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Tribotechnics and tribomechanics – prolongation of firearm lifetime

CAPACITY FOR IMPROVING TRIBOLOGICAL CHARACTERISTICS OF BARREL INTERIOR LINE ON A GUN

D. JOVANOVIĆ[a], B. STOJANOVIĆ[b]*, R. JANJIĆ[c]

[a] *ZASTAVA Arms, 34 000 Kragujevac, Serbia*
E-mail: *zo.tehnologija@zastava-arms.rs*
[b] *Faculty of Engineering, University of Kragujevac, 6 Sestre Janjic Street, 34 000 Kragujevac, Serbia*
E-mail: *blaza@kg.ac.rs*
[c] *Technical Test Centre, 11 000 Belgrade, Serbia*
E-mail: *lari32@open.telekom.rs*

ABSTRACT

Barrel is the most important part of a weapon. It represents an element in which double energy transformation is performed: chemical energy of gunpowder combustion transforms into thermal energy, and then it transforms to mechanical energy. A barrel gives a projectile necessary initial speed and flight direction, and through helical grooves, high spinning necessary for stability during the motion towards the target. Barrel exposure to combined effects of heat, high pressures, chemical effect of gunpowder gases and external influences points out the necessity of comprehensive researches of this element of the weapon. Subject of the paper is a presentation of improving tribological characteristics of barrel interior lines of a gun using modern means for surfaces modification in the conditions with high temperatures and pressures.

Keywords: barrel, tribology, wear, caliber, gel.

AIMS AND BACKGROUND

As any other mechanism, firearm has its lifetime which is determined according to the wear of barrel interior line. Globally accepted criteria refer to the method of determining barrel condition over precision demand or the value of bullet initial speed (bullet speed on a muzzle). Barrel is an element in which double energy transformation is performed: chemical energy of gunpowder combustion trans-

* For correspondence.

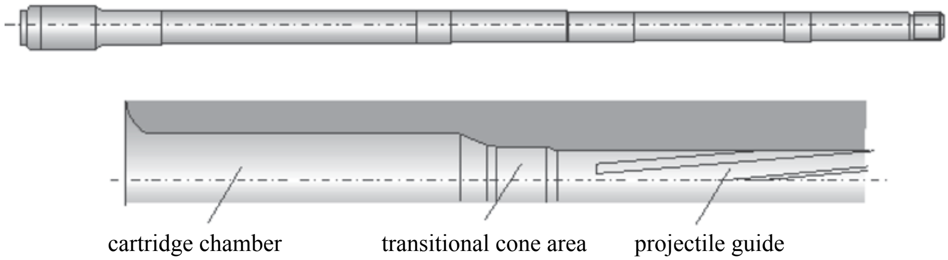


Fig. 1. Interior line of a barrel

forms into thermal energy, and then it transforms into mechanical energy. The barrel gives a projectile necessary initial speed and flight direction, and through helical grooves, high spinning necessary for stability during the motion towards the target[1,2].

While studying interior ballistic problem, we only consider barrel interior line. Basic terms which define a barrel of a weapon (Fig. 1) are:

- gunpowder cylinder;
- transition cone;
- projectile guide.

Gunpowder cylinder is a section where powder charge is set before firing. For barrel constructors, the term rear cylinder includes whole internal unrifled barrel characteristics, except slide cylinder. For interior ballistics, this term represents only the one in which powder charge starts combustion.

Transition cone is a conical part of the barrel that bullet case leans on. It is connected to a rifled barrel part and a smooth part where cartridge case is placed.

Projectile guide is a front, usually rifled barrel part. Projectile moves across it and it determines steady motion.

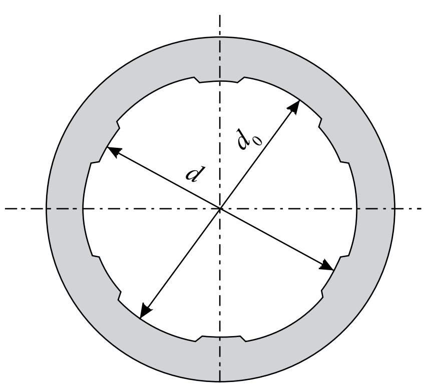


Fig. 2. Cross section of rifled barrel part

Figure 2 represents an illustration of the rifled barrel part. Dents in the rifled part are grooves, and bulgings between two grooves are lands.

