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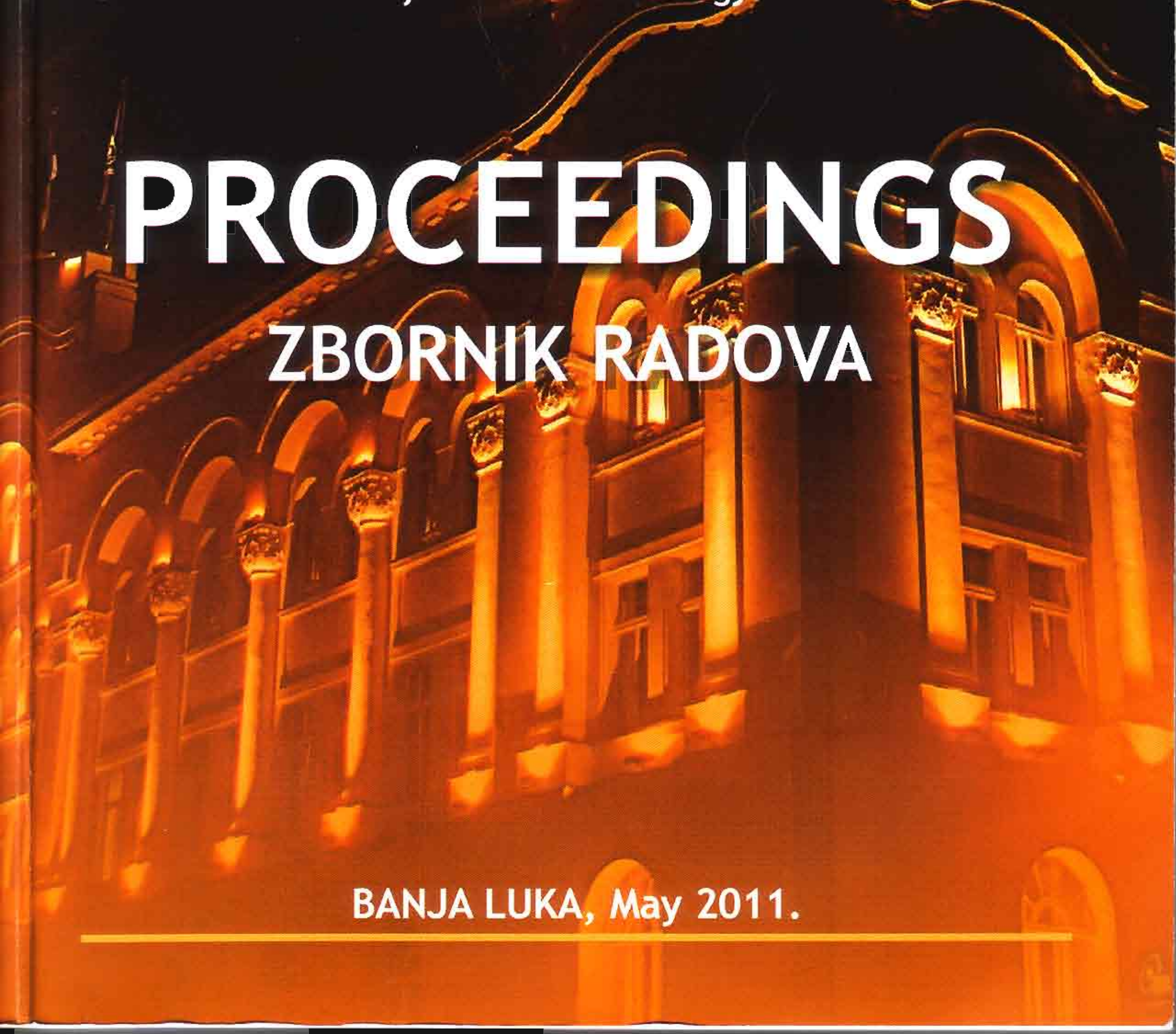

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CONTENT

COMPARATIVE ANALYSIS OF THE FORMATION OF SMALL GRAIN GUIDANCE

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Summary: Classical theory of internal ballistics for small-arms represents a very rough approximation. The assumption is that interior profile of the barrel of the small calibers can be defined on the basis of theoretical and practical tests primarily (experiment) for a family of weapons, i.e. all weapons of small caliber (including 12.7 mm). The aim is to determine the feasibility of standardization of one or the other barrel profile (12" and ...) based on the advantages of one over the other profile, verification of the modified internal ballistics model and the confirmation of such a hypotheses.
***Key words:** small grain, ballistics, small caliber, weapon*

