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Design of New Pparameters 9mm Luger Cartridge for Using in Combination with the Short Gun Suppressor

Abstract

The aim of this work is to design new parameters of the 9mm Luger cartridge for using in combination with the short gun suppressor. In the theoretical part is clarified the origin and types of unmasking effects, which occurs during the gunshot. We focus on the sound effect and the way it can be suppressed. Subsequently, we describe suppressors and silencers and their types. Furthermore, we parse the efficiency of bullet and ways of changing parameters of cartridges in order to achieve the desired efficiency.

In the practical part, we implement internal ballistic calculation, in order to design the parameters for 9mm Luger cartridge, with the aim to reach the velocity of bullet below the sound speed to ensure a sufficiently effective removal of the sound effect of the gunshot when the suppressor is used. The results obtained from designed samples are compared with the standard 9mm Luger cartridge, with focus on the energy of the bullet and also evaluation our designed samples in terms of the functional cycle of weapon.

Keywords: design, cartridge, bullet, suppressor, silencer, 9mm Luger, unmasking effects, reloading

INTRODUCTION

It is well known that in good weather conditions the gunshot sounds may be heard at distances over kilometers. This noise is in many cases considered to be as an undesirable effect, and therefore, sound suppressors or silencers are used in some combat actions of special units. However, in order to be effective, it is necessary to reduce the bullet speed below the speed of the sound through air.

The aim of this work is to design new parameters of the 9mm Luger cartridge for using in combination with the short gun suppressor. In the theoretical part is clarified the origin and types of unmasking effects, which occurs during the gunshot. We focus on the sound effect and the way it can be suppressed. Subsequently, we describe suppressors and si-

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1. UNMASKING EFFECTS OF GUNSHOT

Unmasking effects of gunshot of small-caliber weapons are caused by intense expansion of gas from the barrel of the weapon, as a result of leaving projectile from the barrel. The gas expansion process is called a muzzle blast, which is characterized by light and sound effects. Both of these effects unmask the weapon and its location. The noise can also damage the auditory organ of the weapon operator and people in its vicinity. Moreover, it impairs communication.

1.1 Light effect

A light effect is one of the mentioned unmasking effects of gunshot. It occurs when an explosive charge is ignited to propel a projectile from the barrel.It is a flash of visible radiation of expanding gases from the barrel. The duration of this flash is relatively short for small-caliber weapons.

The flash consists of two components, physical and chemical. Physical component occurs due to radiation of gases, as a result of high temperature. Chemical component due to subsequent gas burning process. Reducing the flash can be provided by removing or suppressing of these components.

For suppression of flame we use a mechanical part called flash suppressor. It reduces the temperature of expanding gases below their temperature of ignition. We recognize two basic design solutions for flash suppressors. The first design is conical in shape, which is screwed into the barrel (Picture 1). The second one is cylindrical in shape, with longitudinal wedge slots, where gases are decomposed (Picture 2).

Picture 1: A flash suppressor with conical shape

Picture 2 A cylindrical flash suppressor with longitudinal wedge slots

The flash suppressor is usually attached to the gun by metric threaded screw connection. It is secured with a flexible pin that fits into the groove formed on the circumference of suppressor. There is no optical flash thanks to the flash suppressor. It eliminates the detection of the weapon's position and the dazzle of the shooter, especially during the fight at night.