Weapon caliber *d* is a distance between two opposite lands. Groove depth is usually 0.01*d*. Grooves themselves are not parallel to the barrel axis, but they comprise a certain angle ß which is defined as angle of twist.

Barrel is usually made of chrome-nickel-molybdenium (Cr-Ni-Mo) steel because they obtain best characteristics between 350–400°C, their hardness and tenacity increase, and the temperature in a barrel reaches 400°C. Bullet is an element which moves across the barrel and which flies through air towards a target. Bullet core is usually made of lead, and bullet case is usually made of tombac – copper and zinc alloy. The purpose of bullet case is to cut into grooves and to lead the bullet across the barrel.

During combustion of gunpowder gases, barrel interior surface is exposed to combined mechanical, thermal and chemical forces. These processes result in damaging barrel interior surface and decreasing barrel ballistic lifetime (Ballistic lifetime means the number of bullets that a barrel can fire without significantly reducing precision and range)[3]. Mechanical characteristics of barrel materials decrease (strain and erosion occur, and brittleness of surface layer increases). These alterations are more considerable if demands for increasing shooting range, precision and speed are stricter. Barrel exposure to combined effects of heat, high pressure, chemical forces of gunpowder gases with highly energetic characteristics, and external forces indicates the necessity for comprehensive research of this fire arm element[4,5].

From the aspect of tribology adequate constructions, the basic functions executors that act on the principle of friction contacts at the elements with relative motion are very important. Those basic functions executors are known as tribomechanical systems (TMS) in the tribological theories. At the zones of friction contacts the complex, non-stationary physical, chemical and mechanical processes are present and they are followed by friction and wear of contact surfaces. The problems related to friction and wear present the problems of contact mechanics acting, chemical processes in the friction zones and physical problems of dissipative processes at surface levers of contact surfaces[6–9].

Causes for barrel wear are numerous, they are very complex and still insufficiently tested. That is why it is impossible to predict the lifetime of a barrel.

CAPACITY FOR IMPROVEMENT

Firearm lifetime is limited because of complex process of mechanical and erosive wear. Surfaces in contact, which comprise tribomechanical system barrel-bullet, consist of tops and dents of microreliefs, contaminated with various products of decomposition of oil and additives. The essence of modern devices effects for surfaces modification reflects in capacity for forming metalloceramic coating on surface metal layer in conditions of extremely high temperatures, pressures, sufficient friction energy and interaction of materials with different hardness[10,11].

In the moment of firing, pressure in a barrel reaches the value of 400 MPa. Moving through a barrel, at extremely high speed and high pressures, a bullet bears particles from interior barrel surface. Gunpowder gases penetrate formed cracks and wear is manifested by creating fissures and damage of the surface.

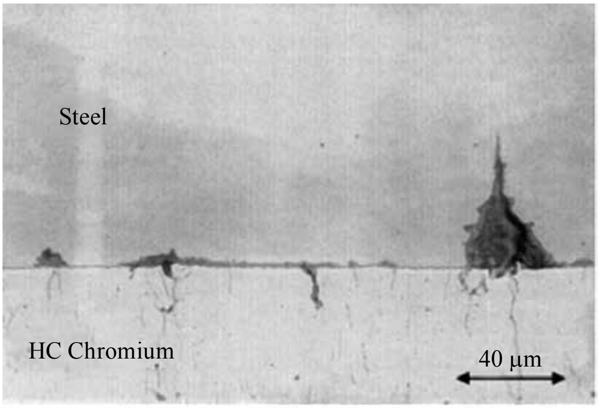


Fig. 3. Interior line of a barrel (HC Chromium-hard chromium)

With appropriate structural and technological solutions for a barrel, slower wear is provided, in other words erosion, which makes maintenance more efficient and easier. One of the economical and currently most common methods for increasing resistance of barrels interior surfaces to mechanical, thermal and chemical forces is protective coating made of electrolytic chromium[12].

Resistance to wear and corrosion considerably increases with chromium precipitation over basic material; hardness and thermostability also increase. That implies that weapon ballistic lifetime can be lengthened and maintenance can be facilitated by precipitating chromium on basic material of a barrel. During weapon exploitation, which has chromed interior line of a barrel (coating thickness up to 0.3 mm is recommended), due to gunpowder gases force, they could react through formed cracks, penetrate under coating and under high pressure and temperature cause its separation from basic material and falling out in pieces (Fig. 3) (Ref. 13).

