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AN IMPULSIVE SOURCE OF STRONG UNDERWATER ACOUSTIC DISTURBANCES

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The present paper discusses the problems connected with the construction of an impulsive high-power electroacoustic transducer. The operating principle of the transducer is the discharge of a capacitors by a thin wire.

The paper also shows the electrical system of the transducer and gives the values of the basic electrical components (parameters) of the circuit.

The transducer generates acoustic disturbances of very short duration, which permits this type of source to be used in studies of sea physics.

The paper presents the results of the investigation of the source itself, performed in an anechoic basin. The maximum level of the acoustic pressure obtained at a voltage $U = 3.8$ kV and a capacitance $C = 450$ μF was 230 dB relative to a pressure of 1 μPa, at a distance of 1 m from the source.

Introduction

Experimental investigations in underwater acoustics require strong sources of acoustic waves. They are particularly necessary in the investigation of sound scattering and absorption, in the measurement of the velocity of sound, and in the investigation of the structure of the sea bottom. They are also used to investigate reverberation and scattering from the rough sea surface.

The classic high – power transducers are severely limited in their use. The maximum efficiency (the maximum level of the acoustic pressure) is limited by overheating, possible electrical breakdown, or by the cavitation threshold. A disadvantage of the magnetostrictive and piezoelectric transducers is that their maximum efficiency can only be obtained at a frequency equal to the frequency of the mechanical resonance, which causes the disturbances radiated by these sources to have almost the character of harmonic waves (in the case of a sharp resonance). These transducers are not very useful for investigations at low frequencies.

Workers very often use strong sources of underwater acoustic disturbances, i.e. underwater detonations of explosives [3, 4, 5, 12]. A disadvantage of these sources is that the repeatability of the sound effects accompanying them is low, for a given mass of detonating explosive, which makes statistical processing of the results difficult. Moreover, this method of investigation is dangerous.

The recent years have seen an increasing use of impulsive sources, driven by a discharge of capacitors [5, 8, 11, 12, 14]. Electrical energy is transformed to acoustical energy, using different physical phenomena. Magnetic short – circuit transducers [8], breakdown (spark) discharges [12] and the so-called exploding wires (discharge by a thin wire) [5, 11] are most often used.

This paper will present the results of investigations performed in an anechoic basin which permitted the acoustic characteristics of an exploding wire to be investigated over a wide range.

2. The short characteristic of the discharge of capacitors by a thin wire placed underwater

The discharge of capacitors by a wire underwater is different in its essential mechanism from the breakdown discharge (sparker). The wire strung between the electrodes prevents the breakdown stage from occurring, and the distance between the electrodes can be longer at the same electrodes voltage.

The use of a bridge between the electrodes essentially decreases the duration of the pulse, which in turn causes an increase in the energy density at discharge, thus making this process more violent, compared to that of a breakdown discharge. The effectiveness of converting electrostatic energy to acoustical energy is several percent higher.

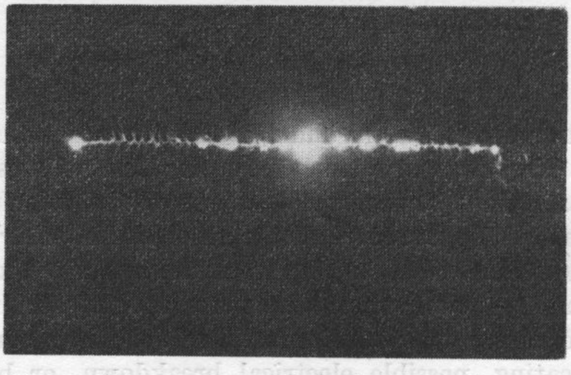

Fig. 1. The process of the discharge of the capacitor by a thin wire underwater

In the case when the circuit of the wire sparker was short circuited a rapid heating of the wire strung between the electrodes initially occurs as a result of the Joule heat. At this stage of the discharge there is still no influence on the magnetic field of the wire through which the electric current is flowing. In the next stage, the wire melts and turns into a region of ionised gas called the plasma filament. In connection with the plasma filaments, the pinch effect causes narrowing of the discharge channels. Most probably droplets of plasma are formed in these which are the sources of the pressure waves.

