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INTERIOR BALLISTIC PRINCIPLE OF HIGH/LOW PRESSURE CHAMBERS IN AUTOMATIC GRENADE LAUNCHERS

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Automatic grenade launchers renew the interest for the interior ballistic principle of high/low pressure chambers which is applied in them. For the sake of principle optimisation in the specific automatic grenade launcher the theoretical and experimental investigations are carried out. In theoretical modelling special attention is paid to flow of two-phase mixture of propellant gases and unburned propellant from the high-pressure chamber to the low-pressure chamber, and to continuation of propellant combustion in the low-pressure chamber and the launcher barrel. Through experimental investigations the influence of propellant type, relation of chamber volumes, number, dimensions, and position of holes in wall separating chambers, and type of liner across the holes are studied. All these influences the code based on theoretical considerations simulates correctly.

INTRODUCTION

Automatic grenade launchers are the best answer to a very concrete operational requirements which justify their introduction as an additional weapon type at company (or equivalent) level. Current automatic grenade launchers exhibit technical characteristics linking them to the other area weapons deployed at the same echelon level, in particular to machine guns and mortars. When one properly considers the three basic criteria – mobility, firepower and self-sustainability – according to which infantry combat units are organised, it becomes evident that each level must be given the tools to rapidly and effectively solve the most critical situations in which it could find itself, without having to rely on fire support from upper levels. Automatic grenade launchers are intended to solve that problem [1,2].

Current automatic grenade launchers renew the interest for the interior ballistic principle of high/low pressure chambers which is applied in them. In order to improve ignition of propellant charge and uniformity of grenade velocities we applied the interior ballistic principle of high/low pressure chambers instead of classical one in 30 mm automatic grenade launcher. Through theoretical modelling and experimental investigations we consider influence of different factors on the interior ballistic characteristics of modified concept.

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THEORETICAL MODEL

Interior Ballistic Cycle

The schematic presentation of interior ballistic cycle in the automatic grenade launcher using the high/low pressure chambers principle is given in Fig. 1.

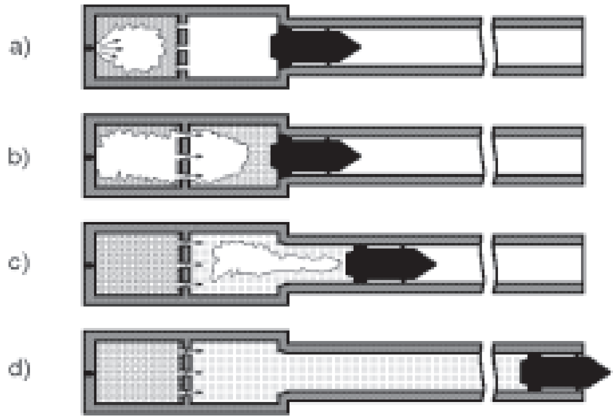

Figure 1.

The interior ballistic cycle starts with initiation of ignition cup and ignition of propellant charge placed in the high-pressure chamber (see Fig. 1-a). The propellant charge burns in the constant volume of high-pressure chamber until the moment when the propellant gas pressure achieves the value pe at which the propellant charge covering and additional liner are penetrated. Then starts flowing out of propellant gases and ignited propellant grains through holes on the separating wall between the high-pressure and low-pressure chambers (see Fig. 1-b). The part of propellant charge burns on high pressure achieved in the high-pressure chamber, and the part of propellant charge which passes through holes continues to burn in the low-pressure chamber. When the pressure in the low-pressure chamber achieves the grenade start value ps the grenade starts to move in the launcher barrel (see Fig. 1-c). During firing the propellant combustion first ends in the high-pressure chamber. Then through holes flow only propellant gases, and the propellant combustion in the low-pressure chamber is near the end (see Fig. 1-d). After the end of propellant combustion the grenade is further accelerated due to propellant gases expansion.