1. INTRODUCTION

The barrel is an essential part of weapons. It represents the part in which there is twofold energy transformation: chemical energy of combustion of gunpowder is converted into heat and the heat into mechanical energy. The barrel provides the necessary initial projectile speed and direction of the boom, and the projectiles that have no wings to stabilize them, through the helical grooves, it provides high rotation needed for stability when the projectile is moving towards its aim.

The classical theory based on geometrical law of combustion and adiabatic processes in small arms barrel, gives a fairly satisfactory solutions for large-caliber weapons because the assumptions on which these methods are based do not differ from the actual firing processes. There are several two-phase models developed in the last decade that represent a significant step forward in studying the process of firing in small arms [1]. To solve the internal ballistics problem the most realistic strategy is to follow the works by P.S. Gough and that the solution to the model should be sought by using the finite differences model [2], [3].

Fundamentals of numerical treatment PDJ were given by Richtmayer and Morton, Roach, Patankar and Smith, and for the numerical solution of two-phase flow in small arms we used three methods: MacCormack, Lax-Wendroff and Spalding. PS Gough [3] and others, and Gokhale and Krier used MacCormack two-stage, explicit

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method with finite differences. Later for numerical modelling of flame propagation through the granular environment Spalding implicit method is used [4].

The entire survey was realized as a contribution to the study of flame propagation through a granular environment [4]. The experimental determination, calculation of pressures at firing weapons, and nonstationary gas dynamics is applied to the internal ballistics problem of small-arm weapons.

In the US armament the 5.56 mm machine gun M16 with a bullet M193 was introduced, but other members of NATO did not accept it. Parallel study of several types of bullets, adopt the same bullet for the all members. For the survey Belgium prepared a bullet under the designation SS109, which uses the same cartridges and has the same dimensions as the U.S. M193, but the projectile has significantly enhanced features (which required pitching twisting grooves of the barrel from 12" to 7").

Inside profile of the barrel for small-arms can be defined in terms of theoretical and above all practical tests [experiment] to a family of weapons that meet the following requirements: safety of use and reliability and simplicity of construction and maintenance. For analysis was taken the internal profile of the barrel of the small firing arms. As the basis was taken 5.56 mm caliber, and discussed it in two variants of existing models internal ballistics two-phase flow [5].

2. COMPARATIVE ANALYSIS

Belgium conducted a parallel investigation with three types of bullets (7.62 mm x 51 SS77; 5.56 x45 mm M193 and 5.56 mm x 45 TW7" SS109, valid gunpowder L110, P112 armour). Advantage of the system 5.56 mm was showed and confirmed the accuracy in operational steps in twisting grooves of grain SS109 and M193. Thereby, they set the initial velocity of the projectile SS109, 4g weight $V_0 = 940$ m/s of the tube length of 508 mm and $V_0 = 925$ m/s from the barrel length 465 mm. Sweden also conducted tests of ballistic projectile stability of 5.56 mm projectiles fired from weapons of different length and steps twisting grooves (guns: U.S. M16A1 - 12", the Belgian FNC - 7" and the Swedish FFV 890C - 9").

Based on these findings, for the SS109 projectile the step folding grooves 7" (177.8 mm) is confirmed. Because the bullet 5.56 mm SS109 has the same capsule as the 5.56 mm M193 bullet (SS92), two basic parameters for design of internal alignment tube can be defined: a step twist and propellant chambers.

The increased velocity of the projectile is a function of increased pressure propellant gases p, which in cal. 5.56 mm exceeds the value of 3600 bar. It also means that it increases the specific pressure on the working side gutters of the barrel, i.e. pressure force of projectile shell is also greater.

When moving through the channel of the barrel, the projectile receives a large radial velocity along the axial rotation axis. The shell is faced with significant centrifugal forces of inertia that are transmitted to the surface of the guidance since the projectile is in contact with it. At the exit from the barrel, the centrifugal force cause shear stress in the shell and that may even harm the strength of shell and proper route of the projectile. Between the shell and core there is usually soft lead lining - layer that, lining the engraved projectile and gutters protect the channel of barrel from intense damage.