Examinations conducted on coatings made by physical precipitation or on surfaces modified by ionic treatment show that they have the same or maybe even better performances. Advantage of these hypothetically alternative procedures for use in firearms production are lower cost and more economical ecological conditions compared to chrome plating procedure[14].

One of suitable methods for solving a problem of barrel wear and improving ballistic as well as tribological characteristics is the use of special modern devices for surfaces modification. Development of these devices for improving tribological characteristics of surfaces dates back to the period of the Cold War, when in the former Soviet Union, military experts and scientists were given the task to develop specific treatment for motors and transmission of armoured fighting vehicle which would enable the vehicles to quickly depart from battlefield, the moment greasing system is seriously damaged, in other words, it was necessary to develop a system of functioning tribomechanical systems in extremely difficult exploiting conditions, without oil or grease. It was not even presumed then that these inventions would be used on firearms[15].

By means of micrometallurgical processes, with temperature of around 1200°C, molecules of modification devices diffuse into crystal grid of surface layer on interior line of a barrel, they replace it and create new crystal grid. Formed coating with increased hardness and reduced surface roughness result in decreasing friction force, in other words, friction coefficient equalises coefficient of rolling friction. That conditions bullet casing cutting into grooves on interior line of a barrel more evenly, as well as regular bullet trajectory after leaving a barrel muzzle[16].

So, modern technologies are able to restore any mechanism, simple or complex, if there are motion and friction. Tribomechanical system barrel-bullet, represents perfect combination of all necessary conditions for creating metallo-ceramic coating, high temperature, sufficient friction energy, interaction of materials with different hardness.

EXPERIMENTAL

Examination was conducted in the Laboratory for testing in the factory 'Zastava Arms' from Kragujevac. Tested device is multicomponent fine mixture of natural minerals, additives and catalytic converter. Basic characteristic of the devices is capacity for forming protective coating with metal surface layer on places in contact where wear occurs. Reparation process on interior line of a barrel happens during shooting. Gel is applied on interior line of a barrel and on a bullet. Number of necessary shots depends on barrel type and varies from 3 (minimum) to 10 (maximum). Barrels with following defects are suitable for reparation: cutting in, microfissures, removed chrome layer, formed dents, corrosion, abrasion of barrel interior line, bulging. Treating barrels with exterior bulgings is not recommended.

Gun barrel needs to be completely cleaned before treatment. Gels with various functions are in the same tube. Mixing the order when using gels is impossible because they are set in a tube in suitable order and coloured red, yellow and green. Red gel is used in the first phase. It is a preparation of the surface using specific method similar to grinding. Coating is formed by itself in second phase during the treatment of a barrel and a bullet with yellow gel. Green gel is applied in third phase. It strengthens the coating. New barrels are treated by shooting two bullets using green gel. After that barrel characteristics are improved, in other words compression, shots grouping and initial bullet speed are increased. The physical and chemical characteristics of the gels are given in Table 1.

Examinations of capacity for improving exploiting characteristics of firearms by applying specific gels for regeneration, based on variation of precision param-

Table 1. Physical and chemical characteristics of the gels

Melting temperature (with boiling) (°C)	65–70
Density at 20°C (kg/m^3)	887.9
Dripping temperature (°C)	44
Sedimentation stability at 40°C (%)	100
Particle size (mm)	5
Corrosive effect on metals	–
Content of water (%)	–
Appearance and scent	gel with fruit scent

eters, bullet speed and alteration of interior geometry of barrel channel (barrel diameter alterations on rifled part) were conducted on weapons:

– AP M21, caliber 5.56, chromed barrel, gun with 5000 fired bullets,

– AP M70, caliber 7.62×39, unchromed barrel, firearm with 10000 fired bullets,

– SP M70, caliber 7.62×39, chromed barrel, new firearm.

The experiment used the following methods in order to determine exploiting characteristics of weapons:

– before gel treatment,

– during treatment and immediately after treatment,

– after treatment and 200 fired bullets,

– three months after the treatment.

