Use of Plasma for Intensification of Ignition and Combustion of High-Energy Materials

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Abstract - The results of the investigation of the influence of a powerful electric discharge on initiating and intensifying combustion of poured high-energy materials in manometric and ballistic devices are presented in the paper. Data received with use of plasmatron are compared to the results of a traditional way of igniting with electric ignition cap.

Research aimed at the use of plasma for improvement of the ignition and combustion parameters of high–energy materials is stimulated by high thermalphysic characteristics of plasma and the possibility to control the level of thermal action. Another advantage of this method of thermal action is the variety of engineering solutions for practical realization. Due to different location and form of initiating conductors it is possible to produce a discharge in the studied material under investigation or to inject plasma to the given areas of the material using the plasmatron. In particular, use of plasma proved prospective for solving a number of problems of inner ballistic. [1]. Using plasma as the igniter makes it possible to substantially reduce and stabilize the period of projectile ignition and the overall duration of shot. Injecting the plasma into the projectile charge burning during the period of the thrown body moving through the barrel makes it possible to raise the speed of the charge burning-out and to control the changing of the pressure in all the space beyond the projectile.

Increasing of the weight charge burning rate allows using the charges of higher mass and density which results in increasing of the muzzle energy of thrown bodies. One of the possible areas of using electric plasma in ballistic systems is compensating the temperature gradient the combustion speed. When injected into projectile charge with different initial temperatures, the necessary amount of electric energy can to ensure the necessary character of changing the pressure of combustion products, thus securing the practically identical speed of the thrown body.

The work evaluates the possibility of solving the problems listed above and presents some research results in this sphere. For this purpose a plasmatron was developed and tested. The scheme of plasmatron is shown on Fig. 1.

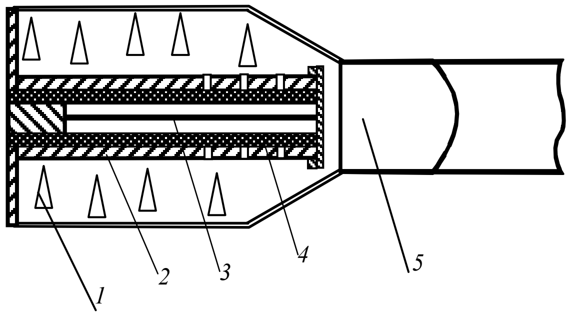

Fig. 1. General scheme of shot electric energy input:
1 – powder charge; *2* – plasmatron;
3 – wire; *4* – polyethylene; *5* – thrown body

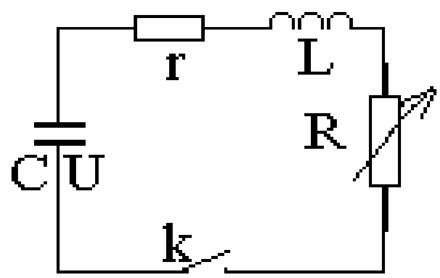

Fig. 2. Power supply circuit for the plasma (common scheme)

It represented a thick perforated metal tube (cathode) with an insulated electrode (anode) inside. The plasmatron, which had changeable length sufficient to reach bottom of the thrown body was fastened to the screwed closure of the loading chamber, placed on its axis. First cathode and anode were bridged by a thin metal conductor initiating the discharge. After detonating the conductor an axled discharge canal injecting electric plasma to the charge was formed inside the coaxial plasmatron. The interior surface of the plasmatron was covered by volatile insulator, polyethylene, in oder to increase the mass of the nascent plasma.

Therefore the plasma included the products of evaporating the explosive conductor, supplying anode and polyethylene and also surrounding gas warmed-up by the discharge.

The products of discharge flowed out to the chamber through the axled and radial openings in the cathode's body. Thus while changing the diameter and location of outcome openings it is possible to influence any part of the projectile charge. The above shown construction of the plasmatron is one of the possible variants of similar devices. Power supply of the discharge gap was realized as it shown in Fig.2.

The specific character of the plasmatron functioning in the concerned conditions is determined by the relatively low tension (U<3кV) in the power supply system and by the possible influence of the pressure increase in the chamber during charge ignition on the arc development process.

The above mentioned construction was tested in numerous experiments. Prospective parameters of plasmatron were forecast with the help of mathematical model taking into account the heating and fusing of conductors before explosion and the next stage of developing the arc discharge canal on the basis of the data [2,3] Load $R(t)$, modeling plasma discharge canal was represented as a cylindrical cave widening radial direction and having the same length as the initiating conductor.

For copper and aluminum conductors used in the plasmatron as initiating wires the rated current dependences well agree with the corresponding experimental data (Fig.3).