The most frequently used method of increasing ballistic lifetime of the barrel is chrome. The reason for this is an excellent reliability of this production in terms of the achieved level of the barrel performance compared to other technologies.

Classically applied cutting technology did not give many opportunities to change a rectangular profile of the rifling and its substitute. Rifling forging is a relatively new method, which is currently brought to a satisfactory level of quality. Its use, unlike other technologies has two main advantages: projectile deposits are made as simultaneous continuation of rifling operation and with this technology a more flexible variation of rifling profile is possible.

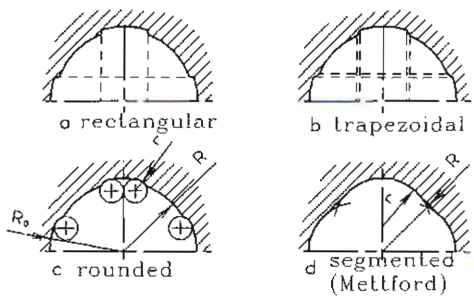

Fig. 1 Shapes of the grooves

The shape of the cross-section or the profile of the projectile guidance was for a long time considered to have very significant effect on weapons ballistics, Fig 1. Studies of the practical results have shown that it has the largest influence on the wear and lifetime of the barrel. For selection of a profile, the valid criteria is determined to define the restrictions such as: a minimum distribution of hits on the target, the maximum lifetime of barrel and a minimum of cleaning (the low-maintenance) and minimum cost pipe. When shooting caliber weapons below 12.7 mm, there are 4 or 6 grooves.

Adoption of the four-grooves for the profile of the barrel 5.56 mm SS109 is accompanied by the satisfaction of demands that the specific pressure on the working side of the guidance in this new profile does not exceed the value that occurs in the profile with 6 grooves. Three profiles were tested: profile 1 (with 6 grooves), profile 2 and profile 3 (with 4 grooves), for the purpose of comparative analysis and the general results. Tab. 1.

Table 1 *Profile dimensions*

	Profile 1	Profile 2	Profile 3
Diameter bar *d* [mm]	5.50 – 5.59	5.44 – 5.53	5.38 – 5.47
Groove d_o [mm]	5.63 – 5.72	5.64 – 5.73	5.61 – 5.70
Change interval *d* and Δd_o [mm]	0.09	0.09	0.09
Twofold depth of the groove $2\delta_1$ [mm]	0.10 – 0.16	0.17 – 0.23	0.20 – 0.26
Surface S_c [mm^2]	24.51 – 25.31	24.36 – 25.16	24.23 – 25.03

3. MATHEMATICAL MODEL FOR THE TWO-PHASE FLOW WITH QUASISTATIC ENGRAVING THEORY

The two-phase flow model takes the pressure of forcing p_0 as developed propellant gas pressure when the projectile was launched and the engraving happend.

The main drawback of this model is the empirical defining the pressure of forcing, and then the Drozd method defines the initial values of parameters and the duration of combustion till the moment of initiation of the projectile.

Basic assumptions of the model would be implemented as follows:

- Launching of the projectile at the pressure generated in the cartridge for overcoming a strong link between the projectile and cartridge (plucking the projectile force).
- The projectile travels to the contact of front grooved barrels and transition cone. Speed that the projectile reaches on the road is relatively small and does not affect the process of quasistatic engravement.
- Engravement is a time process and is not instantaneous, but a gradual transition in which the projectile passes the transition cone with its length.
- The force between the shell and surface of the transition cone remains constant and is provided through the yield strength of material under static conditions.
- Engraving force increases with the moving of the projectile, caused by increasing of the contact surface.

The system of equations of two-phase flow at combustion of gunpowder can be represented by partial differential equations (PDE) in matrix form:

$$\frac{\partial Y}{\partial t} + A_s \frac{\partial Y}{\partial s} = b \tag{1}$$

- matrix of partial derivatives depending on the time t and generalised coordinate s

$$\frac{\partial Y}{\partial t} = \left[\frac{\partial u}{\partial t} \; \frac{\partial u_b}{\partial t} \; \frac{\partial \varepsilon}{\partial t} \; \frac{\partial \rho}{\partial t} \; \frac{\partial e}{\partial t} \right]^T \text{ and } \frac{\partial Y}{\partial s} = \left[\frac{\partial u}{\partial s} \; \frac{\partial u_b}{\partial s} \; \frac{\partial \varepsilon}{\partial s} \; \frac{\partial \rho}{\partial s} \; \frac{\partial e}{\partial s} \right]^T \tag{2}$$