Basic system of equations

Using the usual interior ballistic assumptions the system of equations which describes physical processes in the system with high/low pressure chambers gets the following form:

a) High-pressure chamber

– equations of propellant burning

$$w = \frac{e}{e_0} \;; \qquad \frac{dw}{dt} = \frac{a\,p^n + b}{e_0} \;; \qquad z = C_1\,w + C_2\,w^2 + C_3\,w^3 \tag{1}$$

– energy equation

$$p = \frac{f_i\,\omega_i + f\,\omega(\xi - \eta)}{W_0 - \dfrac{\omega\,(1 - z - \xi)}{\delta} - \omega\alpha\,(z - \eta)} \tag{2}$$

– flow out equations of propellant gases and propellant through holes

$$\frac{d\eta}{dt} = \frac{\dot{m}}{\omega} \quad ; \qquad \frac{d\xi}{dt} = \frac{\dot{m}_b}{\omega} \qquad 3)$$

In previous equations the following symbols are used: p – mean ballistic pressure in high pressure chamber, ω – propellant charge mass, ω_i – igniter mass, f – propellant force, f_i – igniter force, δ – propellant density, W_0 – volume of high-pressure chamber, z – propellant mass share burned in high-pressure chamber, η – propellant gases mass share flowed out through holes, ξ – propellant mass share flowed out through holes, α – covolume, w – relative burnt web of propellant grain, $2e_0$ – propellant web, $2e$ – propellant burned web, t – time, a, b, n – burning law constants, C_1, C_2, C_3 – shape coefficient of propellant grain, $\dot{m}$ – mass flow rate of propellant gases through holes, $\dot{m}_p$ – propellant mass flow rate through holes.

b) Low-pressure chamber

– equations of propellant burning

$$w_1 = \frac{e_1}{e_0}; \qquad \frac{dw_1}{dt} = \frac{a\,p_1^n + b}{e_0} \;; \qquad z_1 = C_1\,w_1 + C_2\,w_1^2 + C_3\,w_1^3 \tag{4}$$

– energy equation

$$p_1 = \frac{f\,\omega\xi\,z_1 + f\,\omega\eta - (\kappa - 1)\varphi\,m_{gr}\dfrac{V_{gr}^2}{2}}{W_1 - \dfrac{\omega\xi\,(1 - z_1)}{\delta} - \omega\alpha\,(\eta + \xi\,z_1) + s\,X} \tag{5}$$

– equations of grenade moving

$$p_1\,s = \varphi\,m_{gr}\frac{dV_{gr}}{dt} \quad ; \quad V_{gr} = \frac{dX}{dt} \tag{6}$$

In previous equations is: p_1 – mean ballistic pressure in low-pressure chamber and launcher barrel, φ – coefficient of fictitious grenade mass, W_1 – volume of low pressure chamber, z_1 – propellant mass share burned in low-pressure chamber, κ – coefficient of propellant gases adiabatic expansion, m_{gr} – grenade mass, V_{gr} – grenade velocity, s – surface of barrel cross-section, X – grenade path in barrel, w_1 – relative burned web of propellant grain in low-pressure chamber, $2e_1$ – propellant burned web in low-pressure chamber.

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For the sake of determination of mass flow rates of propellant gases and grains ($\dot{m}$ and $\dot{m}_p$) we consider two-phase flow through holes between chambers. This flow is treated as homogeneous mixture of gas and solid phase. In that case the mixture adiabatic coefficient is defined by relation:

$$\kappa_m = \frac{(1-\varepsilon)c_p + \varepsilon c_{pr}}{(1-\varepsilon)c_\upsilon + \varepsilon c_{pr}} \quad ; \qquad \varepsilon = \frac{1-\xi-z}{1-\xi-\eta} \tag{7}$$

where: c_p, c_υ – specific heats of propellant gases at constant pressure and at constant volume, c_{pr} – propellant specific heat, ε – mass share of solid phase in mixture flowing through holes.

c) Characteristic important model relations

The flow of homogeneous mixture through holes in the separation wall between chambers is determined by relation between pressure in the high-pressure chamber and pressure on the bottom of low-pressure chamber. The critical pressure value on the bottom of the low-pressure chamber is given by relation:

$$p_{1,crit} = p\left(\frac{2}{\kappa_m + 1}\right)^{\frac{\kappa_m}{\kappa_m - 1}} \tag{8}$$

We analyse two cases:

1^0 $p_{1,w} \le p_{1,crit}$ In this case the mass flow rate and flow velocity of mixture through holes are given by expressions:

$$\dot{m}_m = \mu \cdot p \cdot S_h \sqrt{\kappa_m \left(\frac{2}{\kappa_m+1}\right)^{\frac{\kappa_m+1}{\kappa_m-1}}} \cdot \sqrt{\frac{1}{(1-\varepsilon)f}} \; ; \qquad V_{fi} = \sqrt{\frac{2\kappa_m}{\kappa_m+1}} \cdot \sqrt{(1-\varepsilon)f} \tag{9}$$

where: S_h – total surface of holes cross-sections, μ – flow out coefficient through hole.