1.2 Sound effect

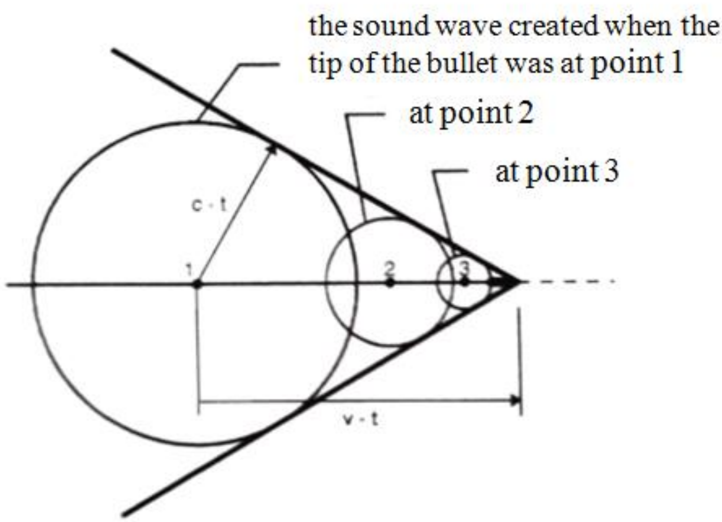
The second unmasking effect of gunshot is the sound effect. The sound or acoustic effect is a noise. We recognize three major sources of noise during gunshot: gas explosion, weapon mechanisms and bullet.

The first source of the sound effect is the noise generated by the weapon mechanisms. These mechanisms provide charging and discharging of weapon. The noise in these operations is caused by the action of the movable parts of the weapon mechanism and their interaction, vibrations and impacts.

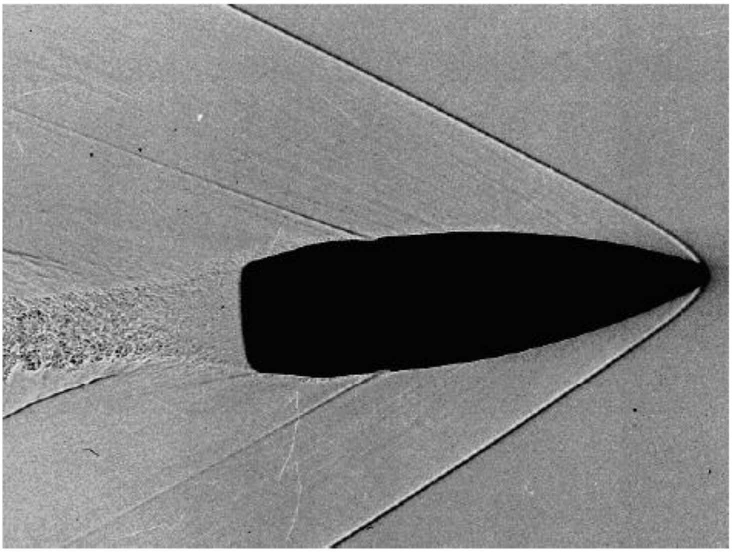
Another source is the noise generated mainly by the air turbulence that follows the bullet and by the so-called sonic boom, which occurs as a result of supersonic speed of moving bullet through the air. The muzzle noise is generated by pressing the air column in the barrel twist and by the expanding gases escaping from the muzzle mainly after leaving the bullet from the barrel. The noise can also occur when air leaks from other parts of the weapon than the barrel.

The third and the most intense source of sound effect is muzzle blast. It is created by a shock wave of leaking gas from the barrel, following the bullet. If the velocity is higher than the sound speed (dry air at 25 ° C = 346.3 $m.s^{-1}$), there occurs to thickening of wavefronts along the conical surface (Picture 3). The shock wave is called the Mach cone. It is characterized by a jump of pressure, which is accompanied by intense sound, which is also known as sonic boom.

