Optimization of Construction of the rocket-assisted projectile

Vladimir Arkhipov[1], *Ksenia* Perfilieva[1,*]

[1]National Research Tomsk State University, 634050 Tomsk, Russia

Abstract. New scheme of the rocket motor of rocket-assisted projectile providing the increase in distance of flight due to controlled and optimal delay time of ignition of the solid-propellant charge of the SRM and increase in reliability of initiation of the SRM by means of the autonomous system of ignition excluding the influence of high pressure gases of the propellant charge in the gun barrel has been considered. Results of the analysis of effectiveness of using of the ignition delay device on motion characteristics of the rocket-assisted projectile has been presented.

1 Introduction

Rocket-assisted projectile (RAP) is the artillery shell that has appearance of normal (active) shell in the body of which the jet motors is built [1].

The special thing about external ballistics RAP is that at the time of a departure from in the gun barrel the shell has the maximum (muzzle) speed [2]. Thus, the shell takes maximum resistance from environment, proportional to the square of its speed. Engaging of the rocket-assisted projectile of solid-propellant rocket motors (SRM) directly at the time of shell departure from barrel does not allow using the thrust of SRM for increase in flying range of RAP effectively. To increase the efficiency of RAP it is worth to realize start of SRM on flight trajectory of rocket-assisted projectile with using various ways and delay devices time of ignition (inhibitor) [3-4].

2 The scheme of the rocket-assisted projectile

To increase the RAP flying range the new scheme of autonomous ignition system is presented [5]. The scheme of RAP is presented in Fig. 1. The rocket motor rocket-assisted projectile operates as follows. When driving a shell in a gun barrel under the influence of high pressure of propellant gases of a propellant charge the protruding edge of a flange adaptor 10 is cut off, and the rod 14 with the console 18 fixed on it moves towards the pierced membrane 4 and squeezes a spring 20. At the same time the conic section 11 of a rod 14 interfaced to a the conic cavity 9 in the basis 8, interfering with breakthrough of powder gases in a self-contained cavity 5. After shell exits from the gun barrel pressure of

* Corresponding author: k.g.perfiljeva@yandex.ru

powder gases upon the cut-off cover of a nozzle 13 sharply decreases, at the same time the rod 14 with the attached console 18 fixed on it under the influence of a spring 20 moves back and influences strikers 16 in the pyrocartridge 15. The products of combustion of the pyrocartridge, through perforations 17 in the console 18 received to a self-contained cavity 5 and ignite face surfaces of inhibitor charges 21. Thermo insulation fillers 22 interfere with penetration of powder gases into prenozzle volume from a self-contained cavity 5 before the complete combuston of the inhibitor charges 21. After a burnout of charges of a inhibitor 21 during the given time t_{ign} products of combustion through pierced membrane 4 come from a self-contained cavity 5 to prenozzle volume and set fire to an igniter 23. The products of combustion of the ignitor 23 ignite the charge of solid propellant 2. At achievement in a combustion chamber of the predetermined pressure the cut of turning 7 the cut-off covers of a nozzle 13 is cut off, providing a departure from the diffuser of a nozzle of 6 all elements of system of ignition (membrane 4, sleeving 19, basis 8, etc.). Thus, the launch of the SRM on flight path through tightly controlled time t_{ign} determined by the burning rate and the height of the charges of the inhibitor 21.

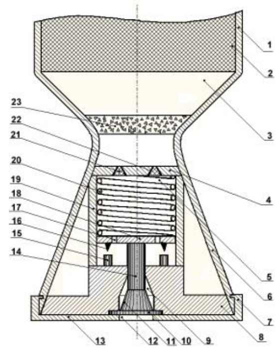

Fig. 1. The scheme of the rocket motor rocket-assisted projectile.

Thus, the scheme of the rocket motor ARS provides the increase in flying range due to providing a controlled and optimum delay time of ignition of the solid-propellant charge of the SRM and increase in reliability of initiation of the SRM by the expense of the independent ignition system excluding influence of high pressure gases of a propellant powder in the gun barrel.

3 Determination of the optimal value of ignition delay time of the solid-propellant charge

Let's consider the motion of ARS with a caliber of 76 mm (ZIS−3) [6] with SRM tubular-channel charge armoring at the face end surfaces of size 40/8–150 mm.

The main characteristics of the solid-propellant rocket motor ARS received by results of intra ballistic calculation of SRM operated by a technique [7] given in table 1.

Table 1. The main characteristics of the solid-propellant rocket motor ARS.

Parameter	d_{cr}, mm	d_a, mm	p_k , MPa	P , N	G, kg/s	J, m/s	t_* , s
Powder H	9.2	27.8	8.0	778	0.35	2214	0.82

Motion of an inert body in the air environment determinate by the system of equations of external ballistics [7]:

$$\frac{dU}{dt} = -\frac{F}{m} - g\sin\theta, \qquad \frac{d\theta}{dt} = -g\frac{\cos\theta}{U},$$
$$\frac{dy}{dt} = U\sin\theta, \qquad \frac{dx}{dt} = U\cos\theta,$$

where U is shell speed; F is force of a head resistance; m is mass of a shell; g is free fall acceleration; θ is a corner between a vector of speed and the line of the local horizon; y is vertical coordinate; x is horizontal coordinate.