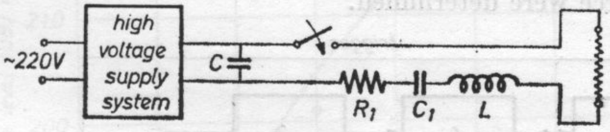

Fig. 2. The electrical system of the transducer and supply circuit

The process of the discharge of capacitors by a thin copper wire is shown in Fig. 1.

3. Design and performance principle of the transducer

The magneto system consists of a battery of capacitors adapted for pulse performance, a connector, supply cables, supply source and transducer. The sparker has two electrodes, between which a thin copper wire is strung. The electrical system of the wire sparker together with the supply circuit are shown in Fig. 2.

The parameters of the supply system and the remaining data are the following: the supply voltage $U = 0\text{-}4$ kV, the capacitance of the capacitors $C = 450$ μF, the capacitance of the circuit $C_1 = 7.3$ μF, the resistance of the circuit $R_1 = 0.09\ \Omega$, the resistance of the copper wire $R \approx 0.056\ \Omega$, the inductance of the circuit $L = 10$ μH, the diameter of the copper wire $d = 2 \cdot 10^{-4}$ m.

Fig. 3 shows a block diagram of the measuring system, which consists of the following elements of the measuring chain (all manufactured by Brüel and Kjaer): a 8103 type measuring hydrophone with a transmission band ±2 dB of 0.1 Hz-140 kHz; a 2626 type conditioning amplifier with a transmission band ±2 dB of 0.3 Hz-100 kHz; a 2606 measuring amplifier with a transmission band ±0.5 dB of 2 Hz-200 kHz.

An oscilloscope OG-2-31 RFT with memory with a transmission band of 0-10 MHz was also used. The analogue – digital system used had a transmission band of 0-50 kHz (the sampling rate was 10^5 kp/s).

The signal from the hydrophone (which had a receiving characteristic that was flat to 100 kHz) was, after amplification, supplied to an oscilloscope with a memory. It was also transformed to a digital form and fed to the computer. The power spectrum and the autocorrelation function, were determined using an FFT algorithm.

4. The results of the experimental investigations

Using the system shown in Fig. 2 for the generation of strong transient acoustic disturbances and the system shown in Fig. 3 for recording the waveform and the spectral – correlation analysis, a number of characteristics of the pulse source were determined.

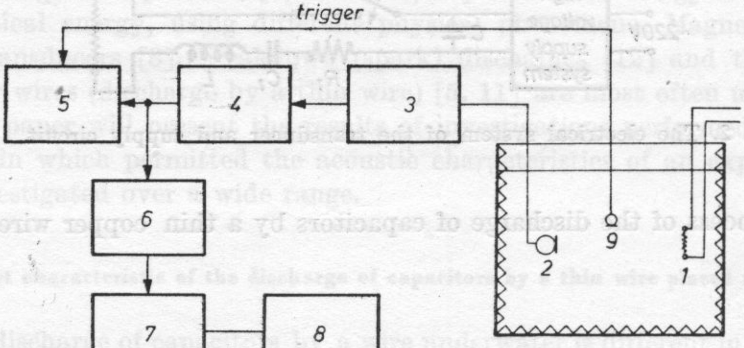

Fig. 3. The diagram of the measuring system

1 – transducer, *2* – a 8103 type Brüel and Kjaer measuring hydrophone, *3* – a 2626 type Brüel and Kjaer conditioning amplifier, *4* – a 2606 type Brüel and Kjaer measuring amplifier, *5* – an. oscilloscope OG 2-31 type RFT with memory, *6* – the analogue-digital convertor, *7* – an ODRA-1305 type computer, *8* – an *X/Y*, *9* – a receiving hydrophone

