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Experimental Analysis of Characteristics of Small Arms Weapon with 9×39 mm Armor-Piercing Subsonic Ammunition System

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The paper presents research conducted on the current VSS Vintorez rifle and the concept of an improved modular weapon system on the AM20 platform with a subsonic system of ammunition 9×39 mm. The test was conducted with the aim of comparing the characteristics of the weapon required for special tasks. The determination of the characteristics of the existing weapon and the concept of an improved modular system on the AM20 platform was carried out through experimental tests. The test was conducted to compare the accuracy and precision of the weapon with a subsonic ammunition system with a 9×39 mm bullet. The tested automatic weapon systems were realized at 100 m under standard conditions, with the appropriate number of shots (ten groups of ten shots each with identical ammunition). The emphasis during the testing was on measuring the muzzle velocity, accuracy, and precision, according to standard testing methods. The results of experimental tests showed a high level of accuracy and precision and an adequate level of initial velocity values. Based on the conducted comparative analysis of accuracy and precision, the possibilities of use in the implementation of tactical tasks in urban environments for the proposed concept of an improved modular system on the AM20 platform were given.

Key words: **special rifle, precision, accuracy, muzzle velocity.**

Introduction

BALLISTICS tests of firearms and ammunition involve measuring elements of the trajectory of an unguided projectile or parameters on the trajectory. The main objective of ballistics tests is to collect, verify and reconcile data necessary for compiling ballistic data sets, i.e. shooting tables. In addition, firearms and ammunition are evaluated to assess their applicability and level of quality, through reliability, precision, and accuracy. The development of theoretical methods and computational techniques has not diminished the importance of experimentation [1].

The precision of weapons and ammunition is characterized by the size of the shooting pattern, i.e. the size of the area on which the hits are distributed in relation to the mean point of impact obtained by shooting under the same conditions. The accuracy of weapons is the deviation of the mean point of impact from the control point at a certain distance and is subject to adjustment [2]. Qualitative benchmarks for representing precision, as one of the basic parameters of weapon quality, have been presented in different sizes in different countries, throughout the history of the development of weapons and military equipment. However, each of these criteria for assessing precision was based on experimentally measured values, mathematically, i.e. statistically processed and numerically and graphically presented. Within some benchmarks, probability distribution functions are used to assess precision, developed for the statistical processing of experimental samples in technical and social scientific disciplines. Weapon precision is the dispersion of hits relative to the mean point of impact. It is not subject to change but is directly related to the ballistics of the weapon and ammunition [3].

In addition to the methodology, the technical conditions of implementation and the quality of the equipment are also responsible for the quality of the test results. The preparation of measuring equipment for testing includes the selection of equipment defined by the standard, which is regularly metrology tested (calibrated) and certified by an accreditation institution. It is necessary to check the measuring devices and equipment before and during the test [4]. The procedure for performing the test depends on the purpose of the test, measuring equipment, the type of firearm or ammunition, and the atmospheric conditions. Shooting begins after all necessary preparations have been made, the measuring devices have been checked, the

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weapon and ammunition have been inspected, the shooting conditions and characteristics of the weapon and ammunition have been recorded, and after the shooting has been realized.

The aim of the work is to research the possibility of using a powerful subsonic caliber, in urban conditions by applying the concept of an advanced modular system on the AM20 platform. All pistol ammunition has limited ballistic capabilities, considering the muzzle velocity, mass of the projectile, and the penetration capabilities. Standard rifle ammunition is designed as supersonic, and the use of silencers is limited. A compromise between penetration, projectile mass and subsonic velocity is difficult to achieve, and some of such successful projects are the special sniper rifle VSS Vintorez in 9×39 mm caliber (Figure 1) designed for use in urban conditions [5].

Figure 1. Rifle VSS Vintorez 9×39mm

The initial development of the 9×39 mm special round was prompted by the general dissatisfaction of Spetsnaz troops during the war in Afghanistan with the AKM and AKMS rifles used in combination with the 7.62×39 mm subsonic ammunition and the PBS-1 silencer, as this combination was not effective.

The introduction of the 5.45×39 mm caliber ammunition, which has even less efficiency than the 7.62×39 mm, has increased the problems when used at subsonic speeds. Problems occurred with the AK745.45×39 mm with a longer barrel when the projectiles jammed in the barrel due to the reduced powder charge. During the Afghan War (1979-1989), it was determined that only the short-barreled AKS74U could be used effectively in combination with the subsonic 5.45×39 mm ammunition and silencers. The field requirements prompted the development of effective rifles that were truly silenced and reliable. The development of the 9×39 mm round was a direct result of the problems encountered during the Afghan War [6].