The system of equations of motion of ARS in the active site includes the modified equation for the velocity of the given thrust of the rocket motor and the additional equation for mass change ARS with the combustion SRP:

$$\frac{dU}{dt} = \frac{P}{m} - \frac{F}{m} - g\sin\theta\,;$$

$$\frac{dm}{dt} = -\rho_T u_T S_T\,,$$

where P is force of draft of SRM; $\boldsymbol{\rho_T}$ is density of solid propellant; u_T is burning rate of solid propellant, S_T is surface area of combustion of solid solid propellant.

Force of a head resistance was calculated by the formula:

$$F = C_x \rho_b S_m \frac{U^2}{2}\,,$$

where C_x is coefficient of a head resistance; ρ_b is density of air; S_m is area midship section of the shell.

The coefficient of head resistance was calculated by approximating equations depending on Mach number [7].

Conduction series of external ballistics calculations of flying range of an inert shell (without SRM) weighing 6.6 kg and with SRM (the mass of fuel is equal 0.29 kg or 4.3% of the mass of a shell) with tign ignition delay time variation, at a shot from the tool with the initial (muzzle) velocity of $U_0 = 680$ m/s, a corner $\theta_0 = 45^o$.

The results of the calculations, the range of inert shell ZIS-3 (no SRM) is $x_к = 13.7$ km, which well coincides with the results of full-scale tests ($x_к = 13.3$ km) [6].

The results of parametric calculations of the motion of the rocket-assisted projectile with SRM for different delay times of ignition t_{ign}, are given in table 2 ($x_к$ is range capability, $t_к$ is time of flight).

Table 2. The results of parametric calculations of the motion of the RAP with SRM.

t_{ign}, s	0	5	10	15	18	19	20	25
$x_к$, km	15.12	15.37	15.66	16.35	16.50	16.53	16.52	16.17
$t_к$, s	64.06	64.37	64.55	64.69	64.21	63.94	63.63	61.69

The calculated dependence of the rate of motion of the RAP from time is shown in Fig. 2, and the trajectory motion of the RAP shown in Fig. 3: 1 is inert shell (without charge SRP); 2 is charge with SRM at t_{ign}=0 s; 3 is charge with SRM at t_{ign}=19 s.

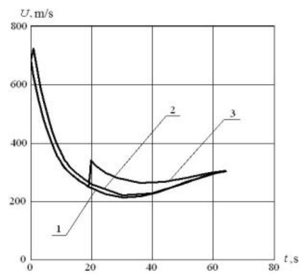

Fig. 2. Dependence of the rate shell from time.

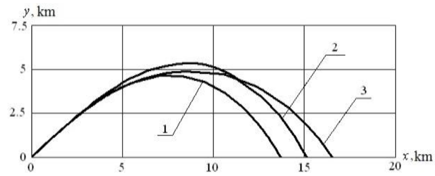

Fig. 3. Trajectory motion of the rocket-assisted projectile.

4 Assessment of the height of the inhibitor charges

The height of the charges of the inhibitor provides the optimal value of delay time of ignition of solid propellant charge in which the range of the ARS maximum [8].

To determine the height of the charges of the inhibitor, consider the equation of conservation of mass in a closed cavity between the pierced membrane and cut-off cover of a nozzle:

$$\frac{d}{dt}\left(\rho_g V\right) = \rho S u , \tag{1}$$

where t is time; ρ_g is density of the gaseous products of combustion inhibiter; ρ is density inhibite cherge; V is volume close cavity; S is the total surface combustion charge of the inhibitor; u is rate combustion inhibitor.

In accordance with the state equation Mendeleev – Clapeyron

$$\rho_g = \frac{p}{RT} , \tag{2}$$

where p is the pressure in the closed cavity; R is the gas constant of the combustion products of the inhibitor; T - temperature of the combustion products of the inhibitor.

Substituting (2) into (1), we get

$$\frac{dp}{dt} = \frac{\rho S R T}{V} u . \tag{3}$$

The law of burning rate inhibitor will take the form [8]:

$$u = u_0 \left(p / p_0 \right)^{\nu} , \tag{4}$$

where u_0 is the burning rate inhibitor at atmospheric pressure; p_0 is atmospheric pressure; ν is the exponent in the dependence of the combustion rate inhibitor from the pressure.

