ELECTRICAL DISCHARGE IN PENTAERYTHRITOL TETRANITRATE POWDER

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The article presents some results of oscillographic investigations of an electric discharge in pentaerythritol tetranitrate (PETN) powder of density (0.5-1.2) g · cm^{-3}. A hydrodynamic model of the development of the current-conducting channel was used; estimates of the rate of its development and values of its radius and of conductivity in it are given. It is shown that the transformation products of PETN have a conductivity not above $7 \cdot 10^6$ sec^{-1}.

A zone of rather high electrical conductivity is recorded in a stationary detonation of condensed explosives. In [1] an estimate is given of the conductivity of explosion products which was determined by thermal ionization from the experimentally measured temperature of the detonation products of explosives. Its value lies within 10^7 and 10^9 sec^{-1}. The authors of [2] measured the conductivity of explosion products, which proved to be considerably higher than the estimated values in [1] and amounted to $(0.23\text{-}5.00) \cdot 10^{12}$ sec^{-1}. However, an analysis of the oscillograms given in [2] shows that a narrow zone in the front of the detonation wave has a high conductivity, and the products themselves, if they conduct at all, then their conductivity is apparently not higher than the estimates in [1]. The effect of the detonation front on the measurement process can be eliminated by igniting powdered explosives with an electrical discharge.

Results of investigating an electric discharge in PETN powder of low density (0.5-1.2 g/cm^3) enclosed in a Plexiglas shell are presented below. Its diagram is shown in Fig. 1, where 1 is the housing, 2 is the cover, and 3 is the electrode. It is shown that the transformation products, which are under a high pressure, have a conductivity not exceeding $7 \cdot 10^6$ sec^{-1}.

During the investigation we changed the density and dispersity of the PETN particles. The current and voltage of the discharge were measured by the oscillographic method with the use of a compensation circuit (Fig. 2). The use of known circuits for measuring the current and voltage was hampered in the given case by the high corrosiveness of the explosion.

The circuit operated as follows. On discharge of capacitor C practically the entire discharge current flowed through section AOB of the circuit, since the resistances of r_1 and r_2 are much less than those of R_1 and R_2, respectively. We will take the potential of point O as the zero potential. At a certain instant the potential of point A relative to O will be equal to

$$U_1 = r_1 I + L_1 \frac{dI}{dt}$$

and the potential of point B relative to O will be

$$U_2 = -\left(r_2 I + L_2 \frac{dI}{dt}\right)$$

Here I is the current in the circuit and L_1, L_2 are the inductances of circuits AOO'A' and BOO'B' respectively. The parameters of circuits AOO'A' and BOO'B' were selected so that $L_1 = L_2$ and $r_1 \neq r_2$.

Then the voltage drop in section AB will be

$$U = U_1 + U_2 = (r_1 + r_2) I$$

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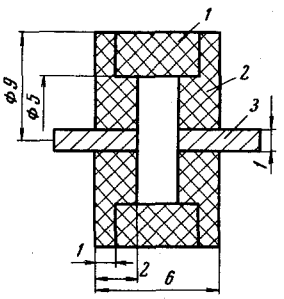

Fig. 1

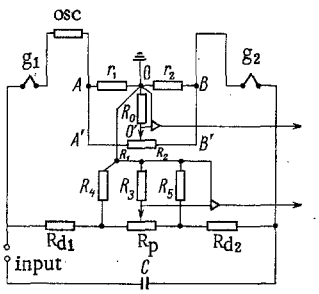

Fig. 2

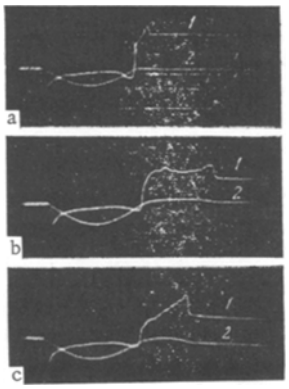

Fig. 3

The signal from resistor R_6 is proportional to U. In most cases we can set $r_2 = 0$ (copper wire) with a sufficient degree of accuracy. A resistor coinciding with r_2 in rating and form is connected into the measuring arm in place of resistor r_1 to check the balance of the circuit. If the circuit is balanced, the oscillogram of the current coincides with the zero line of the given trace.

The circuit for measuring the voltage is constructed on the same principle as the current circuit, from which it differs only by the magnitude of the resistances in the compensating arms. The circuit is balanced with the investigated gap short-circuited. In this case the oscillogram of the voltage should coincide with the zero line of the given trace.

The parameters of the discharge circuit were the same in all experiments and were C ~0.1 μF and L ~4 μH. A change of the initial voltage at the capacitor made it possible to obtain various power and energy released in the investigated gap, which was 2 mm in all experiments. Examples of the oscillograms of the current and voltage of the discharge in PETN powder are shown in Fig. 3a, b, c.