The 9×39 mm cartridge is based on the Soviet 7.62×39 mm cartridge case, but with an enlarged throat to accommodate a 9.2 mm caliber bullet. The subsonic bullet was originally designed to have an optimistic effective lethal range of 400 to 530 meters and a maximum steel penetration of up to 10 mm [6].

There are two basic variants of the 9×39 mm bullet:

- SP-5 (ammunition with metal and lead core and a copper jacket).
- SP-6 (armor-piercing bullet with a full-length tungsten steel core, exposed black tip and copper jacket).

The Russian military designations for these bullets are: 7N12 (SP-6) and 7N9 (SP-5 Sniper) shown in Figure 2.

Figure 2. Basic ammunition types of 9×39 mm

Following the trends in tactical requirements for the use of automatic rifles, Zastava Arms Kragujevac has developed a new modular weapon model M19 (Figure 3). Compared to other manufacturers, Zastava Arms has gone a step further by offering a rifle that, in addition to easy barrel replacement and the ability to use barrels of different lengths, also allows for a change of caliber, with a choice between the conventional 7.62×39 mm and the new 6.5×39 mm caliber [7]. In addition to the M19 model, which was developed in a standard barrel length of 415 mm, a modular platform was also developed, which bears the designation AM20 with a barrel length of 254 mm. The AM20 modular platform was used for this research, for which a 9×39 mm caliber barrel was made (Figure 3).

Figure 3. Modular Rifle M19 and Modular SMG AM20 in 7.62/6.5×39 mm caliber [7]

Since the shape of the bullet sleeve is identical for the 7.62×39 mm, 6.5×39 mm and 9×39 mm calibers, no additional changes are needed on the mechanism for locking and triggering. The idea of the research itself was to look at the possibility of improving the existing AM20 platform with minimal design and production changes.

It should be noted that tools of the rifle system 9×19 mm were used to make the bore of barrels. The caliber is 0.02 mm smaller compared to the original barrel of the VSS Vintorez rifle.

Methodology

The general model for processing ballistics tests, includes the processing measured parameters and sizes, analysis of the procedures for measurement results, then selection of defined standard precision measures and finally the evaluation of shooting results. Processing of measurement results is realized through primary processing of measurement results and statistical processing of values.

The primary processing of the results is the determination of the required sizes, based on the registered data on the measuring devices: the muzzle velocity based on the recorded measurement data (Doppler radar or ballistic chronograph) and the shoot point coordinates. The measured values of the velocities at a certain distance from the muzzle are recalculated to the values at the muzzle by the standard calculation.

The statistical processing of results represents the determination of statistical quantities for all measured quantities and for each group of tests - shooting: mean value, minimum and maximum value, spread, probable deviation or deviation.

Various metrics are used to assess precision: spread of the shooting pattern, mean radial deviation, circle radius of the of the better half of the hits, probable deviation, standard deviation, core band, and circular probable error.

The concept of precision is related to the concept of so-called mean point of impact (MPI), i.e. the penetration of the middle path from the beam of paths through the plane of the target (vertical plane). The term mean point of impact can be practically evaluated or determined by calculation in relation to the results of measurements, the penetration of the projectile through the target plane and it represents a point, which is obtained by intersecting the ordinate and abscissa of the mean deviation of all hits in the group.

The calculated abscissa of MPI is an arithmetic mean of all horizontal coordinates of the shots along x-axis ($\bar{x}$), while the calculated ordinate of MPI is an arithmetic mean of all vertical coordinates of the shots on y-axis ($\bar{y}$).

The mean radial deviation (*Rs*), [1] represents the arithmetic mean of the radial deviations of individual hits from the mean point of impact (MPI).

The radius of the better half of the shots (R_{50}), [1] is a measure of precision that is used when the shot pattern surface is close to the shape of a circle and when determining the measure of precision in tests with groups of more than 10 bullets. In addition to R_{50}, it is necessary to determine the largest deviation of the hits from the mean point of impact, i.e. it is necessary to describe a circle that includes 100% of the shot pattern (R_{100}), which is recorded in the shooting protocol next to R_{50}.

The standard deviation (σ), [8, 9] is a summary measure of the differences of each observation from the mean, i.e. each shot from the MPI, Figure 4.