Substituting (4) into equation (3) and carrying out the integration, we get:

$$p = p_0\left[1+\frac{(1-\nu)u_0 t\rho SRT}{p_0 V}\right]^{\frac{1}{1-\nu}}. \qquad (5)$$

The height of the charges of the inhibitor is determined by the equation:

$$h = \int_0^{t_{ign}} u(dt).$$

Taking into account (4), (5), we obtain the desired relation:

$$h = \left\{\frac{\rho SRT}{p_0 V}\left[u_0(1-\nu)t_{ign}\right]^{\frac{1}{\nu}}\right\}^{\frac{\nu}{1-\nu}}. \qquad (6)$$

Calculate the height h of the charge of the inhibitor (medium diameter 5mm), which provides the necessary time delay ignition of the charge of SRM. The main characteristics of the inhibitor composition of the TCS-20 are given in table 3 [9].

Table 3. The main characteristics of the inhibitor composition of the TCS-20.

ρ, kg/m^3	RT, kJ/kg	u_0, mm/s	ν
1600	280	0.6	0.06

The results of the calculations by equation (6) the height h of the inhibitor depending on the required magnitude of time delay of ignition t_{ign}, for different values of the free volume of the closed cavity are shown in Fig. 4 For time t_{ign}=19s, the height of the charge of the inhibitor is equal to h=14 mm in the free volume V=10 sm^3.

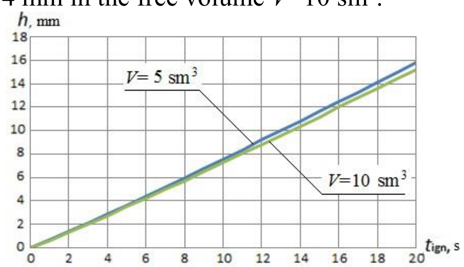

Fig.4. The dependence of the height h of the inhibitor depending on the required inhibitor of time delay of ignition t_{ign}, for different values of the free volume of the closed cavity.

The results of the calculations by equation (5) of value of the maximal pressure p in the closed cavity during the combustion of the inhibitor charges for different values of the free volume are shown in Fig. 5. The pressure value essentially depends on the free volume and V=10 sm^3 is p=12.7MPa.

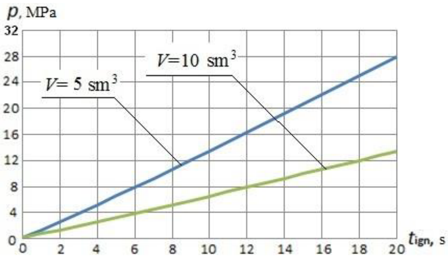

Fig. 5. Dependence for the values of the maximum pressure *p* in the closed cavity at combustion of the inhibitor charges for different values of the free volume.

5 Conclusion

- The modified scheme of the rocket motor rocket-assisted projectile is presented.
- It is defined that using the tubular and channel charge of ballistite (gunpowder H) propellant in SRM rocket-assisted projectile, increase in flying range of a shell by 10% (is provided at t_{ign}=0 s) and for 20% (at t_{ign}=19 s) in comparison with an inert shell.
- Inhibitor charge height (h=14 mm) at the free volume of V=10 sm^3 for an optimum delay time of ignition is calculated.
- The pressure in a self-contained cavity during combustion of charges of a decelerator is determined (p=12.7MPa) with a free volume of V=10 sm^3.

The work it is executed at financial support of the Ministry of education and science of the Russian Federation in the framework state task, project No. 9.9063.2017/BP.

References

1. M.E. Serebryakov, *Vnutrennyaya ballistika* (Barongis, Moscow, 1949) [In Russian]
2. B.A. Raizberg, B.T. Erokhin, K.P. Samsonov, *Osnovy teorii rabochikh processov v raketnykh sistemakh na tverdom toplive* (Mechanical Engineering, Moscow, 1972) [In Russian]
3. Patent US No 7360355 B1, IPC F02K 9/36. Long range artillery shell / M.H. Guillaume, J.L. Gadiot – Date of patent: 22.04.2008
4. Patent US No 9207054 B2, IPC F42C 11/06, F42B 15/10, F42B 15/36, F42C 11/02. Solid state ignition safety device / V. Jeffrey, A. James, V. Robert, M. James – Date of patent: 08.12.2015
5. The application on patent RF No 2017113324, IPC F02K 9/08. Method the increase in distance of flight due rocket-assisted projectile / V.A. Arkhipov, S.S. Bondarchuk, A.I. Konovalenko, K.G. Perfilyeva. – Filing date: 17.04.2017 [In Russian]
6. A. Ivanov, *Artillery of the USSR in World War II* (OLMA of Media groups, Moscow, 2003) [In Russian]
7. V.P. Stepanov, *Dynamics of flight of rocket projectiles*. *Manual* (Publishing house of the Tomsk university, Tomsk, 1977) [In Russian]
8. A.P. Hardt, *Pyrotechnics* (Post Falls, Idaho, 2001)
9. D.B. Demyanenko, A.S. Dudyrev, I.G. Strakhov, M.N. Tsynbal, The letter of the St. Petersburg state technological university, **42** (2012) [In Russian]