Ignition delay of the travelling additional propellant charge

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Abstract: In order to increase muzzle velocity of the weapon system, the propellant charge could be split into basic and additional. The ignition delay of the additional charge travelling with the projectile is crucial characteristic of the system. The tank cannon D-81 and 125 mm PPSV-97 APFSDS projectile, matches up with the characteristics of the separated propellant charge system, after minor adjustments. For the purpose of system abilities examination the adjustment was made and the experimental shootings have been carried out and the ignition delay has been focused. The examined weapon system does not offer worthwhile muzzle velocity increase by the propellant charge split and the ignition delay control.

Key-Words: Propellant charge, interior ballistics, subcalibre, tank cannon, ignition delay.

1 Introduction

The weapon system using separated propellant charge is considered to be one of the principles alternative to conventional technique of accelerating projectile with the big advantage among others alike – the process of producing such a gun is not dependent on any new technology. Two types of the weapon system using separated propellant charges could by recognized – the system using the separated propellant charge with additional propellant charge still relative to barrel and the system using the separated propellant charge with travelling additional propellant charge. Both of them are supposed to increase projectile muzzle velocity by rise of the mean pressure of propellant gases under the condition of not exceeding the maximum pressure of propellant gases. Characteristics of the separated propellant charge with travelling additional propellant charge could be matched up by the system of tank cannon D 81 and 125-EPpSv-97 cartridge after minor adjustments. The mentioned system is in service in the Army of the Czech Republic currently, therefore the possible advantages of that were focused particularly.

Fig.1: 125-EPpSv-97 cartridge

2 Additional charge

The propellant charge is split into two parts. The basic part of the propellant charge is placed in the cartridge case as the additional (travelling) part is appropriately attached to the rear part of the projectile. In the case of 125-EPpSv-97 cartridge is the travelling propellant charge the part of the set comprising the 125mm APFSDS projectile and N62M CZ cartridge case (propellant is bound to the stabilizer and covered with combustible container).

Fig.2: Projectile and travelling charge conjointly.

After the basic propellant charge is ignited, the projectile is forced into the motion together with the additional propellant charge. The ignition of the additional propellant charge follows after the certain amount of time (ignition delay), when the combustible case is burnt through. The projectile is accelerated together with the unburnt part of the additional propellant charge by the mixture of propellant gases from the both propellant charges. The additional propellant charge has to burn before projectile reaches the muzzle, as well as the basic propellant charge.

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The 125-EPpSv-97 cartridge is not design to perform this way originally, the both cartridge cases (Z62M CZ and N62M CZ) are equipped with ignition channels in centres of fronts facing each other and all the propellant is to be ignited in the same time and to burn in common volume.

3 Mathematical model

The mathematical model of the interior ballistics of the system was assessed. The core of the assembled computational model of the weapon system using separated propellant charges is based on the classical system of seven equations describing the geometrical theory of propellant combustion:

$$\psi = \kappa z + \kappa\lambda z^2 + \kappa\mu z^3, \tag{1}$$

$$p = \frac{f\omega\psi - \frac{1}{2}\Theta\varphi m_q v^2}{s\left(l_\psi + l\right)} + p_z, \tag{2}$$

$$\varphi m_q \frac{\mathrm{d}v}{\mathrm{d}t} = s\left(p + p_z\right), \tag{3}$$

$$\frac{\mathrm{d}z}{\mathrm{d}t} = \frac{u_1\left[m + \left(p + p_z\right)^{\nu}\right]}{I_k}, \tag{4}$$

$$l_\psi = l_0\left[1 - \frac{\Delta}{\delta} - \Delta\psi\left(\alpha - \frac{1}{\delta}\right)\right], \tag{5}$$

$$\frac{\mathrm{d}l}{\mathrm{d}t} = v, \tag{6}$$

$$T = T_V\left[1 - \frac{1}{\psi}\left(\frac{v}{v_{\lim}}\right)^2\right], \tag{7}$$