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-1}}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(r_i - \bar{r})^2}{n-1}}$$

$$\bar{r} = \frac{\sum_{i=1}^{n} r_i}{n}$$

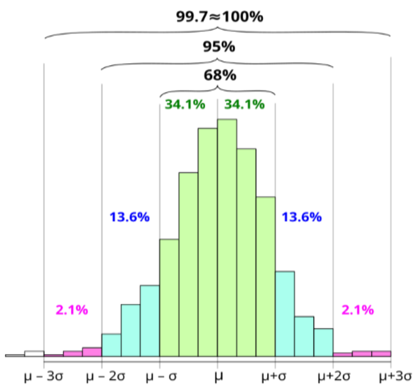


Figure 4. The standard deviation

Circular error probable (CEP) [9-12] or circle of equal probability is a measure of the precision that represents the radius of the circle, centered on the MPI, such that 50% of the impact points lie within it, Figure 5. CEP is based on circular bivariate normal distribution (CBN), analog to normal (Gaussian) distribution.

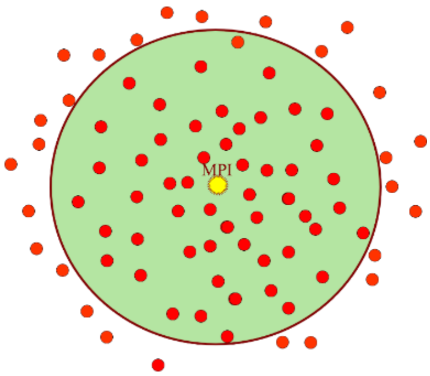


Figure 5. Illustration of Circular Error Probable – CEP

CEP is described as equations, depending on the ratio, as follows,

$$\begin{cases} \sigma_L(0{,}67 + 0{,}8w^2), & 0 < w < 0{,}5 \\ 0{,}59\sigma_L(1 + w), & 0{,}5 \le w \le 1 \end{cases}$$

$$\sigma_L = max(\sigma_x, \sigma_y), \sigma_S = min(\sigma_x, \sigma_y), w = \frac{\sigma_S}{\sigma_L}$$

The analysis of the results will be presented according to mentioned measures of precision, accuracy, and muzzle velocity values.

Objectively determined characteristics show the level of reliability of work, the range of muzzle velocity values, i.e. they provide measures of precision and accuracy. Experimentally measured and determined parameters provide basic information about the weapon's performance, i.e. the basic combat characteristics of the weapon. Based on the defined criteria for a certain type of weapon use, i.e. tactical conditions, an assessment of the possibilities and level of application can be made.

Experimental Setup

Examination of the characteristics of automatic weapons for short distance with specially designed ammunition involves examination of the muzzle velocity, precision and accuracy during shooting, as well as the characteristics of the ammunition, in addition to the general condition and functional operation of the weapon. Integral testing involves shooting at a target while monitoring the operation of the weapon with the specified ammunition, measuring the muzzle velocity and registering the pattern of the impact points (precision and accuracy).

The complete measurement process was carried out in the experimental facilities of the Agency for Testing, Stamping and Marking of Weapons, Devices, and Ammunition in Kragujevac, Figure 6. The measurement methodology is performed according to the procedures (standards) for testing weapons and ammunition according to C.I.P. organization, [13].

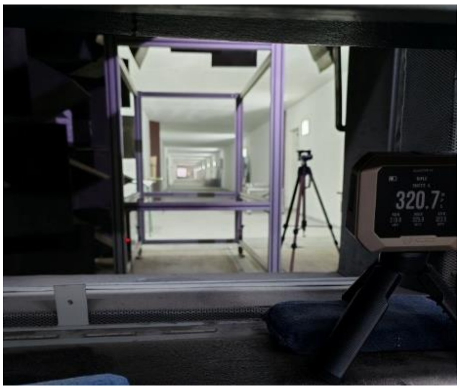


Figure 6. Test conducted in facilities of Proof House

Within the framework of the conducted research, the focus was on examining the functional work, measuring the muzzle velocity and determining the precision and accuracy of the existing weapon system with an integrated optical sight and with two types of ammunition, standardly used for the weapon system.

Precision and accuracy are determined based on standard test conditions [14]. Shooting was performed with ten groups of ten shots each in identical ambient conditions (standard atmospheric conditions of temperature, humidity, pressure, no wind), within the ballistic tunnel. The target was located at 100 m, circular, with a diameter of 500 mm. The shooting was carried out with both types of weapons: rifle VSS Vintorez 9×39 mm (VSS) and the test rifle 9×39 mm (XM24, derived on modular AM20 platform), Figure 7. The shooting was carried out by an official test shooter.