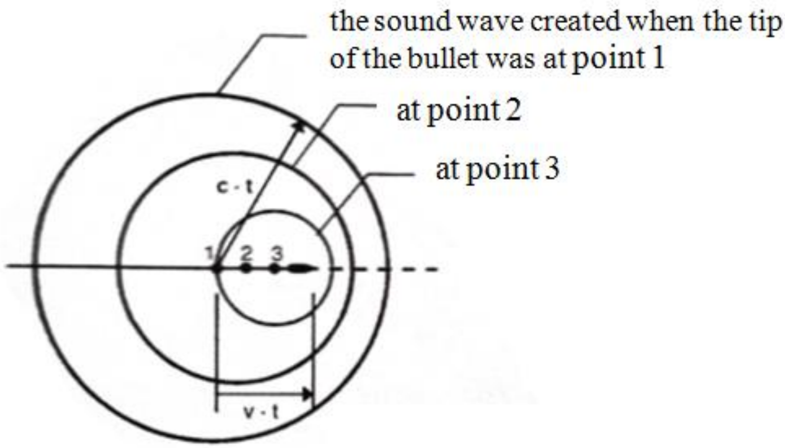
If it moves at a speed that is less than the sound speed, the wavefronts are overtaking the bullet (Picture 4). It means that the sound waves are progressive and they are difficult to hear.



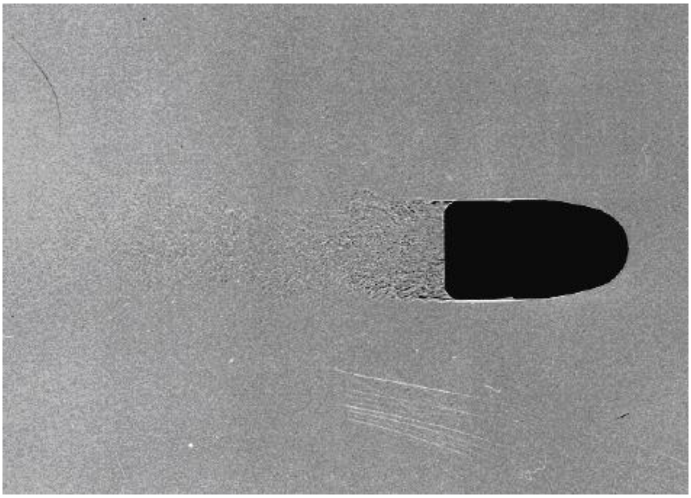
Picture 3.1 Sound spreading – supersonic bullet



Picture 3.2 Supersonic bullet Winchester FMJ - leaves behind shock waves and turbulence



Picture 4.1 Sound spreading – subsonic bullet



Picture 4.2 Subsonic bullet .32ACP – does not produce shock waves

1.3 THE WAYS OF SUPPRESSING THE SOUND

We recognize two elementary ways of suppressing the sound:

– to prevent the ballistic wave - or to minimize it,

– by absorbing the already created ballistic wave.

The basic method of suppressing the sound before the occurrence of the ballistic wave is to reduce the velocity and pressure of expanding gases. This is accomplished by controlled expansion and other methods such as gas swirl, absorption and reflection. The suppression of the sound after the formation of the ballistic wave is realized by the following principles: absorption, reflection, overlapping and dispersion. The absorption occurs whenever gases come into contact with an ambient atmosphere, which absorbs part of their energy. The reflection leads to a substantial absorption of the energy of the ballistic wave by an obstacle which reflects the wave. A diffusion is an action, when one ballistic wave devides to several smaller ones. During overlapping we mask the sound of the gunshot by another sound, which is stronger and completely overlaps the sound of the gunshot or the weaker that mask gunshot to such an extent that no one recognize it was a gunshot.

1.4 Suppressors and silencers

The silencer of sound is used for weapons, which use subsonic ammunition to completely silence the sound of the gunshot. The suppressors are structurally and functionally identical and are used for gunfire, which also use supersonic ammunition generating sonic boom. This means that the sound of the gunshot cannot be completely eliminated, but only reduced to a certain desired value. Therefore, it is advantageous to use subsonic ammunition to increase the effect of the suppressor, thereby to reduce the loudness of the gunshot. However, due to the reduced speed of the bullet, it is necessary to count with the reduction of the effective firing range, the wounding range and the reduction of the accuracy of shooting. In addition, there is also a reduction of light effect of the gunshot and other features such as the muzzle brake.