Testing programme before and after treatment with gel for reparation of barrel interior line included:

– measuring barrel caliber,

– recording of the condition of the surface on barrel interior line,

– determining initial bullet speed,

– determining weapon precision.

Recording of the condition of barrel interior line was performed with endoscope type AVIASCOPE-869001 KL 1500 KARLHEINZ-HINZE. Recording was performed on four positions. Initial bullet speed was measured with measuring equipment AVL Ballistic Measurements Equipment Type 211. Testing initial speed is performed in three groups, each has 10 bullets, firing ammunition in normal conditions. Barrier which consists of two beams of infrared light, on particular distance between them, is located 7 m from barrel muzzle. That is why the device shows speed value of v_{7m}, and the speed barrel muzzle v_0 is calculated according to the equation: $v_0 = v_{7m} + 9.2$ m/s.

Table 2 shows the results of measuring before the beginning of the experiment.

Weapon precision implies dimension of scores image (data grouping – scoring points) obtained on vertical target, set on particular distance from the weapon[17]. Testing precision with mechanical, optical and optoelectronic sights is performed according to the standard SORS-5566, with single shootings with three

Table 2. Weapon characteristics before experiment

Characteristics	AP M21 cal. 5.56 mm	AP M70 cal.7.62×39 mm	AP M70 cal.7.62×39 mm
	chrome barrel	chrome barrel	unchromed barrel
	gun with 5000 fired bullets	new gun	gun with 10 000 fired bullets
	1	3	4
Caliber (mm)	limiter 5.57 mm, goes from flash hider to chamber, 5.58 mm, eats barrel muzzle away	limiter 7.63 mm, goes from bear cylinder to chamber	caliber 7.62 mm exceeds limiter 7.63 mm from bear cylinder to chamber
Initial speed, v_{sr} (m/s)	903	796	683
Precision, D (mm)	106	56	102
Precision R_{50} (mm)	55	26	48

groups, each has 10 bullets aiming at specific target, located on the distance of 100 m. Shooting is performed on anticipated target or on black rectangle with particular dimensions which is fixed to a white board 1 m high and 0.5 m wide. The middle of lower edge of black rectangle is used as aiming point which should approximately be located in shooter horizon. Taking into account values that are used for evaluating precision in this examination, the following were considered:

- diameter of scoring image D,
- circle radius of the half with better scores $R_{50,}$ which are, according to SORS standards, basic parameters for determining precision[17].

Table 3 shows the alteration of initial speed of tested guns, and Table 4 shows the results of the precision in all parts of the experiment.

Table 3. Initial speed value

Characteristics	AP M21 cal. 5.56/J4	AP M21 cal. 5.56/J2	AP M70 cal. 7.62×39/J5
	chromed barrel	chromed barrel	unchromed barrel
	gun with 4000 fired bullets	new gun	gun with 10 000 fired bullets
		v_{sr} (m/s)	
Before treatment	903	796	683
Immediately after treatment	898	785	683
Alteration (%)	–0.6	–1.0	0
After 200 fired bullets	904	790	681
Alteration (%)	0.1	–0.8	–2.9
3 Months after experiment	908	797	683
Alteration (%)	0.6	0.2	0

Table 4. Characteristics of weapon precision

Characteristics		AP M21 cal. 5.56	SP M91 cal. 7.62 mm	AP M70 cal. 7.62×39
		chromed barrel	chromed barrel	unchromed barrel
		gun with 4000 fired bullets	new gun	gun with 10 000 fired bullets
		1	2	3
Before treatment	*D* (mm)	106	56	102
	R_{50} (mm)	55	26	48
Immediately after treatment	*D* (mm)	103	45	100
	alteration (%)	3	18.2	2.0
	R_{50} (mm)	48	24	55
	alteration (%)	14.5	7.7	–12.8
After 200 fired bullets	*D* (mm)	86	44	105
	alteration (%)	23.2	21.43	–2.9
	R_{50} (mm)	38	25	51
	alteration (%)	30.9	3.8	–6.25
3 Months after experiment	*D* (mm)	108	50	94
	alteration (%)	–1.8	10.7	8.5
	R_{50} (mm)	51	25	48
	alteration (%)	7.8	3.8	0

RESULTS AND DISCUSSION

AP M21, cal. 5.56, tested gun No 1: Technical condition of the gun barrel before treatment with reparation device is not satisfactory. Recordings of barrel interior line show visible damage. Immediately after treatment significantly better condition of barrel interior line is evident. The wear traces visible on recordings before treatment are smaller. Caliber is lowered from 5.56 to 5.55 mm, which reduces gap between barrel and projectile, which results in better bullet cutting in and improved weapon precision compared to the indicators before treatment.