Figure 7. Test Rifle 9×39 mm

Analysis of the results

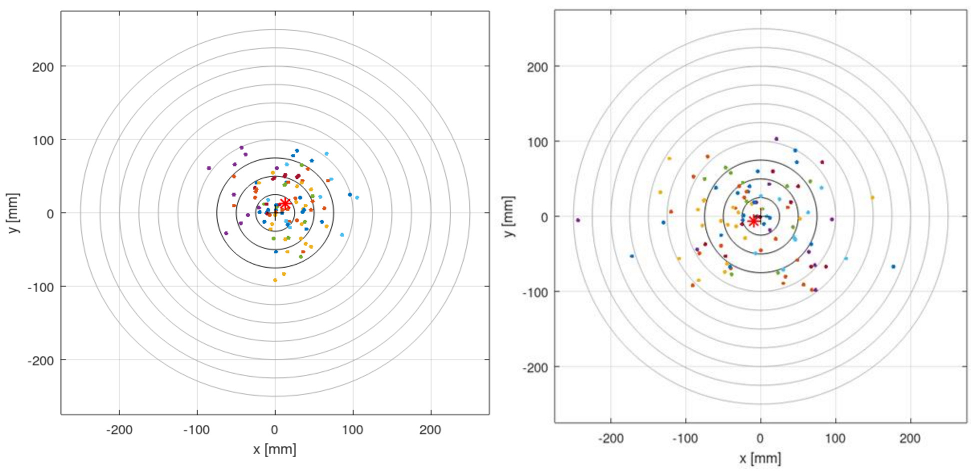
Muzzle velocity measurement was performed with an infrared barrier, a chronograph for measuring the muzzle velocity of firearms at 2.5 m from the muzzle of the barrel. The average values of muzzle velocities are presented in Table 1.

Table 1. Muzzle Velocity Values

Group (10 shots)	Average Muzzle velocity for 10 shots, [m/s]	
	VSS Vintorez	XM24
1	283.26	283.28
2	282.50	282.86
3	280.26	279.83
4	283.74	282.05
5	280.68	288.35
6	281.91	282.29
7	283.85	279.37
8	282.21	283.85
9	283.44	283.53
10	282.78	280.16
Average	**282.46**	**282.56**
Spread (min – max)	**3.59**	**8.98**
Standard Deviation	**1.234**	**2.591**

Standard deviation of the measured values of the muzzle velocity is between 1 and 3 m/s for both types of tested arms and all groups in compared to the averaged value of 282 m/s. A small standard deviation in a dataset indicates that the data points are clustered closely around the mean, meaning there is less variability or spread in the data. This is the very confident initial condition for the processing data to determine the measures of precision of all shots, without correction (very low systematic uncertainty), and present shot pattern. It should be noted that both types of rifles were tested with standard sight. The VSS Vintorez are equipped with optical telescopic sight PSO-1-1 (1P43), and XM24 used standard Red Dot Point sight of AM20.

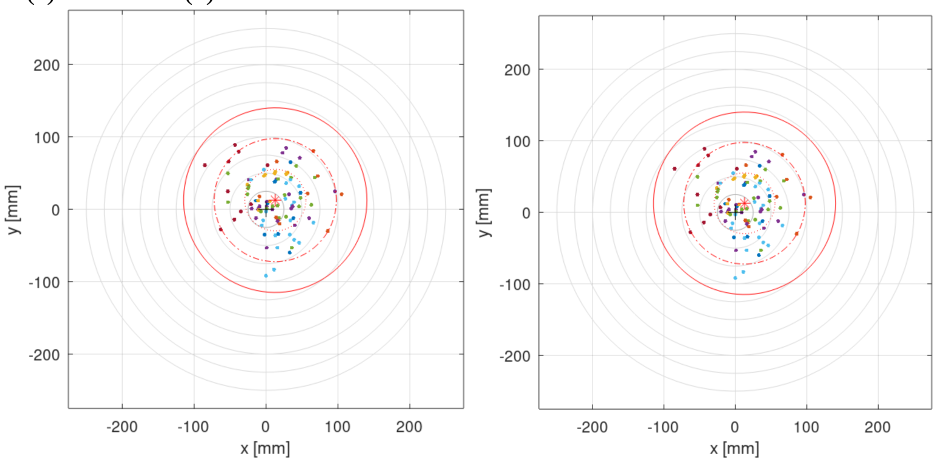
The results of the experimental test are presented in the following figures and tables as a shot pattern on the vertical target plane, a circular target with a diameter of 500 mm in Figure 8, where VSS (a) and XM24 (b) are presented. In Figures MPI of all shots is marked with a red sign asterisk (*) and the center of the target as a black sign of cross (+), as a coordinate origin.



