Identification of experimental form function using lumped parameters interior ballistics model

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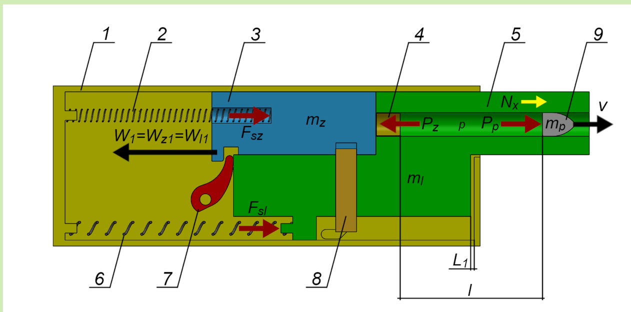
Background

In the Institute of Armament Technology of the Military University of Technology new designs of small arms are developed. Mathematical models of the action of the automatics systems of the arms (like illustrated in the Figure) are used in the design process. An interior ballistics lumped parameters model form a part of these models. The model takes into account pecularities of combustion of fine grained propellants in the way explained in the paper.

Diagram of automatics system of 12.7 mm gun

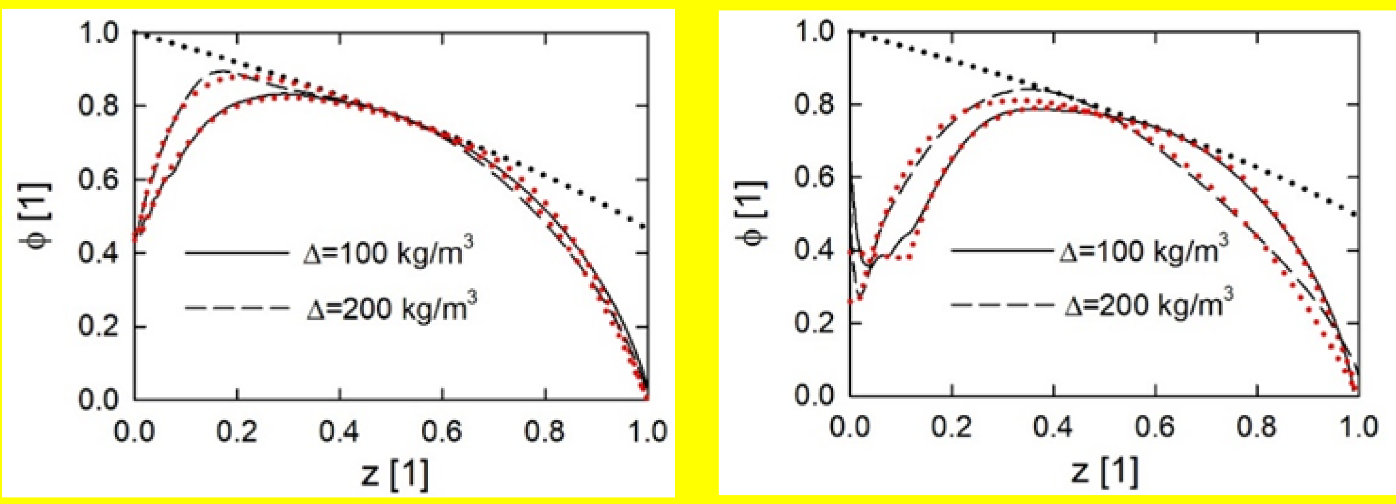


Experimental form function

The experimental form function is defined as an average of form functions of individual propellant grains:

$$\phi_{ex}(z) = \sum_{i=1}^{n_g} \phi_i(z_i)/n_g$$

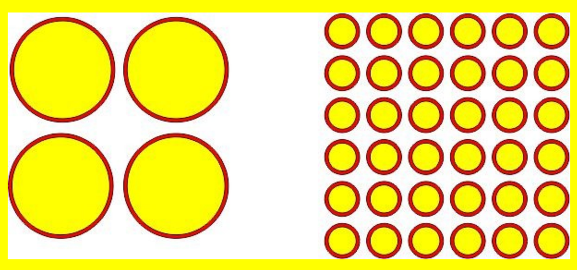
z is the relative burned mass of the propellant charge, z_i is the relative burnt mass of a propellant grain, ϕ_i (z_i) is the form function of a propellant grain, n_g is the number of grains. The experimental form function takes into account the scatter of forms and sizes of propellant grains, as well as prolonged ignition process.