The general course of the gap voltage during discharge in PETN powder of the investigated density and dispersity can be represented by a sequence of four stages. The first three stages are similar in their character to the three stages of discharge in air under normal conditions, but substantial differences begin as early as in the second stage which are characterized by a slower voltage drop in the gap and by its greater magnitude. The durations of the first three stages and the magnitudes of the voltage in them are determined by the parameters of PETN (density and dispersity) and by the initial voltage across the discharge capacitor and amount to $(0.5\text{-}1) \cdot 10^{-6}$ sec for the second stage and $(0.5\text{-}1.2) \cdot 10^{-6}$ sec for the arc stage. The character of the discharge arc in PETN powder depends on the energy released in the investigated gap by this time.

If the energy released is sufficient for the occurrence of self-sustaining transformation of PETN, the arc stage passes into the fourth stage, which is absent in discharges in gases. The first three stages occur only in the first half-period of the discharge. The fourth stage occurs either at the end of the first half-period or at the end of the second depending on the parameters of PETN and the initial voltage across the discharge capacitor. At the end of the first half-period it occurs during discharge in PETN powder of density 0.5-0.6 g/cm^3 and initial voltage of 8-10 kV and also at a density of 1-1.2 g/cm^3 and initial voltage of 13-15 kV (Fig. 3a, where 1 is the voltage in the investigated gap and 2 is the current in the circuit). In this case a characteristic feature of the fourth stage is a rapid (within $0.5 \cdot 10^{-6}$ sec) increase of voltage from the arc voltage to 1.5-2 kV and higher, then an abrupt drop within $\sim 10^{-7}$ sec. As a rule, breakdown of the gap does not occur in the second half-period, and a voltage of 3-6 kV remains in the gap. The discharge ceases.

An increase of the initial voltage across the capacitor during discharge in PETN powder of density 0.5-0.6 g/cm^3 leads to a shift of the fourth stage into the second half-period, beginning with 11 kV (Fig. 3b). In the second half-period it occurs also during discharge in PETN powder of density 0.7-0.9 g/cm^3 at a capacitor voltage of 10-15 kV. In this case, at the beginning of the second half-period the voltage in the investigated gap increases to 1-1.5 kV within $\sim 2 \cdot 10^{-7}$ sec, then slowly drops by 300-400 V by the middle of the half-period, and again increases, reaching 1.5-2 kV at the end of the half-period. In some cases (Fig. 3c) the voltage at the start of the fourth stage increases more slowly and reaches 5-6 kV, then drops

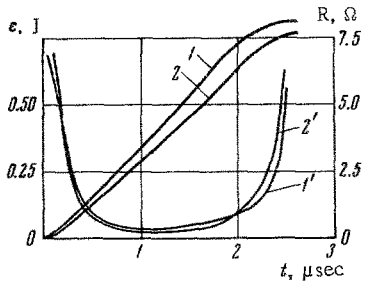

Fig. 4

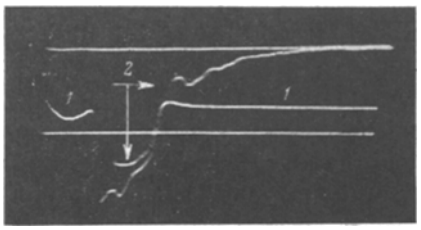

Fig. 5

to 2-4 kV within 10^{-7} sec. In this case the discharge dies out in the middle of the second half-period. Extinction of the discharge is recorded with respect to the zero value of the current.

An analysis of the oscillograms shows that the current of the first half-period in all cases is determined by the parameters of the discharge circuit and coincides in magnitude with the current of a gas discharge. If the fourth stage takes place in the second half-period, the current in this case is by a factor of 2-3 less than the current of a gas discharge.

From the current and voltage oscillograms we can calculate the energy released in the gap and the gap resistance as a function of time; the corresponding dependences are presented in Fig. 4, where curves 1 and 1' are for $\rho_0 = 0.6$ g/cm^3, $U_0 = 10$ kV and curves 2 and 2' are for $\rho_0 = 0.5$ g/cm^3, $U_0 = 10$ kV. It should be noted that during electrical discharge in PETN powder the energy released in the gap is by a factor of 3-5 greater than the energy of a gas discharge under normal conditions.

The development of an electrical discharge in gases exhibits a hydrodynamic character. The energy released in the discharge gap leads to the appearance of a strong divergent cylindrical shock wave which almost completely ionizes the gas [3]. The wave front in this case is the boundary of the current-conducting zone of the channel which develops in the second stage [4].