(a)VSS (b)XM24

Figure 8. Shot pattern of 10 groups by 10 shots on vertical target plane

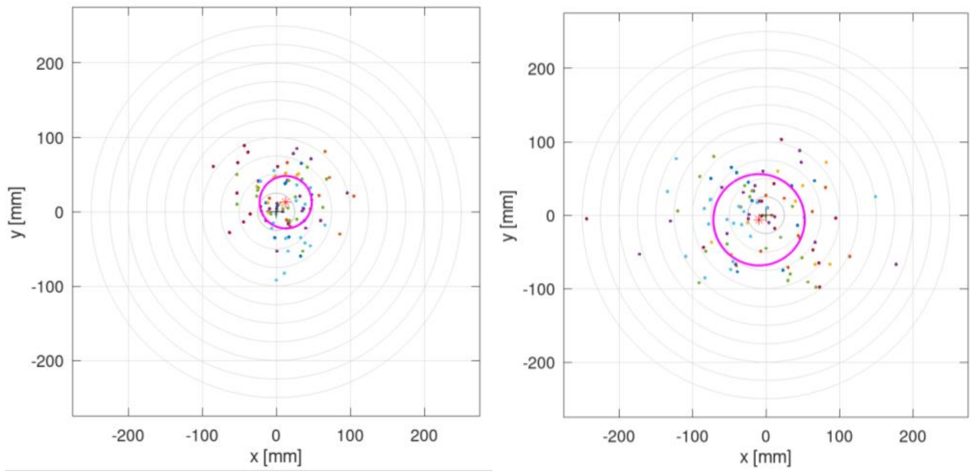
The results of the standard deviation, σ (red lines for σ, 2σ and 3σ) for all shots at vertical target plane are presented in Figure 9, for VSS (a) and XM24 (b).



(a) VSS (b) XM24

Figure 9. Shot Pattern of 10 groups by 10 shots with Standard Deviation

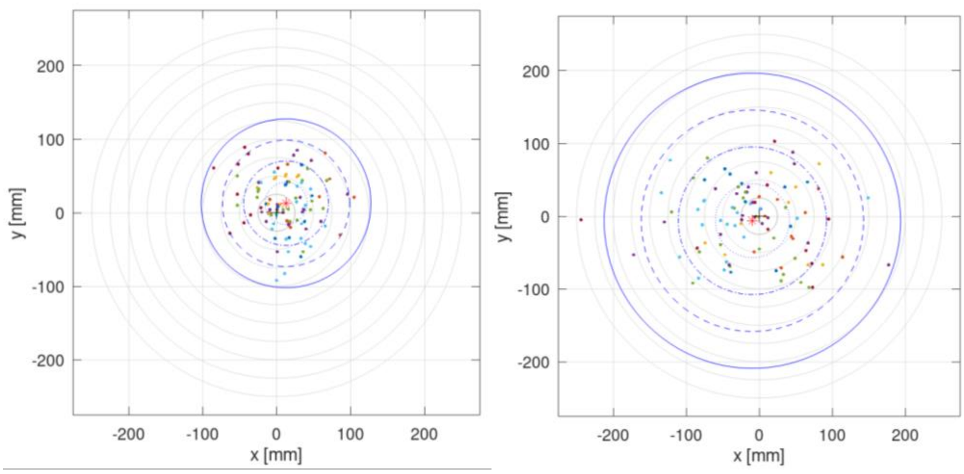
The results of circular error probable, *CEP* for all shots at vertical target planes, are presented in Figure 10, for VSS (a) and XM24 (b).



(a)VSS (b) XM24

Figure 10. Shot Pattern of 10 groups by 10 shots with CEP

The results of probable deviations for all shots at vertical target planes are presented in Figure 11, for VSS (a) and XM24 (b).



(a)VSS (b) XM24

Figure 11. Shot Pattern of 10 groups by 10 shots with Probable Deviations

The accuracy of shooting is determined in experimental conditions and estimated according to the distance of the MPI, from the center of the target. The distances are given in Table 2.