1.5 Types of suppressors

In terms of construction, suppressors are divided into:

- integrated barrel suppressors
- additional suppressors – connected to the barrel by thread (Picture 5).

The integrated suppressor is stung through a perforated barrel, allowing extending gases to be removed through the holes. The additional suppressor is connected to the end of muzzle mainly thanks to the thread that is part of the barrel. Other types of connections are also used, for example bayonet cap or use of vertical pins and others. All connections, however, must be resistant to various loading, must be easily removable and mountable and reliable during shooting or handling with weapon. Additional suppressors are used more, because they are structurally better manufacturable and are used for both short and long weapons.

Picture 5 Additional suppressor Impuls IIA Compact used in Slovak Armed Forces for Glock 17

2. EFFECTIVENESS AND EFFECTS

The effectiveness of the bullet is one of characteristics of bullet, which we can also understand as an ability to effect (effective potential). There is defined a way, how the effectiveness of bullet can be calculated or changed. The term "effect" means a specific result of activity of bullet. A bullet, which has high effectiveness may or may not have a great effect. The effect of the bullet is evaluated retroactively, based on the results of a hit. The effect depends on the effectiveness of the bullet and the location of the hit. It is therefore very difficult to measure or even predict the effect of the bullet. The only magnitude, which can be predicted on the basis of calculations and measurements is the effectiveness of the bullet.

The values, which bullet acquire are crucial to achieve effect. This values are acquired before it reaches the target. Therefore, for description of the movement of the bullet, is sufficient to know the weight and speed of the bullet. The bullet is also characterized by other physical properties, such as temperature and rotation around the longitudinal axis, but these variables may be neglected. From the physical point of view, only momentum and energy are considered.

When developing a new cartridge, it is theoretically possible to change the whole array of amperage parameters. These parameters include, for example, the caliber, the weight, the design and shape of the bullet, the type of gunpowder, the length of the gun and its weight. In practice, however, the possibilities of further development are greatly limited by the physical connections and the contradictions of the requirements. Due to the capabilities of determining parameters, a number of compromise solutions can lead to meeting the requirements. This is reflected by the considerable diversity of construction of ammunition.

3. DESIGN OF NEW PARAMETERS 9MM LUGER CARTRIDGE

3.1. Principle and the aim of design

The aim of this work is to design new parameters for the 9mm Luger for a short gun so that the unmasking sound effect of the gunshot is removed as precisely as possible in combination with the suppressor. This can be realized by reducing the speed of bullet below the speed of sound. If we reduce the speed of the bullet below the speed of the sound, we will prevent the formation of Mach cone. As a result there does not form a sonic boom. Also we prevent jump of pressure and air turbulence, while at the same time the formation of intense sound effect.

We must reduce the speed of bullet in order to make our bullet sufficiently silent. This is achieved by a suitable combination of the weight of the bullet and the weight of the gunpowder. The only effective way of increasing the effectiveness of a subsonic bullet is to increase its weight. That's why we chose a higher bullet weight (9g) than is used for a standard 9mm Luger cartridge. Through internal ballistic calculation, we have calculated and designed several variants of the 9mm Luger cartridge parameters with given conditions.

3.2. Calculation of unknown parameters of gunpowder

We selected the nitrocellulose gunpowder LOVEX S020-2 from the Czech company Explosia a.s. We calculated necessary parameters for internal ballistic calculation from provided data. The powder grain has a shape of a cylinder, its length and diameter are given. We calculated the powder grain size as the mean value from the production dimension interval (Table 1).

Dimensions of grain elements	Production dimension interval [mm]	Mean values [mm]
Length	0,6 ÷ 1,2	0,9
Diameter	0,45 ÷ 0,75	0,6

Table 1: Dimensions of powder grain elements

Subsequently, we determined the physicochemical parameters for our gunpowder, which are needed for further calculation. To produce the indicated density of gunpowder (1350 kg.m^{-3}), we assigned the remaining parameters (Table 2).

