METHODOLOGY FOR COMPUTATION OF INTRABALLISTIC PARAMETERS AND A RESISTANCE PRESSURE

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Abstract
Please take into consideration the fact that the full text of an abstract should contain no more than 1000-2000 characters (including spaces). In the abstract provide information on how the objectives were achieved, which was the main method(s) used, what was the approach to the topic etc. Please provide information on the main conclusions. What are the suggestions for a future research? What practical implications are identified?

Keywords: Thermodynamic interior ballistic model, ammunition, weapon system, aimed at a detailed solution of energy losses.

The problem relating determination, characterizing and assignment of values of all partial aspects of resistance against movement of a projectile in a standard, bored artillery barrel worries its designers from the times of a scientific approach to this issue.

Each weapon system has certain specific features as compared with other weapon systems, which from their construction aspects demand some slight differences in results in measured interior ballistic values and for values of resistance against movement of a projectile in a barrel. History just proves that regularities found on a certain type of a weapon system can be applied on other weapon systems as well.

As each science, the interior ballistic passes experiences its development and in line with a social development some different procedures and methods of calculation of interior ballistic parameters occur also by other authors, not only from authors of Eastern neighbors. Nowadays it is a responsibility of a NATO member country; the Slovak Republic is, to implement and to apply the NATO standard documents in practice. In this area it is first of all an implementation of the STANAG 4367 „The thermodynamic model of an interior ballistic with aggregate parameters"that contains a mathematical model of the projectile movement in bored barrels of weapons with no powder gas exhaust using separated ammunition.

1 Introduction

This standard contains a thermodynamic interior ballistic model with parameters, which are formed by a system of non-linear differential and algebraic equations modeling a one-dimensional movement of standard, rotationally stabilized artillery shells inside the barrel. This model is aimed at a detailed solution of energy losses in course of shoot and so it requires a larger amount of data on a weapon system.

A reason of loss of energy useable for movement of a projectile in a barrel is to be analyzed through a study of values measured during experiments in a practical application of a given weapon system. Then a result is a model of a course of a resistive force against a projectile movement and a solution of a force size and course acting against the projectile movement in a bored barrel.

A model based on a geometrical vision of burning of a powder grain was used for calculation of inner ballistic parameters including the modifications of computation by professor Sluchocký with an author approach to a determination of geometric features of a powder grain shape.

The paper deals also with an issue of determination of pressure ratio between a projectile bottom and a cartridge chamber bottom as a problem, whose solution is needed to determine resistive pressure acting on a moving projectile.

The experiment performed is the very first experiment for proving the model by STANAG 4367 in conditions of the Slovak and Czech Republics, which had been performed for that purpose on an **artillery** weapon system of a medium caliber. The parameters of an artillery weapon system, by now a classic *122 mm H D-30A howitzer* meet the terms; the model of STANAG 4367 has been developed for.

This paper presents also the author design for a calculation of a resistive pressure through a method of material cutting. The results of the design are comparable with intentions of the authors of the 4367 STANAG model and they are comparable also with results achieved and published in [8].

1 Theoretical basis to compute intraballistic parameters and a resistance pressure

This chapter describes regularities and results that had been used for a calculation of intraballistic parameters in terms of references [2], [3], [4], [5] a [6] and a resistance pressure as by a STANAG 4367 a [8].

1.1 Theoretical basis to compute intraballistic parameters

The equations for a computation of a major role of intraballistics for weapons with no gases discharge were used, in particular an analytical method by Prof. Sluchocký using a new author approach for a computation of geometric (dimensional) characteristics of a seven-hole grain forming a base for a powder charge, that had been used for a shooting experiment.

1.2 Project to solve values of geometrical characteristics

A typical form of seven-hole grains is shown in Fig. 1.1. Parameter *R* is an outer radius of a grain, *r* is a radius of inner bores and e_1 is a half of a typical thickness of a powder grain:

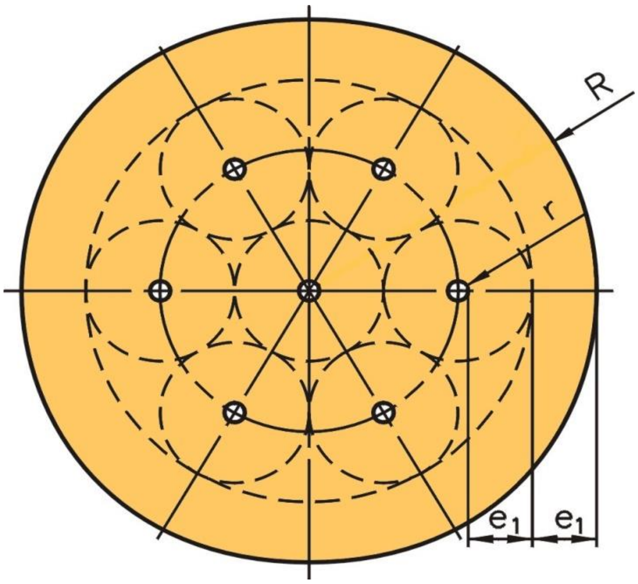


Fig. 1.1 Cross-section of a seven-hole grain

References provide different mathematical procedures for a definition of particular major dimensions of a seven-hole grain for needs of intraballistic computations. As an example the reference [3] or [7] defines a procedure to define grain dimension providing that they are arranged in common, strictly defined ratios of particular diameters and a grain length. During a technology of the powder production a deformation, imprecision occurs due to movement and common contact among grains, e.g. in cutting grains for requested final length etc. However significant changes in supposed dimensions (grains shrinking) occur mainly when powder mass dries. In figures 1.2 and. 1.3 a red color represents a value of various values among computed parameters in accordance with procedures defined in [3] or. [7] and real taken values of dimensions - *R* , *r* and e_1 –of a real seven-hole grain. Values of Rpt´, $r_{pt'}$, $e_{1pt'}$ dimensions of a seven-hole grain as by [3] and values of $R_{p2'}$, $r_{p2'}$, $e_{1p2'}$ are dimensions of a seven-hole grain as by [7]:

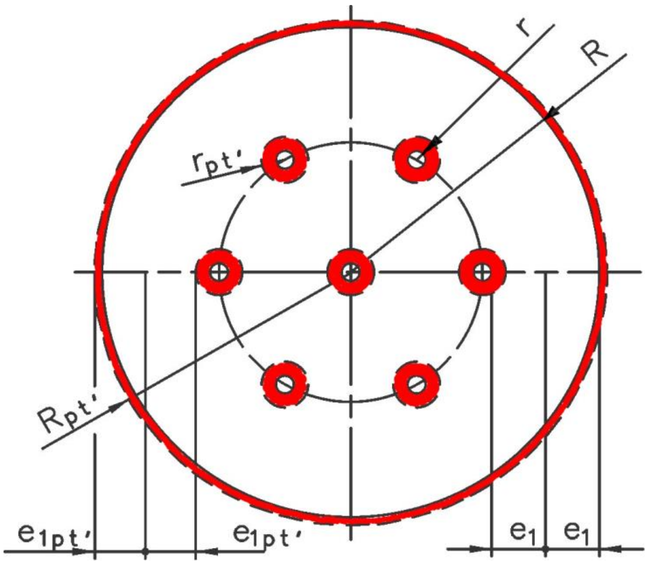


Fig. 1.2 Cross-section of a seven-hole grain as by [3]

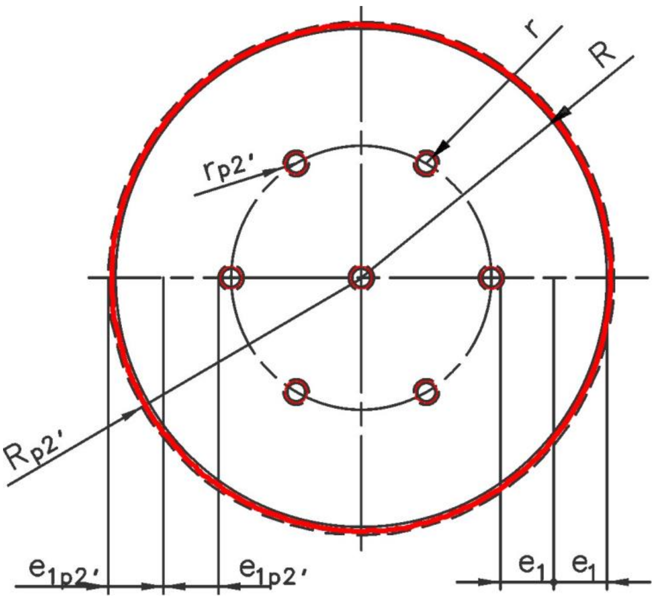


Fig. 1.3 Cross-section of a seven-hole grain as by [7]