where ψ stands for the relative quantity of burnt-out powder, κ, λ, μ are geometric characteristics of the powder grain, z is the relative burnt thickness of the powder grain, p is the ballistic pressure and p_z is the primer pressure, f is the specific energy of propellant, ω is the mass of the propellant charge, m_q is the mass of the projectile, φ is the fictivity coefficient of the projectile, s is the cross-section area of bore, m, u_1, v are rate of burning coefficients, I_k is the pressure impulse of ballistic pressure, l is the projectile travel as $l\psi$ is the relative length of initial combustion volume, Θ is the heat parameter of powder expansion, Δ stands for the loading density, δ for the powder mass density and α is the covolume of powder gases.

The model has to be modified to describe the system of the travelling propellant charge. The effect of the ignition delay forces the split the computation into two parts - before the ignition of the travelling propellant and after it. Due to the fact of non-uniform burning of two propellant masses (basic, ‘still’ propellant mass and travelling, additional mass) the two separate sets of equations (1), (4), (5) and (7) were implemented. The variable mass of the accelerated parts of the projectile and the unburnt travelling propellant could be taken into account via the fictiveness coefficient modification basically. The applicable formula changes from

$$\varphi = k_\varphi + \frac{1}{3}\frac{\omega}{m_q}, \tag{8}$$

into the functional relation

$$\varphi\left(\psi_a\right) = k_\varphi + \frac{1}{3}\frac{\omega + 2\omega_a\left(1 - \psi_a\right)}{m_q}, \tag{9}$$

where indexes a stands for the additional (travelling) propellant charge.

The solution of the presented system could be found by the numerical method only, I have used the Runge-Kutta 4th order method.

4 Experimental shooting

Following the aim of the model results confirmation the experimental shooting was carried out. The modified ammunition was shoot from the 125mm tank cannon D81 (barrel No. C0218) adapted for the pressure measurement in the cartridge chamber. The pressure was measured by the calibrated KISTLER Type 6213B front seal high pressure piezoelectric sensors, the electrical charge yielded was converted into a proportional voltage signal by the KISTLER Type 5011 charge amplifier, digitalized and recorded by the Ballistic Analyser BA04S assembly. The projectile velocity was measured over the mirror by the Doppler Radar System Type B480 assembly.

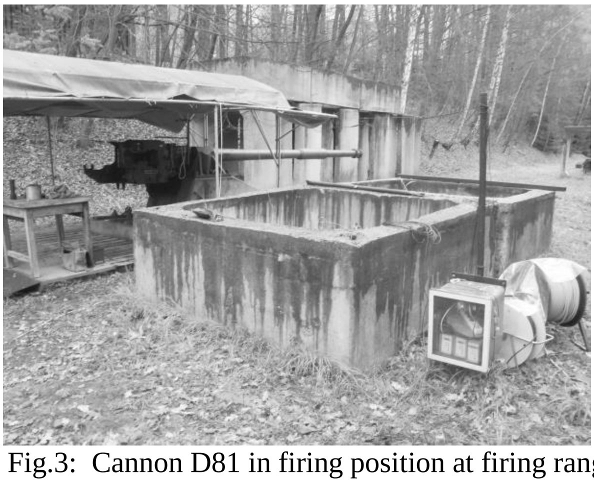

Fig.3: Cannon D81 in firing position at firing range with measuring installation.