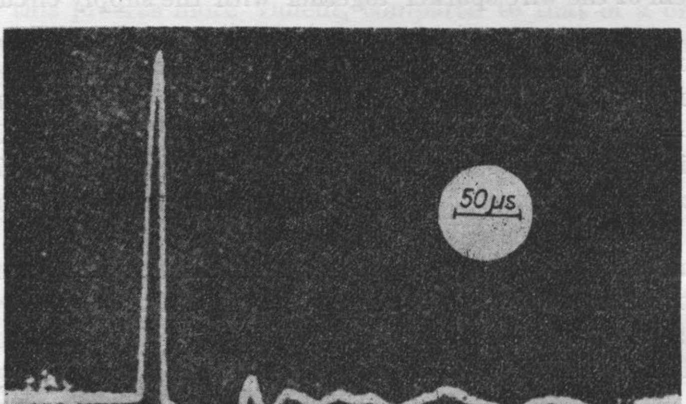

Fig. 4. The pulse shape generated by the exploding wire

The first basic characteristic measured for the source is the pulse shape generated, which is shown in Fig. 4. Fig. 5 shows the dependence of the peak level of the acoustic pressure on the charge voltage of the capacitors.

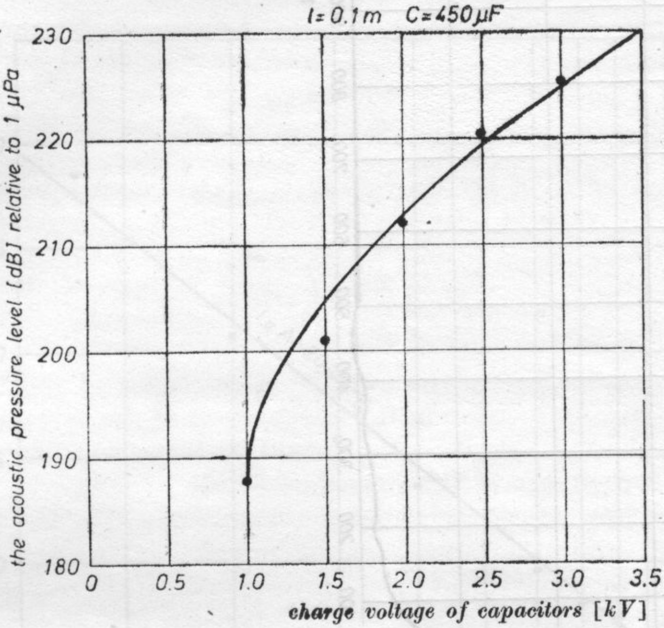

Fig. 5. The dependence of the peak level of the acoustic pressure on voltage

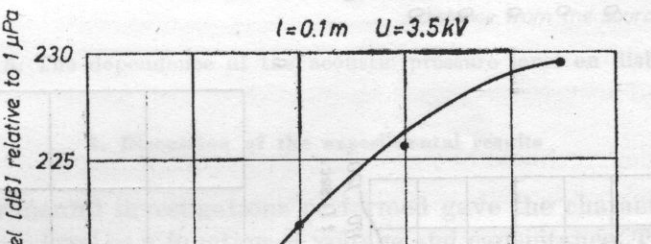

Fig. 6. The dependence of the peak level of the acoustic pressure on capacitance

Fig. 6. shows the dependence of the peak level of the acoustic pressure on the capacitance of the capacitors. Fig. 7 shows the time history of the pulse, the autocorrelation function and the power density spectrum, while Fig. 8 shows the dependence of the acoustic pressure level generated by the wire sparker as a function of the distance from the source.