For a following procedure in defining a geometrical parameter κ there were defined these three partial conditions that had been used in a mathematical procedure in computing the intraballistic parameters through a method by Prof. Sluchocký:

1) A parameter of a specific burnt thickness of a powder seven-hole grain z at a delayed burning of a typical dimension, e_1 will be z=1 and this value is not going to increase, even when a fact is known, that a seven-hole grain has not completed its burning,

2) A parameter of a specific burnt amount of a powder seven-hole grain ψ at a delayed burning of a typical dimension e_1 will be ψ=1 and this value is not going to change further,

3) With regard to a change of a computation of a geometrical coefficient κ, the geometrical coefficient λ and μ have been constantly defined as equal = 0,

4) We consider a whole mass of a powder charge as a seven-hole powder with respect to a ration between masses of other types of powders used to a mass of a seven-hole powder and their typical dimensions $e_{1.}$

In order to define a geometrical coefficient κ we use the following relation as a base for a solution

$$\kappa = \frac{S_0}{V_0} \cdot e_1 \tag{1.1}$$

which was modified based on matters, raised after burning of a typical dimension e_1, for a calculation of a shape characteristics κ in a following way:

$$\kappa = \frac{(S_0 + S_1 + S_2)}{(V_0 + V_1 + V_2)} \cdot e_1 \tag{1.2}$$

where: S_0 is an initial surface of a powder grain,

S_1 is a surface of 6 pieces of inner trihedral cuboids blocks, raised in a decay of a seven-hole grain when having burnt till dimension e_1,

S_2 is a surface of 6 pieces of external trihedral cuboids blocks, raised in a decay of a seven-hole grain when having burnt to a dimension e1,

V_0 is an initial volume of a powder grain,

V_1 is a volume of 6 pieces of inner trihedral cuboids blocks, raised in a decay of a seven-hole grain when having burnt till dimension e_1,

V_2 is a volume of 6 pieces of external trihedral cuboids blocks, raised in a decay of a seven-hole grain, when having burnt to a dimension e_1.

After having burnt till a typical dimension e_1 the grain falls into decay and 12 irregular bodies rise at the same time that can be designated as trihedral cuboids blocks with a certain detached geometrical point of view.

A shape and a size of cuboids edges were adjusted into regular bodies with bases in a shape of equilateral triangles. The size of edges in computed in a following way:

a) Computation of a height v' in an auxiliary equilateral triangle through a side a':

b) $$a' = 2 \cdot (r + e_1) \tag{1.3}$$

where: r is a radius of inner holes of a grain before burning,

then:

$$v' = \frac{\sqrt{3}}{2} \cdot a' . \tag{1.4}$$

Based on a computed height of a base of an auxiliary equilateral triangle we compute:

c) An unadjusted height of a base of inner trihedral cuboids blocks:

$$v_1' = v' - (r + e_1) \tag{1.5}$$

Then an unadjusted length of a base side of inner trihedral cuboids blocks:

$$a_1' = \frac{2}{\sqrt{3}} \cdot v_1' \tag{1.6}$$

And computation of an unadjusted height of a base of outer trihedral cuboids blocks is:

$$v_2' = 3 \cdot (r + e_1) - v' \tag{1.7}$$

Where an unadjusted length of a base of outer trihedral cuboids blocks is:

$$a_2' = \frac{2}{\sqrt{3}} \cdot v_2' \tag{1.8}$$

d) Computation of a resultant shape (length) of sides of bases of inner or outer trihedral cuboids blocks is done as by relations :

$$a_1 = a_1' \cdot k_a \tag{1.9}$$

resp.:

$$a_2 = a_2' \cdot k_a \tag{1.10}$$

Coefficient $\boldsymbol{k_a}$ in equations (1.9) and (1.10) represents a modification of the lengths of bases in residual trihedral cuboids blocks based on ratio between sum of burnt (free) surfaces S_b in a circle with a radius R_a and a surface S_{Ra}, representing a total surface of a circle with a radius R_a, obtained based on a relation:

$$R_a = R - e_1$$

then:

$$k_a = \frac{S_b}{S_{Ra}} \ , \tag{1.11}$$

where: S_b is a sum of burnt surfaces, expressed by a relation:

$$S_b = 7 \cdot \pi \cdot r_a^2 \tag{1.11.1}$$

where:

$$r_a = r + e_1 \ ,$$

S_{Ra} is a surface of a circle with a radius R_a, expressed by a relation:

$$S_{Ra} = \pi \cdot R_a^2 \ . \tag{1.11.2}$$

Based on above mentioned relations for a computation of lengths of base sides of residual trihedral cuboids blocks we can summarize a whole procedure into resultant relations based on a fact, that a coefficient k_a has got the same value for any dimension of a seven-hole grain:

$k_a = 0{,}7777778$,

then:

$$a_1 = 0{,}65746 \cdot (r + e_1) \tag{1.12}$$

$$a_2 = 1{,}13875 \cdot (r + e_1) \ . \tag{1.13}$$

Needed parameters of the surface and volume of trihedral cuboids blocks used in an equation (1.2) will be computed based on the relations:

$$S_0 = 2 \cdot \left(\pi \cdot R^2 - 7 \cdot \pi \cdot r^2\right) + 2 \cdot (\pi \cdot R \cdot 2L + 7 \cdot \pi \cdot r \cdot 2L) \qquad (\qquad 1.14)$$

$$V_0 = \pi \cdot R^2 \cdot 2L - 7 \cdot \pi \cdot r^2 \cdot 2L \ , \tag{1.15}$$

$$S_{1,2} = 6 \cdot \left[a_{1,2}^2 \cdot \frac{\sqrt{3}}{2} + 3 \cdot a_{1,2} \cdot (2L - 2e_1) \right] , \tag{1.16}$$

$$V_{1,2} = 6 \cdot \left[a_{1,2}^2 \cdot \frac{\sqrt{3}}{4} \cdot (2L - 2e_1) \right] . \tag{1.17}$$

2. Theoretical basis for computation of resistance pressure br

This model defined in standardization agreement STANAG 4367 „Thermodynamic interior ballistic model with global parameters“ [8] [13] is a thermodynamic model with a free parameter for barrel weapons with no flux of powder gasses and it is based on a geometrical perception of burning of a powder charge. „Thermodynamic interior ballistic model with global parameters“ is assigned for weapon systems using graduated cartridges and their projectiles are stabilized by a rotation.

The model includes a computation of energy:

- Exerted for a rotational movement of a projectile,
- Exerted for a movement of powder gases and non-burnt part of a powder charge,
- Exerted to overcome resistance against a projectile movement,
- Exerted to accelerate the recoil parts of a weapon,
- Exerted to overcome the air resistance in front of a projectile,
- Lost due to a heat penetration into the barrel walls and a cartridge chamber.

These energies are included into computation mostly in a particular loses coefficients

Next in the model there are taken into consideration:

- Effect of the fuse,
- A pressure gradient between a bottom of a cartridge chamber and a projectile bottom,
- A linear rule for burning of a powder grain,
- Perception of a geometrical burning of a powder charge.

The whole intraballistic model STANAG 4367 is formed by the following equations (index *i* – in formulas represents different kinds of powder):

- equation of burning of i powder:

$$\frac{dZ_i}{dt} = \frac{S_i \cdot r_i}{V_{gi}} , \tag{2.1}$$

- equation of energy expressed using a mean temperature of T gases:

$$T = \frac{\sum_{i=1}^{n} \frac{F_i' \cdot C_i \cdot Z_i}{\gamma_i - 1} + \frac{F_1 \cdot C_1}{\gamma_1 - 1} - E_{pt} - E_{pr} - E_p - E_{br} - E_r - E_d - E_h}{\sum_{i=1}^{n} \frac{F_i' \cdot C_i \cdot Z_i}{(\gamma_i - 1) \cdot T_{0i}} + \frac{F_1 \cdot C_1}{(\gamma_1 - 1) \cdot T_{01}}} , \tag{2.2}$$

where:

· E_{pt} is energy exerted for a straight motion of a projectile:

$$E_{pt} = \frac{m_p \cdot v_p^2}{2} , \tag{2.3}$$

· E_{pr} is energy exerted for a rotational motion of a projectile:

$$E_{pr} = \frac{\pi \cdot m_p \cdot v_p^2}{4 \cdot T_w^2} , \tag{2.4}$$

· E_p is energy exerted for a motion of powder gases and non-burnt parts of a powder cartridge:

$$E_p = \frac{C_T \cdot v_p}{6} \ , \tag{2.5}$$

- E_{br} is energy exerted to overcome a resistance against the projectile motion:

$$E_{br} = A \cdot \int_0^x f_R \cdot br \cdot dx \ , \tag{2.6}$$

- E_r is energy exerted for a motion of recoiling parts:

$$E_r = \frac{m_{rp} \cdot v_{rp}^2}{2} \ , \tag{2.7}$$

- E_d is energy exerted to overcome a resistance of air in the barrel in front of the projectile:

$$E_d = A \cdot \int_0^t v_p \cdot P_g \cdot dt \ , \tag{1.20.6}$$

- E_h is energy lost due to a transition of heat into walls of the projectile barrel:

$$E_h = \int_0^t A_w \cdot h \cdot (T - T_c) \cdot dt \ , \tag{2.8}$$

- motion equation of a projectile:

$$\dot{v}_p = \frac{dv_p}{dt} = \frac{A \cdot (P_b - f_R \cdot br - P_g)}{m_p} \ , \tag{2.9}$$

where:

- P_b is pressure on the bottom of the projectile:

$$P_b = \frac{\overline{P} + \dfrac{C_T \cdot (P_g + br \cdot f_R)}{3 \cdot m_p}}{1 + \dfrac{C_T}{3 \cdot m_p}} \ , \tag{2.10}$$

- P_g is pressure in front of a projectile:

$$P_g = P_a \cdot \left[1 + \alpha_a \cdot M^2 \cdot \left(\frac{1+\alpha_a}{4} \right) + \sqrt{\left(\frac{1+\alpha_a}{4} \right)^2 + M^{-2}} \right] , \tag{2.11}$$

- state equation:

$$\overline{P} = \frac{T}{V_C} \cdot \left(\sum_{i=1}^{n} \frac{F_i' \cdot C_i \cdot Z_i}{T_{0i}} + \frac{F_1 \cdot C_1}{T_{01}} \right) , \tag{2.12}$$

- rule of burning:

$$r_i = f_\beta \cdot f_{\beta T} \cdot \beta_i \cdot \overline{P}^{\alpha_i} \ , \tag{2.13}$$

- motion equation for recoiling parts:

$$\dot{v}_{rp} = -\frac{A}{m_{rp}} \cdot \left(P_0 - \frac{RR}{A} - f_R \cdot br \right) , \tag{2.14}$$

where:

- P_0 is pressure on bottom of a cartridge chamber:

$$P_0 = P_b + \frac{C_T}{2 \cdot m_p} \cdot \left(P_b - f_R \cdot br - P_g \right) . \tag{2.15}$$

In intraballistic model in STANAG 4367 [8] [13] there is a flowchart of the resistance against the motion of the projectile defined by a resistance pressure *br*, whose size is defined by a resistance force related to the surface unit of a cross section of the barrel. Theoretical flowchart of the resistance pressure with relation to the projectile trajectory is depicted in Fig. However this flowchart of the resistance pressure is not valid in general, it depends on design of a leading ring.

It should be mentioned in a table of the STANAG 4367 and as an annex to this standard. However these data are not included in the standard. Other sources on a particular flowchart of a resistance pressure for particular weapon systems are not available nowadays.