In the case of an electrical discharge in PETN powder the density of the energy in the gap within $0.2-10^{-6}$ sec after the start of discharge (when, if judged by the oscillograms, the energy released by PETN can be considered insignificant) is 10^2 cal/cm^3, i.e., of the same order as the energy density of low-calorific explosives. Therefore, we can assume that the development of the discharge in PETN powder, just as in gases, occurs in the manner of a hydrodynamic model. However, in this case the shock wave formed upon breakdown of the gap apparently is not the boundary of the current-conducting channel. The channel is bounded by material accelerated by the shock wave, and its development is accomplished by ionization of gas in the volume freed by the radially expanding PETN, the velocity of which is determined by the intensity of the shock wave and the energy released in the gap.

The value of the energy density was obtained from the magnitude of the energy released in the gap and from the estimates of the radius of the current-conducting channel (Table 1). It should be noted that the energy density in the gap decreases with the course of time, and consequently immediately after breakdown its value is apparently not less than 10^2 cal/cm^3.

The duration of the second stage of the discharge in PETN powder (stage of development of the current-conducting channel) is by an order greater than the second stage of a gas discharge. This is probably related with the fact that the velocity of the shock wave in PETN is much less than the velocity of a shock wave in air, despite the greater (by a factor of 3-5) energy released in the gap. Knowing this energy from experiments, we can estimate the rate of development of the current-conducting channel on the basis of the proposed hydrodynamic model.

Table 1 presents estimates of the rate of development of the current-conducting channel and the value of its radius and conductivity in the channel. As was suggested, the rate of development of the current-conducting channel in the case considered is almost an order less than the rate of development of a channel upon discharge in gas [4].

The values in Table 1 were estimated on the assumption that the channel is cylindrical and the shock wave was considered sufficiently strong to neglect the initial pressure but insufficient for compressing the crystalline material and for exciting detonation transformation of PETN. The latter assumption is justified by the fact that the character of the oscillograms of the gap voltage begins to change only after the arc stage.

TABLE 1

$t \cdot 10^7 = 2$	4	6	8	10	(sec)
$V = 650$	560	500	460	450	(m/sec)
$r \cdot 10^2 = 1.7$	2.9	4.0	5.0	5.7	(cm)
$\sigma \cdot 10^{-14} = 0.40$	0.46	0.47	0.49	0.47	(sec^{-1})

It was assumed further that in the shock transition zone, the PETN is compressed to a density close to a single crystal, the material beyond the shock transition was considered incompressible, and the development of a current-conducting channel due to an increase of the degree of ionization of gas in it was neglected (an estimate of conductivity gives a practically constant value (Table 1)). The last assumptions are rather arbitrary.

The conductivity of the discharge plasma was calculated from the estimated values of the radius of the current-conducting channel on the assumption that the current density is zero in the region occupied by PETN. It proved to coincide with the conductivity of gas-discharge plasma [5], which can indicate indirectly in behalf of the assumption made above.

In the arc stage the gap resistance is considered practically constant and amounts to 0.3-0.5 Ω. Apparently by this time the development of the current-conducting channel ends, and the incipient transformation of PETN still cannot substantially affect ionization of the arc plasma. A part of the energy released in the gap is concentrated as heat in the heated layer of PETN particles. This results in that on reaching a certain temperature the rate of transformation of PETN is such that the transformation products affect considerably the discharge parameters. This moment can probably be related with the moment of translation of the discharge from the arc stage to the fourth stage. The place of the fourth stage in the discharge will be determined by the heating time of the PETN particles and the rate of its transformation. Both these factors should depend on the size of the particles and charge density, which is observed in experiments.

As was indicated above, one of the characteristic features of a discharge in PETN powder is cutoff of the current either at the end of the first half-period or in the second. Cutoff of the current occurs owing to the interaction of the highly conducting zone of the channel with the transformation products of PETN, which are under a high pressure. Apparently the transformation products by this time have a low conductivity. To estimate this conductivity we attempted to measure the current at the end of the fourth stage of the discharge. The signal of the current pickup was sent through a diode clipper to the input of the amplifier of an OK-17M oscillograph. On the oscillogram (Fig. 5, where 1 is the voltage in the investigated gap and 2 is the current in the circuit, recorded through the clipper) we see that within $8 \cdot 10^{-6}$ sec after the start of discharge the current cannot differ from zero, for the given measurement accuracy. (The nonagreement of the phase of the current and voltage in the $4 \cdot 10^{-6}$ sec portion at the end of the discharge is explained by the poor transient characteristics of the clipper.) For the upper estimate of the conductivity we suggest that the possible zone of conductivity is bounded by a region equal in diameter to the discharge electrode (1 mm). In this case the conductivity of the products is not more than $7 \cdot 10^6$ sec^{-1}.

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