Plots of experimental form functions determined in closed vessel tests for N530 (left) and NC1214 (right) propellants: experimental – solid and dashed lines, theoretical – black dotted line, approximation – red dotted line

Deviations from theoretical form function are caused by:

Scatter of shapes and sizes of grains



More energy is necessary to ignite fine-grained propellants

Experimental form function in the lumped parameters model

STANAG 4367 modified

$$\frac{dz}{dt} = \theta \phi_{ex}(z)\left(\frac{p}{p_0}\right)^n, \quad p_0 = 0.1\,\mathrm{MPa}$$

Parameters identified in closed vessel tests: n, θ

The experimental form function is identified by the reverse method.

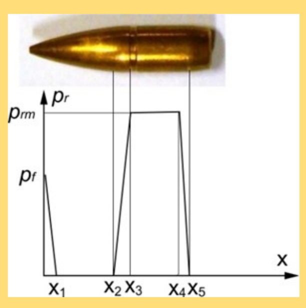
$$\phi_{ex}(z) \approx \phi_a(z) = \psi(z)\phi_d(z)\phi(z)$$

$$\psi(z) = \begin{cases} \psi_0 & z \in [0, z_0] \\ 1-\exp\left[-b_1(z-b_2)\right] & z \in [z_0, 1] \end{cases}, \quad b_2 = z_0 + \log(1-\psi_0)/b_1$$

$$\phi_d(z) = \begin{cases} 1 & z \le z_m \\ c_0 + c_1 z + c_2 z^2 + c_3 z^3 & z > z_m \end{cases}$$

Fitted parameters: ψ_0, z_0, b_1, c_3

Additional fitted parameters: p_{rm}, f_R, h_w



resistance pressure

$$p_R(x) = p_r(x) + f_R p_p$$

heat losses

$$h = h_w (D/D_b)^{0,2} (\rho_{av} v_{av})^{0,8}; \quad D = 378/(T+105)(T/273)^{1,5}$$

Fitting procedure

The first step: minimization of the measure

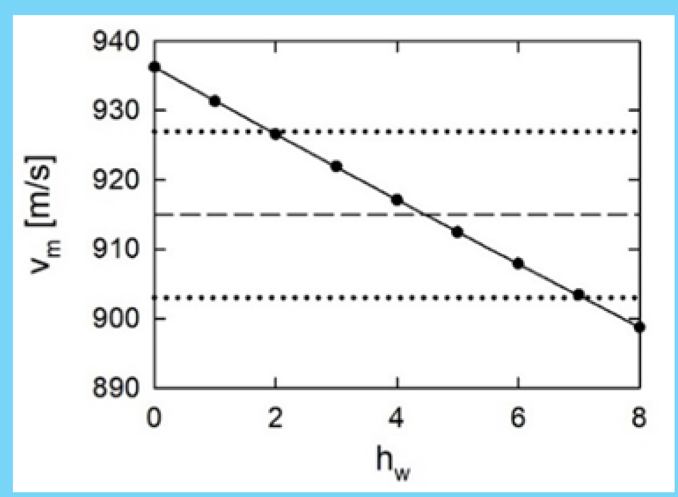
$$F_c(\psi_0, b_1, p_{rm}, f_R) = \left(\frac{p_{\max e} - p_{\max}}{p_{\max e}}\right)^2$$

p_{maxe} experimental (catalogue) maximum pressure value

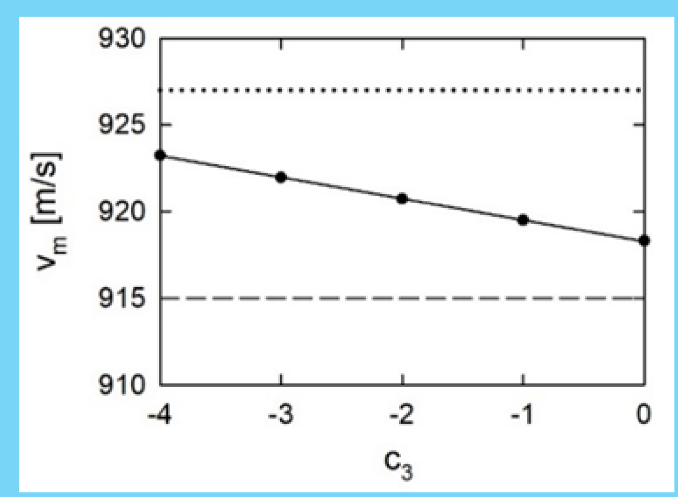
p_{max} calculated maximum pressure value