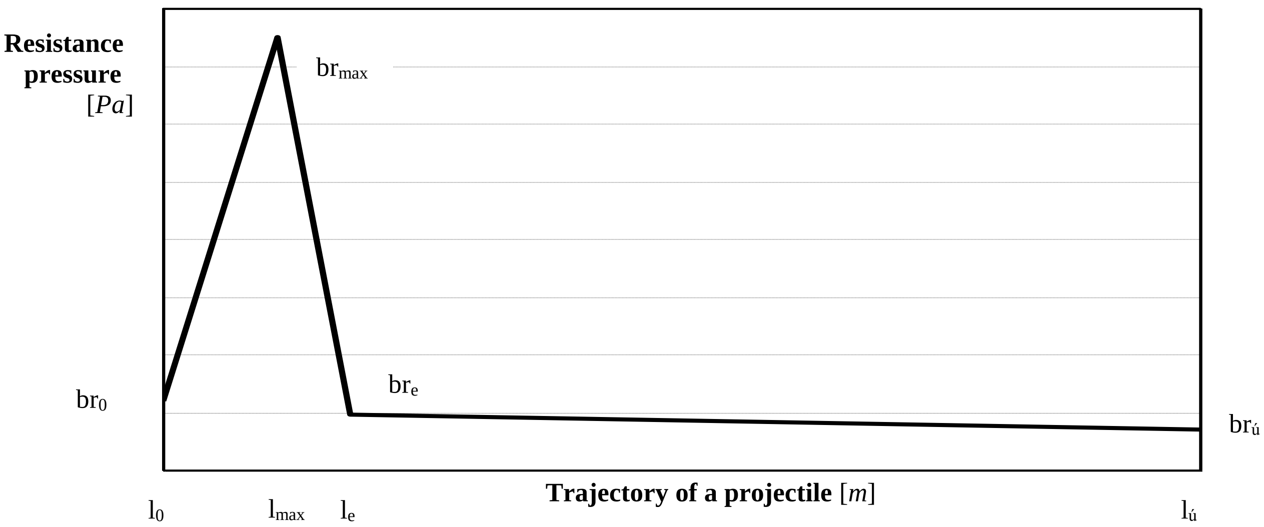


Fig. 2.1. Flowchart of a resistance pressure

3. Computation of intraballistic parameters

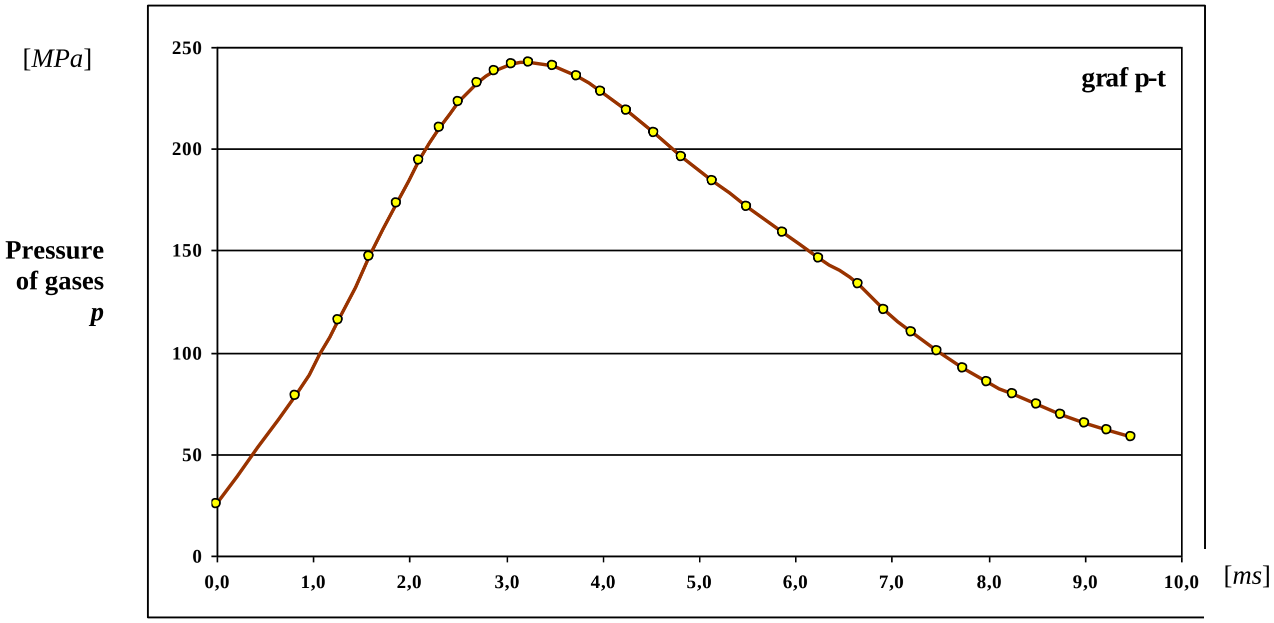
The analytical method by Prof. Sluchocký was chosen in order to compute a theoretical flowchart of intraballistic parameters. Own measurements were taken from weapon and ammunition systems aiming to obtain the most precise results.

