



Soviet-era science, translated into English

PHYSICS

N. A. ROY and D. P. FROLOV

1958

SovietRxiv

View the original and related papers at <https://sovietrxiv.org/items/ru-195801.98997>

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

Fig. 1

Figure 1: Fig. 1

Abstract

Full Text

PHYSICS

N. A. ROY and D. P. FROLOV

ON THE ELECTROACOUSTIC EFFICIENCY OF A SPARK DISCHARGE IN WATER

(Presented by Academician N. N. Andreev on 28 VIII 1957)

1. A spark discharge in water attracts attention as a source of positive-pressure pulses of large amplitude. The present work is an attempt to obtain information on the electroacoustic efficiency of the discharge for various conditions, determined by the length of the spark gap, the magnitude of the capacitance being discharged, and the electrical voltage.
2. Figure 1 shows the circuit of the setup. This circuit makes it possible to obtain breakdown either of a single spark gap, which is what will be discussed in this article, or simultaneous breakdown of several spark gaps. The rectifier supplies a voltage from 0 to 30 kV through a charging resistor to the connected plates of a bank of capacitors of $0.1 \mu\text{F}$ each. The second plates may either be grounded through separate spark gaps in water, or connected and grounded through one spark gap 1. To cause discharge of the capacitors, the plates connected to the charging resistor are grounded by breakdown of successive air gaps between three metal spheres. This breakdown is initiated by ignition of one of the air gaps by an auxiliary spark. The auxiliary spark is produced by a special generator 2. To determine the time dependence of the current and voltage during the discharge, the electrical circuit of the spark gap is equipped with a noninductive resistance 3 and a divider 4, capable of passing pulses with a front up to $0.2 \mu\text{s}$. These dependences were recorded with an OK-17M oscillograph.

Fig. 1

The acoustic pulse from the spark, propagating in the water poured into tank 5, reached two piezoelectric receivers. The first receiver 6 served to trigger the beam of the IO-4 oscillograph. The signal from it was fed to the oscillograph through a special circuit 7, which protected the oscillograph from retriggering by subsequent pressure oscillations. The second receiver 8 served to record the waveform of the acoustic pulse.

Fig. 2

Figure 2: Fig. 2

The receiver had a sensitive element in the form of a small cylinder made of ceramic barium titanate, fastened by means of an acoustically soft suspension to a metal tube. The receivers had constant sensitivity in a band up to 800 kHz. Absolute calibration was carried out by means of static pressure in the range from 1 to 50 atm. The sensitivity of the measuring receiver was 0.18 V/atm, capacitance 800 pF.

3. Figure 2 shows the time characteristics of the current $I(t)$ and voltage $V(t)$ during discharge through various spark gaps l , with capacitance $C = 0.1 \mu\text{F}$ at voltage $V = 30 \text{ kV}$. The characteristics show the following. Ignition by the auxiliary spark of the air gap raises the voltage across the spark gap in water to 30 kV within fractions of a microsecond. After this, for several microseconds the voltage changes hardly at all, and a small current flows through the gap. The duration of this period varies from experiment to experiment and on average decreases as the length of the spark gap is reduced. The period ends with a voltage collapse, indicating breakdown of the gap. The shorter the spark gap, the deeper the voltage collapse and, consequently, the lower the resistance of the spark channel. After the collapse, the voltage falls smoothly, while the current curve forms a peak. The instantaneous resistance at the moment of maximum current for $l = 5 \text{ cm}$ is 8-9 ohms. The peak becomes higher and sharper as the spark gap is reduced. When the gap length becomes shorter than 3 cm, the fall of the current becomes faster than its rise, and the subsequent change in current and voltage takes the form of damped oscillations with a "period" corresponding to the natural oscillation frequency of the circuit with capacitance C and the inductance of the leads supplying voltage to the spark gap. When the capacitance C is increased from 0.1 to $1.4 \mu\text{F}$ at $V = 30 \text{ kV}$ and $l = 5 \text{ cm}$, signs of the second half-period of the damped oscillations appear; the current at the maximum increases smoothly from approximately 1400 to 14000 A, and the duration of the current pulse—from 4 to 10 μsec . As C is increased at constant V , the length of the maximum gap increases: at $C = 1.4 \mu\text{F}$ and $V = 30 \text{ kV}$, gaps up to 8 cm are broken down.

Fig. 2

4. The acoustic field of the spark was determined at a distance $R = 100 \text{ cm}$ from the center of the spark gap. Oscillograms of the pressure pulses were recorded at points whose radius vectors made angles from 0 to 180° with the axis of the spark, conventionally directed from the positive electrode toward the negative. Figure 3 gives oscillograms of the pulses for angles 0° (top) and 90° (bottom) during discharge through a 4 cm gap, with capacitance $0.1 \mu\text{F}$ at 30 kV. In order to show the scatter, the oscillograms

Fig. 3

Figure 3: Fig. 3

are superposed in sets of five. These pulses have duration and amplitude, respectively, of 30 and 10 μsec , 2 and 9 atm.