$h_w = 0$, z_0, c_3 from CVT

The second step: $h_w = h_{wmax}$



Values of the muzzle velocity calculated in the first step for various values of h_w (data for 5.56 mm assault rifle)



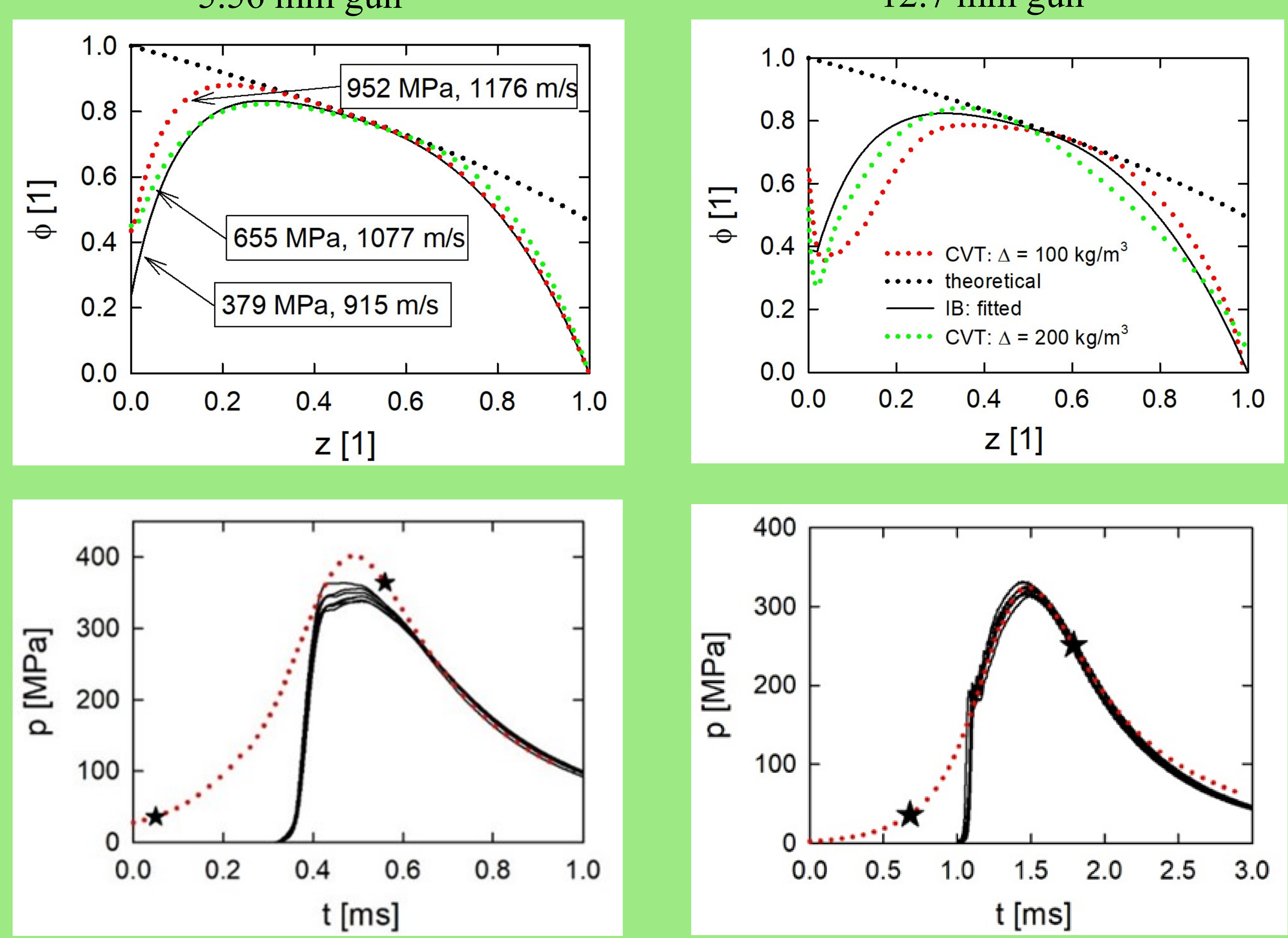
Values of the muzzle velocity calculated in the first step for $h_w = 0$ and various values of c_3

The third step:

$$h_{wopt} = h_{w\max} \frac{v_m(0) - v_{me}}{v_m(0) - v_m(h_{w\max})}$$

Results

5.56 mm gun — 12.7 mm gun



Plots of calculated breech pressure (dotted line) and experimental pressure records at rifle's beginning (solid lines);
stars – start of the projectile and end of the ignition

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