Powder explosion heat (water as steam)	**Qv (v.p.) . 10^{-6}**	**[J.kg^{-1}]**	**2,964495**
Powder explosion heat	**T_v**	**[K]**	**2678**
Powder thermodynamic energy (powder force)	**f . 10^{-6}**	**[J.kg^{-1}]**	**0,945**

Specific heat at constant volume	c_v	**[J.kg^{-1}.K^{-1}]**	**1230**
Ratio of specific heat of gases at constant pressure and volume (adiabatic exponent)	κ_c	**[-]**	**1,286**
Specific volume of powder gases	w_0	**[m^3.kg^{-1}]**	**0,950**
Unit burning rate of powder grain	$u_1.10^{10}$	**[m.s^{-1}.Pa^{-1}]**	**5,916**

Table 2: Physicochemical parameters of gunpowder LOVEX S020-02

3.3. Internal ballistic calculation

We used one of the analytical methods for solving internal ballistics problems in internal ballistic calculations, namely the simplified method of prof. Sluchocky. The purpose of the calculation was to determine the limit range of the weight of gunpowder charge so as to ensure the subsonic velocity of the bullet. Therefore, we estimate the range of the projectile muzzle velocity ($v_ú$) 260 ÷ 310 m.s^{-1} for calculations. Calculations of characteristic variables were considered at normal temperature (+ 15 ° C) even at extreme temperatures (-40 ° C and + 50 ° C). Also we calculated additional input values (Table 3).

d=	0,009	m
s=	0,000065205	m^2
m_q=	0,009	kg
κ =	2,6	-
k_ϕ=	1,1	-
θ=	0,286	-
p_0=	30	MPa

Table 3 Input values for interal ballistic calculation

d – weapon calibre
s – cross-section area of the bore barrel
m_q – projectile mass
κ – geometric characteristics of powder grain shape
k_ϕ - coefficient of passive resistances against projectile motion in the barrel
θ – heat parameter of powder gases expansion
δ – powder mass density

Through the following simplifications and relationships, we were able to implement the differential equations to algebraic and thus calculate the required charge of gunpowder for our 9mm Luger design.

$$v_{lim} = \sqrt{\frac{2fm_\omega}{\theta\varphi m_q}}$$

v_{lim} – limited value of projectile velocity

$$l' = \frac{l_\Delta - l_1}{2} = \frac{1}{2s}\left[2c_0 - m_\omega\left(\alpha + \frac{1}{\delta}\right)\right]$$

m_ω – powder charge mass

$$a = f m_\omega \kappa$$

$$j = \varphi m_q {v_k}^2$$

$$b = \lambda - \frac{\theta}{2}\frac{j}{a} = \frac{1-\kappa}{\kappa} - \frac{\theta \varphi m_q {v_k}^2}{2 f m_\omega \kappa}$$

$$k = \frac{j}{ab} = \frac{\varphi m_q {v_k}^2}{f m_\omega \kappa b}$$

$$M = 1 - k$$

$$A = \frac{f m_\omega \kappa}{s l'} (1 + b z_0)^k$$

$$\nu_i = \frac{v_i}{v_{lim}}$$

$$M_k = (l_1 + l_k)\left(1 - {\nu_k}^2\right)^{\frac{1}{\theta}}$$

$$v_k = \frac{s I_k}{\varphi m_q} . (1 - z_0)$$

$$v = v_k z$$

$$l = l' \left[\left(\frac{1 + bz}{1 + bz_0} \right)^k - 1 \right]$$

$$p = A z\, (1 + bz)^{1-k}$$

$$t = \frac{I_k}{A} [T(bz, M) - T(bz_0, M)]$$

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

$$z_m = -\frac{1}{b(2-k)}$$

$$p_k = f\, m_\omega \frac{1 - \left(\frac{v_k}{v_{lim}} \right)^2}{s(l_1 + l_k)}$$