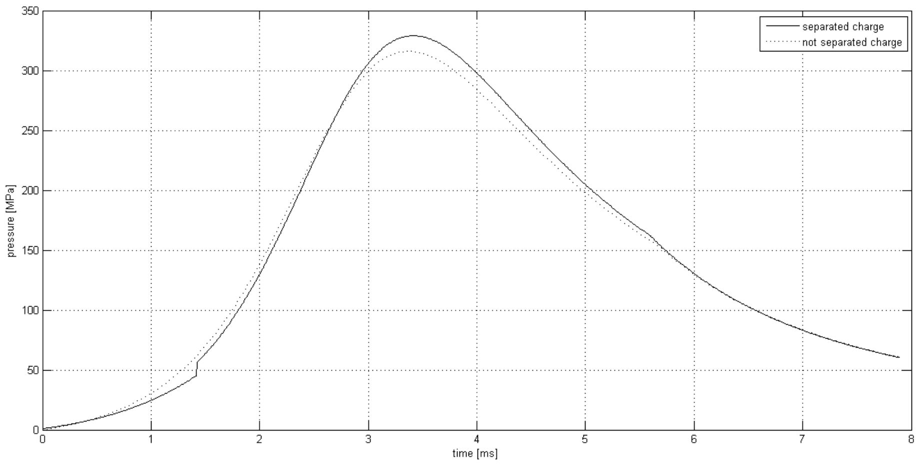

Fig.4: Modelled pressure course of separated charge compared to standard charge.

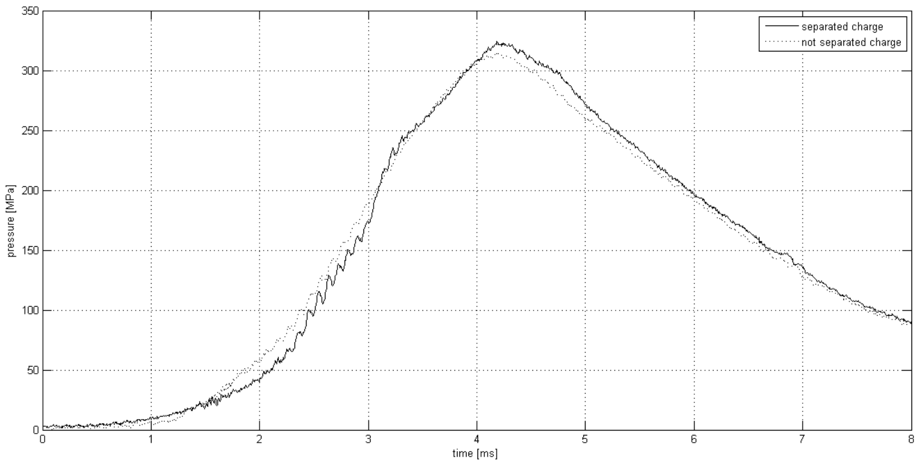

Fig.5: Comparison of measured pressure courses.

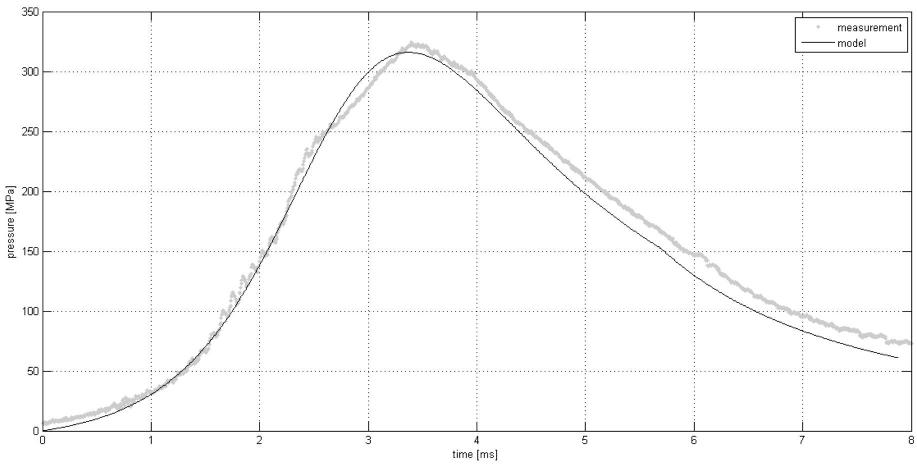

Fig.6: Predicted and measured pressure courses (synchronized initiation).

