressure wave with predictable characteristics. The pressure level generated by electric discharge generators is about 200 – 240 dB at a distance of 1 m from the emitter, depending on the parameters of the electric discharge facility. These sound pressure levels are considerably higher than the noise levels of most of the marine moving objects.

Thus, the possibility of protecting marine mobile objects with the use of electric discharge installations as a source of acoustic interference for of naval weapon guidance systems has been shown.
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