The angular dependence of the pulses is easy to understand if one imagines that each element of the length of the spark radiates a spherical wave beginning with a compression phase, followed by a rarefaction phase as the channel expands and a compression phase as it collapses. The pulse for the angle 90° , to a certain

to some extent conveys this picture, but it is considerably blurred, since, because of the curvature of the channel, signals from different elements of the channel arrive at the observation point not simultaneously, and also because the durations of the second and third phases may differ for different elements of the channel. The delay effect is especially pronounced for pulses at an angle of 0° . In the leading part of the pulse, the pressures from different elements add up only during the first phase; then the pressures corresponding to the second and third phases are added. Knowing the amplitudes of the pulses for 0 and 90° , one can approximately determine the duration of the first phase.

Fig. 3

Let each element dx of the segment l produce only one rectangular pulse of duration τ_0 and amplitude $P_0 dx/R$. Taking $R \gg l$ and neglecting nonlinear effects, one can find that, for the pulse at 0° , the amplitude increases over the time τ_0 to the value $P_0 c \tau_0 / R$, where c is the speed of sound, retains this value during the interval $(l/c) - \tau_0$, and falls to zero in the time τ_0 . The pulse for 90° has a rectangular shape, duration τ_0 , and amplitude $P_0 l / R$. The ratio of the amplitudes of the pulses for 0 and 90° is equal to $c \tau_0 / l$. For the experimental data given above it is equal to 0.22. This gives for τ_0 a value of $\sim 6 \mu\text{s}$, which is close to the duration of the current pulse for these conditions, equal to $\sim 4 \mu\text{s}$. The pulse for 180° of long sparks has a more gently sloping leading front than the pulse for 0° . This is apparently due to the fact that, at the positive electrode, simultaneously with the spark there arise corona rays directed in different directions.

When the spark gaps are shortened, the angular dependence of the pulses weakens, and in the pulses for 90° the pressure after passing through the maximum decreases not monotonically, but with an oscillatory component. The period of these oscillations is approximately equal to the period of the damped current oscillations.

5. The electroacoustic efficiency was defined as the ratio of the energy of the positive-pressure pulse to the energy stored in the capacitor. The energy in the capacitor is equal to $CV^2/2$. The energy of the pulse was found in the following way. Assuming that the pulse is symmetric with respect

to the axis of the spark and to the plane perpendicular to it and passing through the middle of the channel,

the energy passing through the surface of a hemisphere of radius 100 cm was determined. The surface was subdivided into 5 zones. For each zone, an oscillogram of the pulse passing through the middle of the zone was determined as an average from 5 photographs, and this pulse was taken as constant over the entire zone. The experimental pulse shape was represented by a trapezoid, which for a pulse of 90° was transformed into a triangle. The pulse energy per unit area was calculated in parts: for the part occupied by the leading front, for the middle part with practically constant amplitude, and for the part occupied by the trailing front. The total pulse energy was found from the formula

$$W = 2 \sum_{i=1}^5 S_i \frac{p_i^2}{\rho c} \left(\frac{\Delta t_{i1}}{3} + \Delta t_{i2} + \frac{\Delta t_{i3}}{3} \right),$$

where S_i is the area of the i -th zone; ρc is the wave resistance of water; Δt_{i1} , Δt_{i2} , Δt_{i3} are, respectively, the durations of the leading front, the middle part, and the trailing front of the pulse of the i -th zone. The values of the efficiency for different conditions are given in Tables 1 and 2. The accuracy of the efficiency determinations is $\pm 30\%$.

Table 1

$$V = 30 \text{ kV}$$

| $C, \mu\text{F}$ | | | $l = 2.5$ | | $l = 1.5$ | |
|------------------|--------------------|--------------------|-----------|--------------------|-----------|--------------------|
| | $l = 4 \text{ cm}$ | $l = 3 \text{ cm}$ | cm | $l = 2 \text{ cm}$ | cm | $l = 1 \text{ cm}$ |
| 0.1 | 32 | 28 | | 24 | | 12 |
| 0.2 | 30 | | | | | |
| 0.3 | 27 | | | | | |
| 0.4 | 28 | | | | | |
| 0.5 | 28 | | 14 | | | |
| 0.7 | 26 | | | | | 10 |
| 1.0 | 26 | | | | | |
| 1.3 | 24 | | | | | |
| 1.5 | 18 | | | | 5 | |

It is easy to see that the efficiency of converting a given amount of electrical energy into acoustic energy falls when the length of the spark gap is decreased, regardless of whether C and V remain unchanged or C is increased and V is decreased. In the latter case, the shortening of the spark-gap length is forced.

Table 2

$$CV^2/2 = 45 \text{ J}$$

| $C, \mu\text{F}$ | V, kV | $l_{\text{max}}, \text{cm}$ | efficiency, % |
|------------------|----------------|-----------------------------|---------------|
| 0.1 | 30 | 4 | 32 |
| 0.2 | 22.6 | 2.5 | 25 |
| 0.4 | 15 | 1.0 | 13 |
| 0.9 | 10 | 0.3 | 3 |

The efficiency also falls at constant l if the store of electrical energy is increased by increasing C at constant V . In this case l is the farther from the maximum, the larger C is. If, however, l is increased to the maximum, some increase in efficiency can be observed.

Thus, it may be concluded that the transition of energy from the electrical form to the acoustic form in a spark discharge in water occurs most effectively—the electroacoustic efficiency reaches 30%—in long-spark discharges.

Acoustics Institute
Academy of Sciences of the USSR

Received
24 VIII 1957

Note: Figure translations are in progress. See original paper for figures.

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.