The data of the manufacturer were taken to define a volume of the initial combustion space c_0 and measurements before shooting so that all passive volumes filling a combustion space were deducted from the data about the volume of the cartridge chamber:

- Volumes of the pressure gauges for use of pressure gauge cylinders – 2 pcs,
- Volumes of the pressure gauges for use of pressure gauge bullets – 2 pcs,
- Volume of a rear projectile penetrating into the space of the cartridge chamber,
- Volume of a projectile and

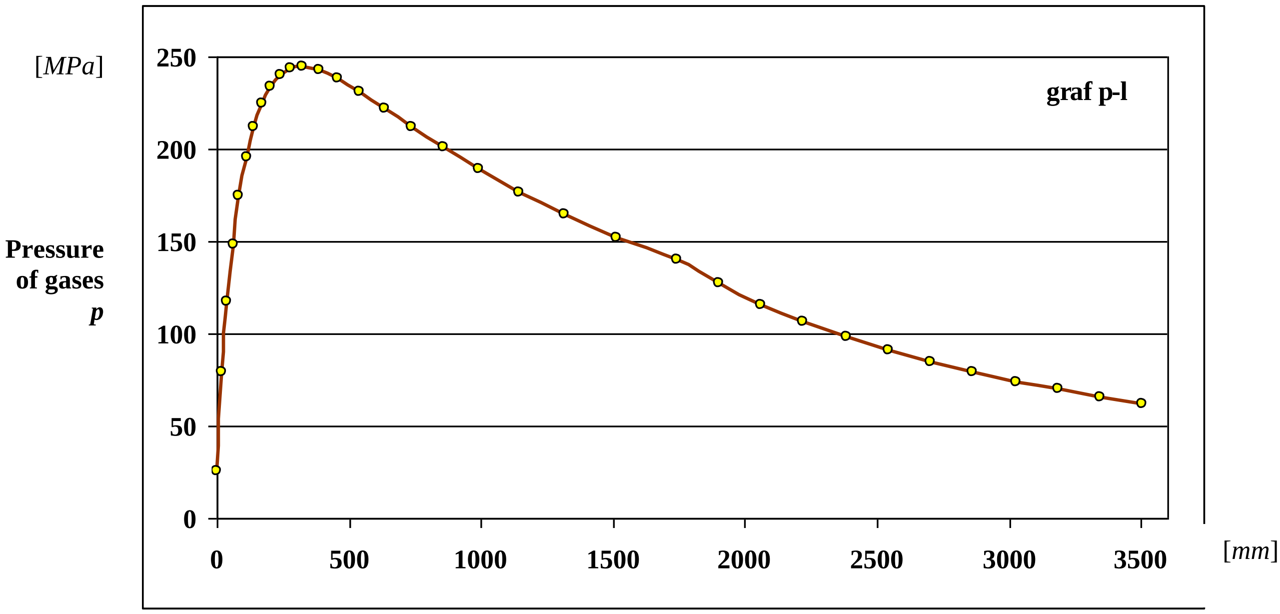
- Volume of ballast parts of a powder charge – a cardboard cap and a bag of a powder charge made from Moline textile.

Examples of results of the intra ballistic parameters are in the Fig. 2.2., 2.3.



Shot time *t*

Fig. 2.2 Image of a theoretical flowchart of pressure with relation to time



Projectile trajectory ly *l*

Fig. 2.3 Image of a theoretical flowchart of pressure with relation to the projectile trajectory

4 Conclusions

This paper stems from needs to unify a methodology for computation of intraballistic parameters in line with standardization agreement STANAG 4367.

The paper makes effort to continue in papers that had been done at University of Defense in Brno and to bring new knowledge in this field. In practice the experimental measurements are to be taken on a particular weapon system and the results are to be compared with a matching theoretical presumption stated by STANAG

4367 model. This model supposes its practical application in standard artillery systems of medium and large calibers using graduated cartridges and projectiles with a leading ring.

Based on such obtained data it has been proved, that we can apply a theory of a resistance pressure into computations of intraballistic parameters through a STANAG 4367 model. Through the calculations it has also be validated and by comparing of ***br*** parameters (a cutting method) and f_R***br2*** *parameters* (STANAG 4367 module) it has been proved, that the author´s solutions in defining the resistance pressure through a material cutting method is a real solution of this problem and it shows a way how to implement it into particular computation programmes. As it is shown, these computations have to be validated by hundreds of shoots with a real weapon and ammunition material.

Acknowledgements

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