Table 2. Estimated Accuracy from Test of Serial Ammunition

Rifle	x_{MPI}	y_{MPI}	r_{MPI}	Accuracy
	[mm]	[mm]	[mm]	[MOA]
VSS	12.91	12.76	18.152	0.62
XM24	- 9.39	- 6.28	11.296	0.38

The results of the different measures of precision are presented in Tables 3 and 4 for 10 groups of 10 shots with SP-5 bullets.

Table 3. Precision Measures (Standard Deviation and CEP) from Test of Serial Ammunition

Rifle	Standard Deviation $\sigma, 2\sigma, 3\sigma$	Circular Error Probable *CEP*	
	[mm]	[mm]	[MOA]
VSS	42.51 85.02 127.53	35.24	1.2
XM24	75.20 150.41 225.61	62.14	2.1

Table 4. Probable Deviations from Test of Serial Ammunition

Rifle	±*Vs*	±*2Vs*	±*3Vs*	±*4Vs*
	[mm]	[mm]	[mm]	[mm]
VSS	28.67	57.35	86.02	114.69
XM24	50.72	101.45	152.17	202.90

Conclusion

The paper introduces experimental and analytical procedures for analysis of the ballistic characteristics of the small arms weapon with a 9×39 mm special subsonic ammunition system (armor-piercing).

Accuracy is a measure for assessing the quality of weapon use, in addition to the weapon itself and ammunition, and in controlled conditions can provide an objective value. Precision is a measure for assessing the quality of a weapon and ammunition system, under identical meteorological and ballistic initial conditions, without the influence of systematic disturbances. Both measures are significant, but different from each other, because they originate from different conditions. Therefore, it is necessary to specifically organize and measure influential parameters during testing.

The precision of both types of rifles is measured at the same distance under control conditions (atmospheric, weapon, test shooter) and shows a good agreement with each other. The VSS Vintorez shows somewhat better precision characteristics than test rifle derived on the AM20 platform for 50% (CEP) and 100% (3σ) of shot patterns. Average precision for 50% of shot pattern: determined by CEP is 35 mm or 1.2 MOA for VSS rifle, while for experimental rifle XM24 it is 62 mm or 2.1 MOA. The reasons for the differences in the precision of the experimental rifle are the subject of further research and development. One of the possible improvements is testing rifles with new types of optical sight and testing of precision and accuracy with the static stand.

Based on the presented results, it can be concluded that the selected AM20 platform can be used for the integration of 9×39 mm barrels. The modifications made in the construction are minor and do not change the basic concept. By improving the construction of the rifle and ammunition, a subsonic automatic weapon is obtained that has significantly better performance compared to current weapons for urban conditions. The platform is domestically produced, and this concept can be implemented with its own resources. Comparison of the accuracy and precision of the experimental rifle on the proposed platform in relation to the existing special rifle justifies its possible application.

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Eksperimentalna analiza karakteristika streljačkog oružja sa pancirno-probojnim podzvučnim sistemom municije 9×39 mm

U radu je predstavljeno istraživanje sprovedeno na aktuelnoj pušci VSS Vintorez i konceptu poboljšanog modularnog sistema naoružanja na platformi AM20 sa podzvučnim sistemom municije 9×39 mm. Testiranje je sprovedeno sa ciljem upoređivanja karakteristika oružja potrebnog za specijalne zadatke. Utvrđivanje karakteristika postojećeg oružja i koncepta poboljšanog modularnog sistema na platformi AM20 sprovedeno je kroz eksperimentalna ispitivanja. Test je sproveden radi upoređivanja tačnosti i preciznosti oružja sa podzvučnim sistemom municije sa metkom 9×39 mm. Testirani automatski sistemi naoružanja realizovani su na 100 m pod standardnim uslovima, sa odgovarajućim brojem hitaca (deset grupa od po deset hitaca sa identičnom municijom). Naglasak tokom ispitivanja bio je na merenju brzine na početku cevi, tačnosti i preciznosti, prema standardnim metodama ispitivanja. Rezultati eksperimentalnih ispitivanja pokazali su visok nivo tačnosti i preciznosti i adekvatan nivo vrednosti početne brzine. Na osnovu sprovedene uporedne analize tačnosti i preciznosti, date su mogućnosti korišćenja u realizaciji taktičkih zadataka u urbanim sredinama za predloženi koncept poboljšanog modularnog sistema na platformi AM20.

Ključne reči: **specijalna puška, preciznost, tačnost, početna brzina na ustima cevi.**