- matrix 5x5 of the coefficients with the partial derivatives from dependent variables by generalised coordinate s

$$A_s = \left[a_{kl} \right]_{k=1,l=1}^{5,5} \tag{3}$$

- matrix of the right of the equation

$$b = \left[b_k \right]_{k=1}^{5} \tag{4}$$

- or the general form

$$\frac{\partial Y_k}{\partial t} + \sum_{l=1}^{m} (a_{kl} \frac{\partial Y_l}{\partial s}) = b_k \tag{5}$$

where, u - gunpowder gas velocity, u_b - gunpowder grain velocity, ε - porosity, as a measure of space that can be fulfil by gunpowder gases, ρ - density of gunpowder gases, e - internal energy per unit volume of gunpowder gases; $m = 5$

during the combustion of gunpowder, and $m=3$ after the combustion, and some of the coefficients a_{kl} are equal to 0.

In addition to these factors, the mathematical model also depends on gunpowder pressure, velocity of grain combustion, mass of grain, parameter of surface forces, energy per unit volume used for grain heating etc.

Quasistatic engravement model [7], was developed for artillery and applied to a small-arms, does not take into account the change in cross section due to grooved barrels [2]. This simplification is possible for the artillery, where the diameter of the rotating band is larger than the diameter of grooves, which is very often not the case with the projectile of firing weapons.

RESULTS AND PRECISION

Real experiment was carried out with 59 samples of barrels cal. 5.56 mm TW7 [illegible] The aim was to make atmospheric conditions [temperature, humidity, atmospheric pressure ...) and factors related to the techniques involved in experiment (assembly, handling, loading, firing ...) as similar as possible for all samples. The average time of maximum pressure values were measured at four measuring points by piezoelectric transducers (p_{1msr}, p_{2msr}, p_{3msr}, p_{4msr}). The average values with standard deviation are given in Table 2.

Table 2 *Statistic analysis of pressure*

Profile	p_{1msr}	st. dev.	p_{2msr}	st. dev.	p_{3msr}	st. dev.	p_{4msr}	st. dev.
Profile 1	3502	100	2608	110	1042	68	700	22
Profile 2	3470	322	2403	534	1075	80	708	18
Profile 3	3628	150	2748	128	1088	42	705	21

Projectile velocity was measured at 10 m from the mouth tube. The average values of calculated and measured initial projectiles velocities (V_{ocal}, V_{omsr}) reduced to the mouth tube are given Table 3.

Table 3 *Statistic analysis of initial velocities*

Profile	V_{ocal}	V_{omsr}	st.dev.
Profile 1	863	873.2	11.0
Profile 2	865	867.2	11.6
Profile 3	868	868.2	7.3

It is obvious that experimental results deviate very little from the calculated, only by +1.2% for Profile 1, +0.27% for profile 2 and +0.02% for the third profile This means complete correspondence of theoretical and experimental models. The average values of R_s and D with the profiles are given in table 3, with measurements in centimetres.

As with velocities, statistic analysis shows that the accuracy obeys the Gaussian distribution with standard deviations, and that the results of the measured initial velocities correspond to the results of precision.

Table 4 *Statistical analysis of precision*

Profile	D_{40}	R_{S40}	st.dev.
Profile 1	4.18	1.16	0.28
Profile 2	3.81	1.03	0.14
Profile 3	3.62	1.01	0.16

5. CONCLUSION

The most stable results of the initial velocity and precision provides the profile 3 with the lowest standard deviation of 7.3 m / s and the smallest average radial drift of the hits R_{S40} = 1.01 cm, and diameter of the distribution of hits D_{40} = 3.62 cm.

This work has no pretensions to study the mathematical models analysed in literature and there is absolutely reason to doubt that information. That leaves rooms for discussion about quality, dimensional accuracy and uniformity of the designed barrels, the quality and uniformity of ammunition and quality of measurement equipment.

To completely define the most appropriate form of the projectile guidance it is necessary to repeat the experimental research several times with barrels and ammunition of different quality and make measurements with quality measuring equipment in various weather conditions.