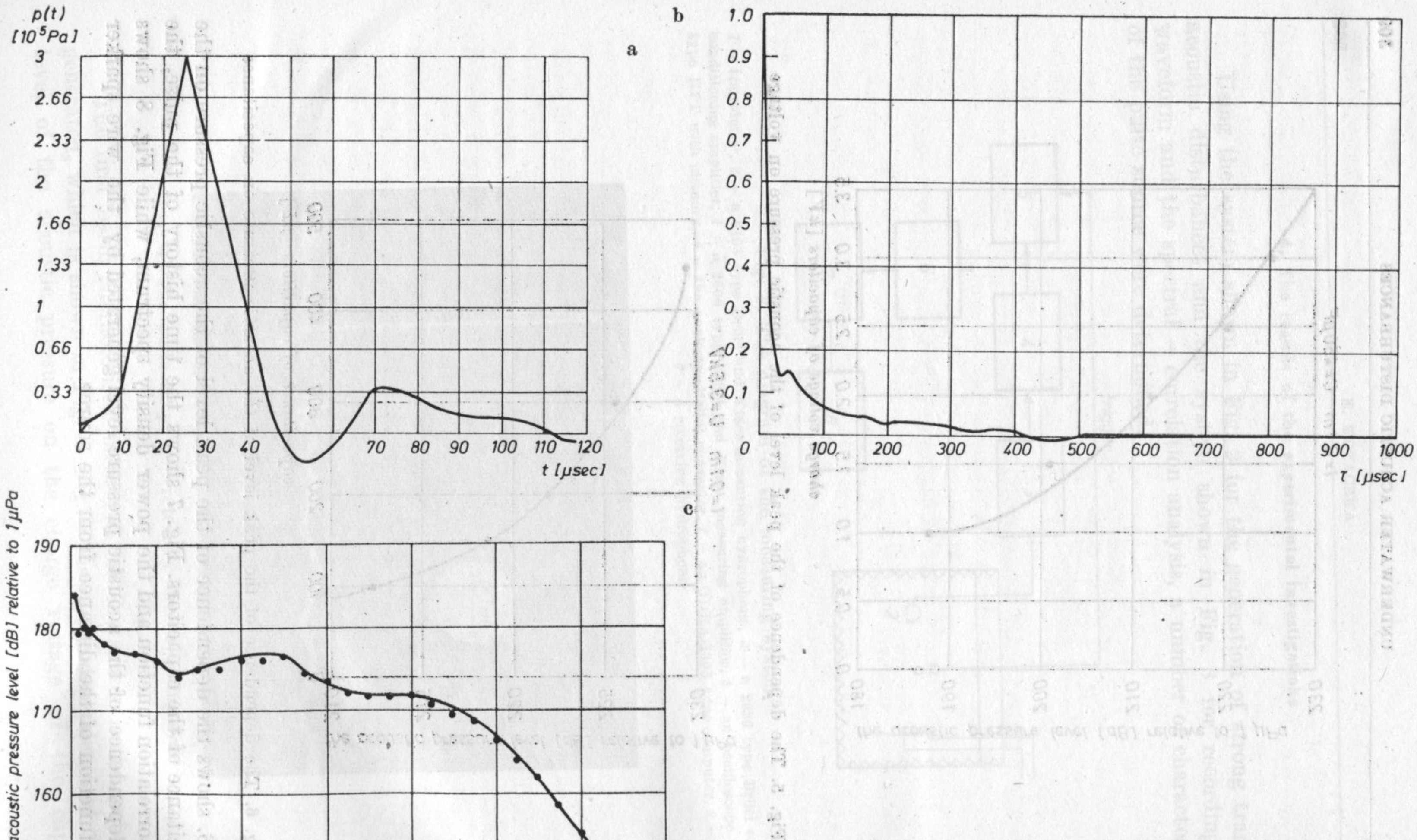

Fig. 7. The characteristics of the pulse

a – the waveform, b – the autocorrelation function, c – the power density spectrum