$$p = p_k \left(\frac{l_1 + l_k}{l_1 + l} \right)^{1+\theta}$$

φ – fictitiousness coefficient of projectile mass

λ - fictitious modulus of powder charge

relative mass

c_0 - initial volume of combustion chamber

α – covolume of powder gases

z - relative burnt thickness of powder grain

I_k - total impulse powder gases pressure

at the end of gunpowder burning

p - instantaneous pressure of powder gases in the barrel in space behind bullet

$T(bz, M)$ – table function

T_v - powder explosion heat

ψ – relative quantity of hurnt powder charge

$\Theta(v)$ – table function

Indices: - k – the instant of burning up of powder char ge

- 0 – the initial value

- m – the instant of analytical maximum of

$$\boldsymbol{v} = \boldsymbol{v_{lim}}\sqrt{\mathbf{1} - \left[\mathbf{1} - \left(\frac{v_k}{v_{lim}}\right)^2\right]\left(\frac{l_1+l_k}{l_1+l}\right)^{\theta}}$$ powder gases pressure

$$\boldsymbol{t} = \boldsymbol{t_k} + \frac{2M_k}{\theta v_{lim}}\left[\boldsymbol{\Theta}(\boldsymbol{v}) - \boldsymbol{\Theta}(\boldsymbol{v_k})\right]$$ - ú – the value at the muzzle of barrel

$$\boldsymbol{T} = \mathbf{T}_v\left[\mathbf{1} - \left(\frac{\mathrm{v}}{v_{lim}}\right)^2\right]$$

From previous relationships, we calculated the value of the interval of the mass of gunpowder charge (Table 4).

	grain $[grs]$	**gram** $[g]$
Minimal mass of gunpowder charge	**3,3**	**0,214**
Maximal mass of gunpowder charge	**4,09**	**0,265**

Table 4: Interval of the mass of gunpowder charge

3.4 Reloading

Reloading consists of several stages. In the first stage, we removed primers from used cartridges and subsequently installed a new ones. We used the Italian primers Fiocchi Small Pistol Primers. After fitting the new primers (Picture 6), we weighed the value of the gunpowder (Picture 7) by internal ballistic calculation and poured it into the prepared cartridge cases.

Picture 6: Primer seating

Picture 7: Weighing of gunpowder

The next stage was the bullet seating. We put the bullet on the cartridge case (Picture 8) and using the press we pressed it into the cartridge case to the necessary depth to regulate the length of the entire cartridge. We have repeated the procedure for all three parameter design variants. In all cases, we used the same gunpowder, primers, and bullets weighing 9 grams. Variants of the design varied in the weight of the gunpowder and the total length of the cartridge, thus we regulate the volume of the combustion chamber.

Picture 8: Bullet seating

3.5 Measurement and its results

During the measurement, we shot the prepared samples of the cartridges, measuring the velocity of movement using a gun chronograph. The gun chronograph was placed at distance of three meters at an outside temperature of 4 ° C. Each measured value was recorded and then evaluated. From the measured values, we calculated the kinetic energy of moving bullet from following relation: $E_k = 0,5.\ m_q\ .v^2$ (where m_q - is the mass of the bullet and v - is the measured bullet velocity).

The calculated values are compared with the kinetic energy values that acquire a standard 9mm Luger cartridge (Table 5). For assessment we also considered the quality and applicability of the sample in terms of the functional cycle of weapon.

Mass of bullet	m_q	**0,008**	**kg**
Distance	**x**	**3**	**m**
Bullet velocity at the distance x	**v**	**347**	$m.s^{-1}$
Kinetic energy of bullet at distance x	E_k	**481,6**	**J**

Table 5: Characteristic of the standard 9mm Luger (FMJ bullet)

The first sample we tested had a weight of 0,246 g and a cartridge length of 29 mm (Table 6). In the second sample, we assigned a weight of 0,259 g with a full length of 29 mm (Table 7). The third and our last sample contained 0,207 g of gunpowder, and the cartridge length was reduced to 27 mm, thus we reduced the volume of the combustion chamber (Table 8).