2^0 $p_{1,w} \le p_{1,crit}$ The mass flow rate of mixture through holes is determined by relation:

$$\dot{m}_m = \mu \cdot p \cdot S_h \sqrt{\frac{2\kappa_m}{(\kappa_m-1)(1-\varepsilon)f}} \cdot \sqrt{\left(\frac{p_{1,w}}{p}\right)^{\frac{2}{\kappa_m}} - \left(\frac{p_{1,w}}{p}\right)^{\frac{\kappa_m+1}{\kappa_m}}} \tag{10}$$

The flow in velocity of mixture through holes in this case is given by expression:

$$V_{fi} = \sqrt{\frac{2\kappa_m}{\kappa_m - 1}} \cdot \sqrt{(1-\varepsilon)f} \cdot \sqrt{1 - \left(\frac{p_{1,w}}{p}\right)^{\frac{\kappa_m-1}{\kappa_m}}} \tag{11}$$

The mass flow rate of propellant gases ($\dot{m}$) and the mass flow rate of propellant grains ($\dot{m}_p$) are given by following relations: $\dot{m} = (1-\varepsilon)\dot{m}_m$, $\dot{m}_p = \varepsilon\, \dot{m}_m$.

In systems with high/low pressure chambers during firing the characteristic pressure profile is established in the low-pressure chamber and launcher barrel. For determination of that pressure profile we use the common Lagrange assumption and the linear velocity flow profile of two-phase mixture $V_x = K_X + V_{fi}$ (see Fig. 2).

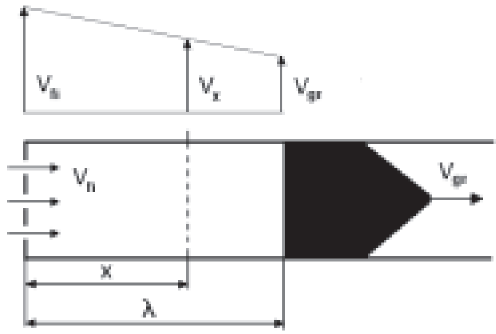

Figure 2.

Through further development (detailed development is given in [3]) we get the relation between the pressure on grenade base $p_{1,gr}$ and the mean ballistic pressure p_1:

$$p_{1,gr} = \frac{p_1 + \dfrac{\rho_\lambda V_{fi}^2}{6}\left(\dfrac{V_{gr}}{V_{fi}} - 1\right)}{1 + \dfrac{\omega'}{3\varphi_1 m_{gr}}} \tag{12}$$

In the eq. (12) the mass ω' and density ρ_λ of two-phase mixture in the space behind the grenade are given by relations: $\omega' = \omega(\eta + \xi)$ $\rho_\lambda = \omega'/(W_1 + sX)$.

The pressure on the bottom of low-pressure chamber $p_{1,w}$ is given by expression:

$$p_{1,w} = p_{1,gr}\left(1 + \frac{\omega'}{2\varphi_1 m_{gr}}\right) - \frac{\rho_\lambda V_{fi}^2}{2}\left(\frac{V_{gr}}{V_{fi}} - 1\right) \tag{13}$$

d) Computer code

The system of equations which describes the interior ballistic cycle of the system with high/low pressure chambers is composed of the first order ordinary differential equations and algebraic ones. Solving of the system of ordinary differential equations by the fourth-order Runge-Kutta method is done. For computation of firing in the automatic grenade launcher with high/low pressure chambers HILOP code is formed. In Fig. 3 computed mean pressures in high and low pressure chambers, p and p_1, respectively, as functions of time t are shown (propellant charge is composed of 2.7 g of nitrocellulose propellant NC1).

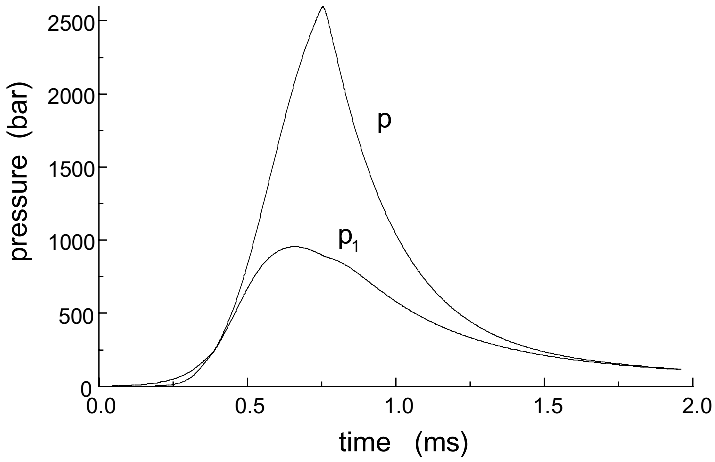

Figure 3.