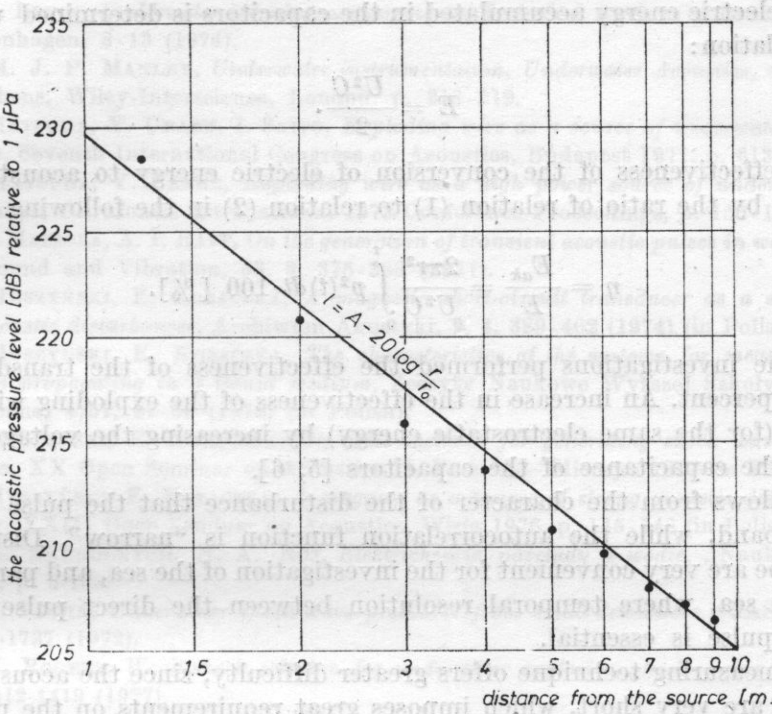

Fig. 8. The dependence of the acoustic pressure level on distance

5. Discussion of the experimental results

The experimental investigations performed gave the characteristics of the acoustic pressure level as a function of voltage and capacitance. The dependence of the acoustic pressure level on voltage is linear. The acoustic pressure level depends on the square root of capacitance, and is in agreement with the dependencies given in [5].

The effectiveness of the conversion of electrical energy to acoustic energy for the exploding wire is higher than that of the sparker type transducer [5, 6].

The expression describing the value of the acoustic energy in terms of the time function of the pressure, measured at a distance r from the source, with the assumption of a point source, (which is satisfied for a short distance between the electrodes) has the following form:

$$E_{ak} = \frac{4\pi r^2}{\varrho c} \int_0^{\tau} p^2(t)\, dt, \tag{1}$$

where E_{ak} is the acoustic energy of the pulse, ϱ is the density of the medium, c is the sound velocity, $p(t)$ is the acoustic pressure, and r is the distance from the receiver to the source.

The electric energy accumulated in the capacitors is determined using the known relation:

$$E = \frac{U^2 C}{2}. \tag{2}$$

The effectiveness of the conversion of electric energy to acoustic energy is defined by the ratio of relation (1) to relation (2) in the following form

$$\eta = \frac{E_{ak}}{E} = \frac{2\pi r^2}{U^2 C}\int_0^{\tau} p^2(t)\,dt\cdot 100\ [\%]. \tag{3}$$

In the investigations performed the effectiveness of the transducer was about 11 percent. An increase in the effectiveness of the exploding wire can be achieved (for the same electrostatic energy) by increasing the voltage and decreasing the capacitance of the capacitors [5, 6].

It follows from the character of the disturbance that the pulse spectrum is broad-band, while the autocorrelation function is "narrow". Disturbances of this type are very convenient for the investigation of the sea, and particularly, a shallow sea, where temporal resolution between the direct pulse and the reflected pulse is essential.

The measuring technique offers greater difficulty, since the acoustic pulses generated are very short, which imposes great requirements on the measuring apparatus, particularly in terms of the width of the transmission band [9].

The drop of acoustic pressure as a function of distance is greater than 20 dB with a tenfold increase in distance.

In conclusion, it should be noted that the impulsive source of acoustic disturbances described can be used in investigations of the acoustics of the sea. It can also be used in small measuring basins on account of the very short duration of the pulse. It is also interesting to note its possible use in the investigation of the structure of the sea bottom, using the production of a side wave.

The sparker has a relatively simple design and performance principle. The optimum effectiveness of the sparker is achieved with dimensions of the copper wire such that its length ranges from $(5\text{-}10)\cdot 10^{-2}$ m and diameter $(0.2\text{-}0.3)\cdot 10^{-3}$ m. Care should also be exercised to ensure that the resistance at the point where the wire connects with the electrodes should be as low as possible. The shape of electrodes does not play an essential role in terms of its effectiveness, but is essential in terms of the barrier in the propagation path of the acoustic pulse.

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