Cartridge length 29 mm	grain	gram		
Powder charge mass	3,8	0,246		
Measured velocity	ft/h	m/s	Kinetic energy	J
	875,6	266,8		320,3
	919,9	280,4		353,8
	871,7	265,7		317,7
	914,0	278,6		349,3
	914,0	278,6		349,3
	927,6	282,7		359,6
Average velocity	903,8	275,5	Average kinetic energy	341,7

Table 6: Measured values from the first sample

Cartridge length 29 mm	grain	gram		
Powder charge mass	4,0	0,259		
Measured velocity	ft/h	m/s	Kinetic energy	J
	915,7	279,1		350,5
	915,8	279,1		350,5
	956,6	291,6		382,6
	978,6	298,3		400,4
	992,9	302,6		412,1
	1006,0	306,6		423,0
	891,5	271,7		332,2
	979,8	298,6		401,2

	903,7	275,4		341,3
	992,9	302,6		412,1
Average velocity	953,4	290,6	Average kinetic energy	380,6

Table 7: Measured values from the second sample

Cartridge length 27 mm	grain	gram		
Powder charge mass	3,2	0,207		
Measured velocity	ft/h	m/s	Kinetic energy	J
	873,9	266,4		319,4
	754,2	229,8		237,6
	862,3	262,8		310,8
	534,5	162,9		119,4
	669,8	204,2		187,6
Average velocity	738,9	225,2	Average kinetic energy	235,0

Table 8: Measured values from the third sample (the gun was not reloaded again after gunshot in highlighted red values)

CONCLUSION

From measured and calculated values, we evaluated that all bullets were flying at subsonic speed, which confirmed the correctness of our interal ballistic calculation. The variance of measured values was caused by the type of used primers, which did not provide a constant impulse for immediate and evenly burning of the gunpowder in the entire volume. A difference between measured values and values calculated by interal ballistic calculations was caused by the ambient temperature and hence the initial temperature of the gunpowder.

We came to the conclusion that our first sample had a lower kinetic energy value than the standard 9mm Luger, considering measured and calculated values. Also it had reduced efficiency. However, a proper functioning cycle of the weapon was ensured. In the second sample, which had a higher weight of the gunpowder, we confirmed the higher kinetic energy of the bullet, which is approaching to the standard 9 mm Luger bullet more, than the first sample.

The third sample, which had a smaller initial volume of the combustion charge and a lower mass of gunpowder did not achieve the required properties during measurement. The kinetic energy values of the bullet were considerably low and the functional cycle of the weapon was not ensured.

With all designed 9mm Luger cartridge parameters, we measured the subsonic velocity of the bullet, thus there was provided a sufficiently efficient removal of unmasking sound effect of the gunshot, when using with suppressor. The samples were different in the kinetic energy of the bullet and its effectiveness.

BIBLIOGRAPHY

1. KADAŇKA V. *Vnitřní balistika hlavňových zbraní*. Praha : Naše vojsko, 1985, p. 341.
2. KNEUBUEHL, B. P. *Balistika.* Praha : Naše vojsko, 2004, p. 236, ISBN 80-206-0749-8.
3. KUCHYNKA, A. *Tichá smrt: Tlumiče zvuku ručních palných zbraní.* Publish weaponry specializatin, 1999, p. 34.
4. LISÝ, P., BEER, S. *Vnútorná balistika*. Liptovský Mikuláš : Akadémia ozbrojených síl generála Milana Rastislava Štefánika, 2014. ISBN 978-80-8040-491-8.
5. PLÍHAL, B. *Balistika.* Brno : VA Brno, 1990, p. 70.
6. PLÍHAL, B. *Vnitřní balistika.* Brno : VA Brno, 1991, p. 219.