EXPERIMENTAL INVESTIGATIONS AND MODEL VERIFICATION

Experimental investigations performed in 30 mm automatic grenade launcher had two main goals: optimisation of design and propelling characteristics of concept of high/low pressure chambers, and verification of presented theoretical model.

Through experimental investigations the influence of propellant type, relation of chamber volumes, number, dimensions, and position of holes in wall separating chambers, and type of liner across the holes are studied. Boundaries of range of studied influence parameters were limited by the existing system configuration.

The influence of propellant type on basic interior ballistic characteristics is presented in Table 1.

Table 1

Propellant charge		p_m [bar]	$p_{1,wm}$ [bar]	V_0 [m/s]
2.7 g NC1	Experiment	2605	1456	176.4
	Computation	2629	1491	177.3
2.3 g NG1	Experiment	2982	1875	184.3
	Computation	3034	1893	184.2

Remarks: p_m – maximum pressure in high-pressure chamber, $p_{1,wm}$ –maximum pressure on the bottom of low-pressure chamber, V_0 –grenade muzzle velocity.

Data given in Table 1 show good correspondence between experimental and calculation results. According to ballistic requirements the nitrocellulose propellant NC1 gives better results then the doublebase propellant NG1. All further experimental investigations are carried out with the propellant NC1.

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The influence of relation of chamber volumes on basic ballistic characteristic is given in Table 2. Data given in Table 2 show good correspondence between experimental and calculation results.

Table 2

W_0/W_1		p_m [bar]	$p_{1,wm}$ [bar]	V_0 [m/s]
10	Experiment	2605	1456	176.4
	Computation	2629	1491	177.3
140	Experiment	2769	1401	177.2
	Computation	2778	1421	178.4

The propellant charge is placed in the celluloid covering. In desire to increase the interior ballistic cycle uniformity additional brass liners of different thickness were placed across the holes in the wall separating chambers. Results of this investigations are given in Table 3.

Table 3

Liner		p_m [bar]	$p_{1,wm}$ [bar]	V_0 [m/s]
celluloid	Experiment	2605	1456	176.4
	Computation	2629	1491	177.3
celluloid + 0.1 mm brass	Experiment	2785	1607	178.6
	Computation	2827	1555	179.3
celluloid + 0.2 mm brass	Experiment	2961	1677	180.3
	Computation	3002	1644	181.0

The program HILOP adequately estimates the influence of the propelling charge covering and the additional liner on holes on the wall between chambers.

For determination of influence of number and diameter of holes in the wall between chambers experiments with 6 holes of 3.0 mm diameter, 6 holes of 3.3 mm diameter and 9 holes of 2.1 mm are carried out. Results of this investigation are presented in Table 4.

Table 4

Propellant charge	Holes (number x diameter)		p_m [bar]	$p_{1,wm}$ [bar]	V_0 [m/s]
2.7 g NC1	6 x 3.0 mm	Experiment	2605	1456	176.4
		Computation	2629	1491	177.3
3.0 g NC1	6 x 3.3 mm	Experiment	3518	1661	183.5
		Computation	3561	1665	184.8
3.0 g NC1	9 x 2.1 mm	Experiment	2430	1438	178.2
		Computation	2462	1451	178.3

Data given in Table 4 show good correspondence between experimental and calculation results.

The choice of optimal design and propelling characteristics of the system with high/low pressure chambers depends on the concrete ballistic requirements.

CONCLUSIONS

Based on previous considerations we can make the following conclusions:

- Automatic grenade launchers are contemporary systems which applications is actualised last years.
- In the interior ballistic sense automatic grenade launchers renew the interest for the concept of high/low pressure chambers.
- The mathematical model for system with high/low pressure chambers is developed and the computer code HILOP is established.
- The mathematical model is verified through comparison with data of experimental investigations of influence of different factors on interior ballistic characteristics.
- Experimental investigations and verified theoretical model enable optimisation of design and propelling characteristics for the system with high/low pressure chambers.

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