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Because of the necessity of the ignition delay the two parts of the propellant charge had to be sealed against the ignition flame. Therefore combustible cases of both cartridge cases without the ignition channels were used. To allow the motion of the travelling propellant charge towards to the muzzle through the forcing cone and leading part of barrel bore, which are tapered relative to the cylindrical part of the cartridge chamber, the combustible coating of the charge walls was replaced with the multi-layered stretch foil wrapper. The shooting range safety measures and economic reasons together allowed the use of substitutive 125mm PROOF inert projectiles only.

Fig.7: Inert projectile with modified charge.

Two basic modifications – sealed (separated) and unsealed (not separated) charges – were prepared using the same type of the propellant, the travelling/total mass of propellant charge ratio was approximately 46%. Pressure courses produced by the modifications of the ammunition are compared in Fig.4 to Fig.6, which corresponds each other.

4 Time delay

Although the pressure courses are very close each other the same effect could be observed in the both figures 3 and 6 representing the prediction by the computational model and the data obtained from experiment. The very low level of difference is the result of very short ignition delay realized (approximately 1.5ms). The validity degree of the model is illustrated in the following figure. Because only two single shots comparison, the reliability is very limited.
If the model would have been considered to be capable to be used, it could be utilized for the ignition delay effect analysis. The value of the maximum pressure is monitored together with the muzzle velocity of the projectile. The maximum pressure value represents the barrel strength requirements and its value is limited by the technologies available. The muzzle velocity stands for the ballistic output of the weapon systems and describes the combat possibilities of the weapon system. The dependencies of the maximum pressure and the muzzle velocity on the time delay are illustrated below.

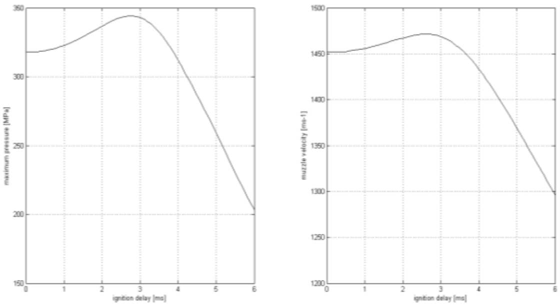

Fig.8: Time delay effect on maximum pressure and muzzle velocity.

The advantages of the maximum pressure value drop in the case of the longer delays are lowered by the muzzle velocity values. When the shorter delays have been focused, the muzzle velocity has reaches the highest values, but so are the maximum pressures.
For the given set of parameters and only ignition delay to be varied the 'optimal' value could be found like the extreme of the muzzle velocity to maximum pressure ratio. It tells 'how much each barrel strength pascal contributes to muzzle velocity generation'.

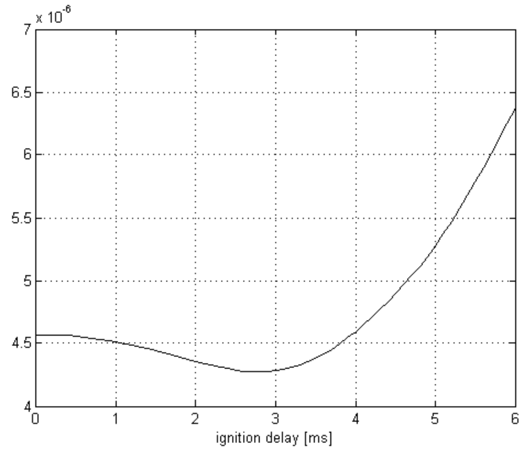

Fig. 9: 'Optimal' ignition delay choice.

4 Conclusion

The computational model of the internal ballistics of the subcalibre weapon system using separated propellant charge 'travelling' is in accordance with the experimental test, although the reliability is very limited. On the basis of the model results, the possibilities of improvement of the weapon system comprising the 125-EPpSv-97 cartridge and the D-81 tank cannon by the way of transformation to separated propellant charge requires longer ignition delays and does not offer the muzzle velocity increase by the ignition delay control under the condition of not exceeding given maximal pressure.

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