The aim of this paper is to point to one possible way of defining a standardized projectile guidance, as for calibre 5.56 mm, and for all calibres up to 12.7 mm, which must meet the following criteria: security Service - the pressures, initial velocity and accuracy must be in pre-defined borderline, simplicity of construction - different levels of quality of tools and human resources, ease of maintenance, low cost of making barrels and certitude.

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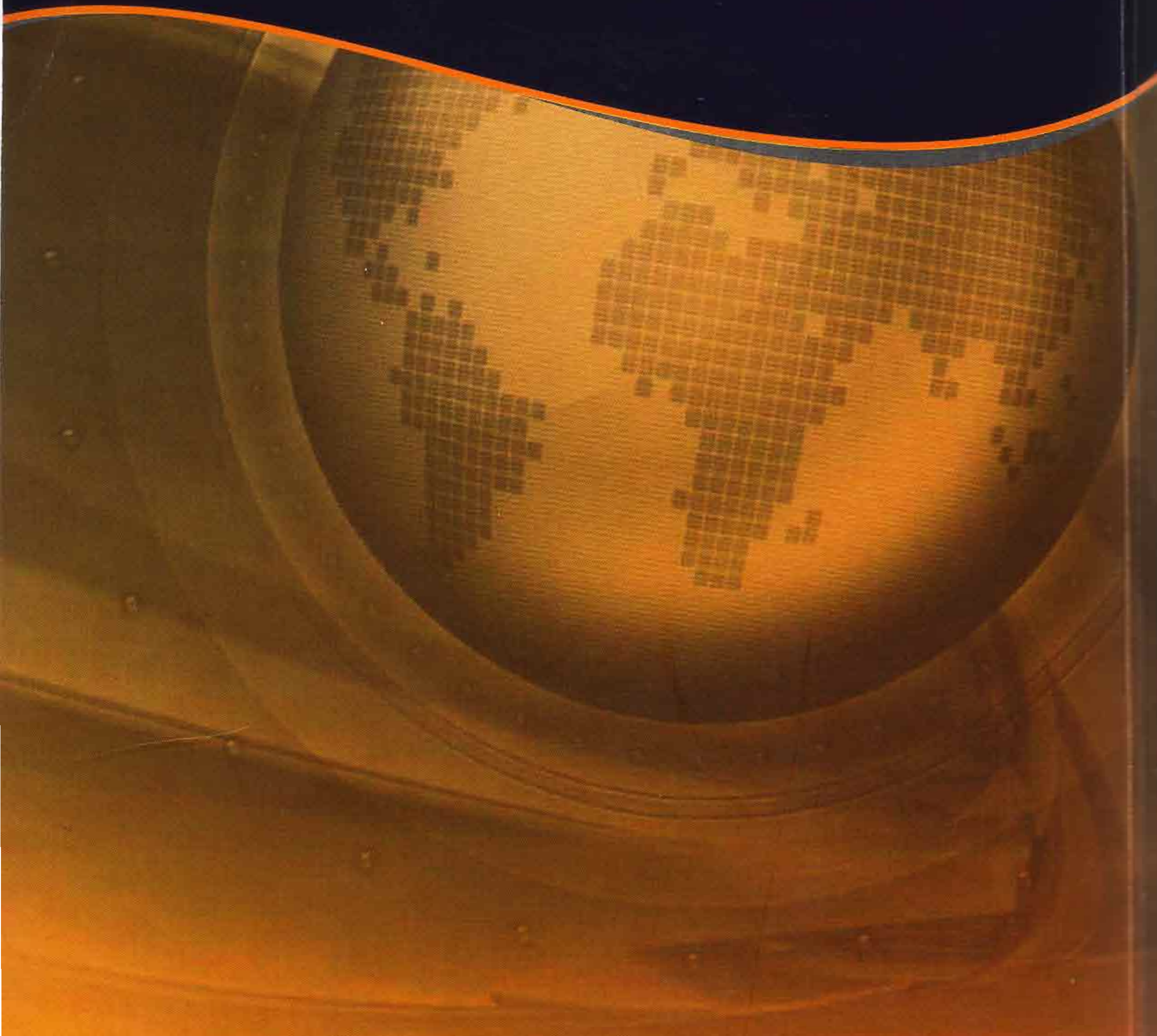

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