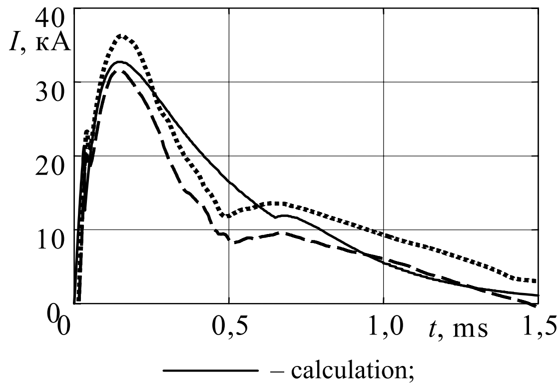

Fig. 3. Dependence current strength on time

Modifying the parameters of plasmatron circuit allows to control the energy input into the discharge gap in a wide range, thus controlling the characteristics of the plasma jet. Increasing the capacity and charge tension makes it possible to control the discharge energy. Induction coils included into the circuit decrease the power of energy input, therefore reducing the powered impact of the discharge on the charge. The experimental and calculated current graphs derived while including induction coils in the circuit are shown in Fig. 4.

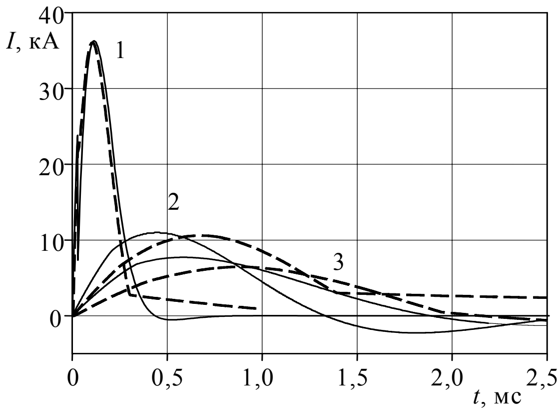

Fig. 4. Changing the current strength in plasmatron circuit depending on its parameters

The developed plasmatron construction was used in manometric investigations as well as and for evaluating the possibility of controlling the inner ballistic parameters of the 23 mm projectile device. One of the practically interesting parameters is the period of the powder charge igniting. In this paper a period of igniting was presented as time necessary for reaching the typical pressure for ballistic researches equal to 100 MPa including both the proper period of igniting and the time of transitional burning-out of gunpowder concerned with its strong heating-up because of the influence of plasma. The dependence of the time necessary for reaching the pressure equal to 100 MPa – t_{1000} on the amount of the stored energy in the source of energy E is shown in Fig. 5.

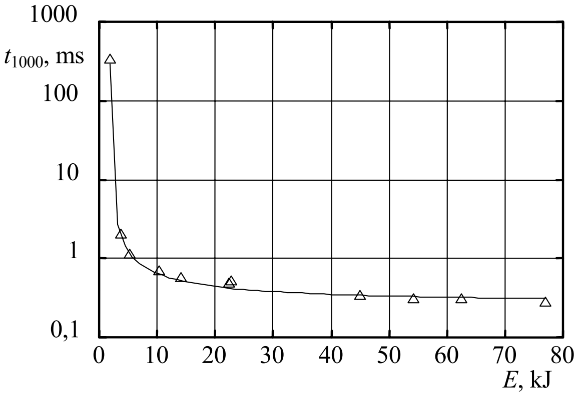

Fig. 5. Dependence of time t_{1000} on stored energy in source

The dependence has a hyperbolic character and reaches the asymptote at $E \approx 22$ кJ, which roughly equal to 6,6 кJ of energy input into the discharge gap.

Further increase of energy does not result in reducing the time of charge igniting. To define the bounds of influence of the charge plasma quantitatively it makes sense to turn to specific parameters characterizing the amount of energy per mass unit of the powder. In the concerned case the specific amount of energy stored in the source is 0,08 кJ/g while the specific amount of energy input into the powder is $Q_{уд}$ = 0,024 кJ/g which is about 0,6 % of its calorie content. In general the amount of energy necessary for the maximum reduction of the ignition period depends on density of projectile charge. [4]

Inputting the amount of specific energy referred to above in the projectile charge makes it possible not only to reduce its ignition time to the minimum but also to compensate the thermal gradient within a certain temperature span. Fig. 6 presents the curves of changing the pressure in the charge chamber in a regular experiment, when the charge was ignited by a standard projectile charge burning in the test compared to those when the plasmatron was used to ignite the charge.

Comparison of the corresponding dependences shows that the maximum pressure level in the experiment with plasma igniting grows by 18%. It results in increasing the speed of the projectile speed by almost 4,6%.

Theoretical calculations made for a polydisperse gas and powder model and the known data on the temperature sensitivity of the powder used give reasons to consider that such changes of basic ballistic figures on the used model set are possible with using the initial charge temperature on the range +20 - +50°C. Thus bringing in the charge 6,6 kilojoules of energy we received the same result as when heating it to the temperature + 50°C. It should be noted that this effect has steady, reproducible nature. So in the series consisting of three experiments using the brining in the same quantity of energy dispersal of the maximum pressure was about 5% and of the speed of thrown body about 1%.

Analysis of the results of realized experiments allows illustrating the possible physical causes of compensating the thermal gradient when using plasmatron as the initiator. The dependences characterizing the changes of the combustion surface of a charge on the degree of powder burning-out ψ in the experiments with the electric ignition cap and with plasma are shown in Fig. 7.

It is evident that with electric plasma injected about half the mass of the charge burns with increased gas discharge. This may be connected either with high transitional speed of powder combustion due to the plasma heating its outer layers or with partial destruction of powder elements caused by the increase of the combustion surface as the effect of the plasma jets. Changing the discharge energy has shown that the rise in the amount of energy input into the charge causes the increase of combustion surface, the maximum of the former tending towards the minor ψ at the initial stage of combustion.

In order to study the possibility of using the developed plasmatron for the temperature gradient compensation within wider span experiments were conducted where the stored energy was varied from 0 to 77 кJ. The maximum pressure in the ignition chamber changed as shown in Fig. 8. The asterisk indicates the figures of the experiment with the electric ignition cap.

It is evident that the energy input into the charge equal to 2,3% of its chemical energy increases the maximum pressure inside the chamber by almost 30%,

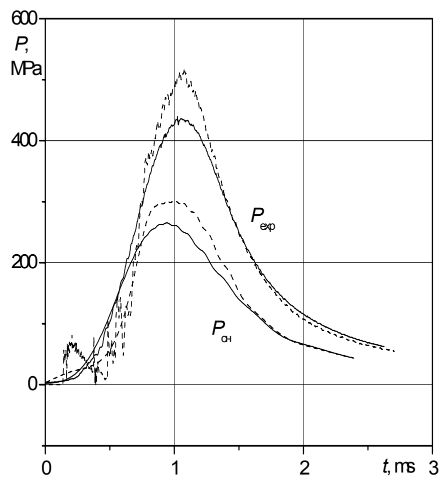

Fig. 6. Dependences between time and pressure in the charge chamber P_{exp} and on the projectile $P_{сн}$
____ - experiment with electric ignition cap;
P -= 440 MPa,
------ - experiment with plasma input;

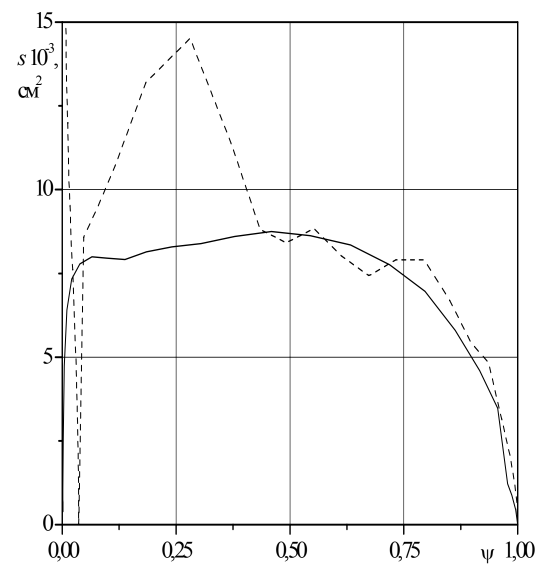

Fig. 7. Dependences of the powder combustion surface on degree of powder combustion:
----- – experiment with electric ignition cap;
- - - - – experiment with plasma input

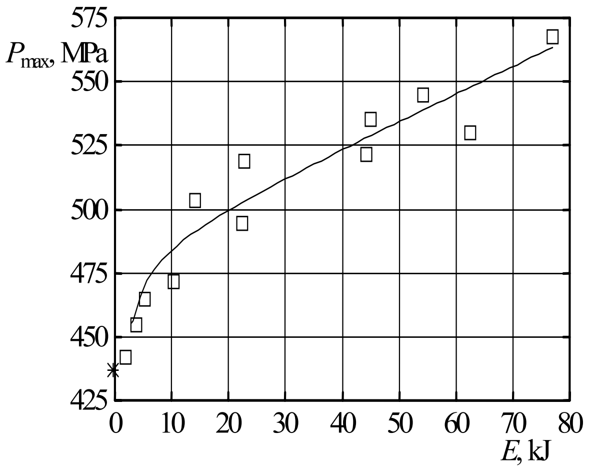

Fig. 8. Dependence of the maximum pressure inside the charge chamber on circuit energy

the projectile speed rising by about 6,5%. According to theoretical ratings the data received imply that it corresponds to the change in similar figures within the range of initial charge temperatures from 0°C to + 50°C.

The results referred to above show that electric plasma is an effective instrument of varying ignition and combustion parameters for high-energy substances, while the function of controlling the essential characteristics of the process can be implemented with the developed plasmatron construction.

The research is supported by the Russian Fund for Fundamental Research (project 04-03-33121).

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