After 200 fired bullets and three-months storage in a warehouse on room temperature, initial speed value is increased for approximately 0.6% while the parameter R_{50} is improved for about 8%, and parameter *D* is on the same level as before treatment. Passability of the limiter of 5.56 mm is 280 mm from muzzle side and 140 mm from barrel muzzle side.

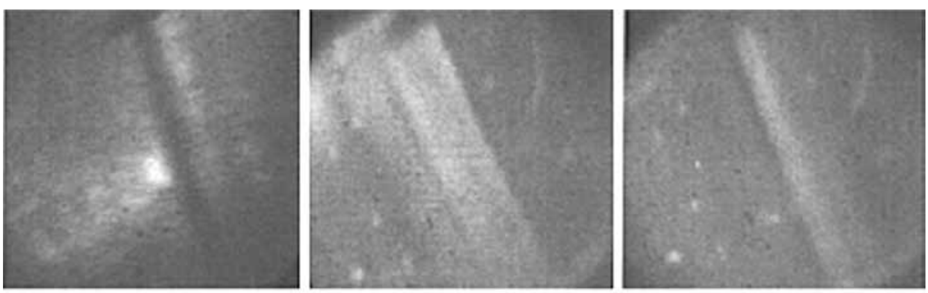
SPM91, cal. 7.62 mm, tested gun No 2: Technical condition of the gun barrel before treatment with reparation device is good. Recordings immediately after treatment show significantly better condition of barrel interior line. Caliber is lowered from 7.62 to 7.61 mm, and precision parameters are improved.

After 200 fired bullets and three-months storage in a warehouse on room temperature, initial speed values are on the same level as before treatment. However, precision parameters are still better compared to previous condition, parameter R_{50} is improved for about 3.8%, and parameter D for approximately 11%.

On all tested weapon samples, no matter what the condition of barrel interior line was, hard coatings of thickness 8–10 μm was formed. Figure 4 shows the recording of barrel interior line AP M70, caliber 7.62×39 mm, before and after treatmenat, recording was positioned 270 mm far from the barrel muzzle. Before treatment, 10 000 bullets were fired from the gun, barrel typically rifled, barrel interior line unchromed.

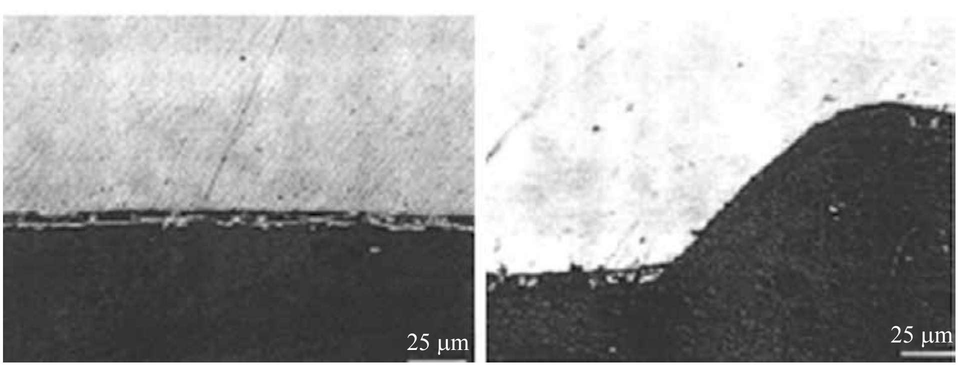
Figures 5 and 6 show recordings of metallographic barrel samples AP M70 7.62×39 mm, immediately after treatment and three months later. Samples are formed on two positions: near slide cylinder (thicker barrel wall) sample 1, and near barrel muzzle (thinner barrel wall) sample 2. Thickness of the coating created this way, is from 6 to 8 μm for sample 1 and 6 to 10 μm for sample 2.

When it comes to wear on barrel interior line, owing to the treatment, there is a possibility for reducing the value of wear on barrel interior line up to 20



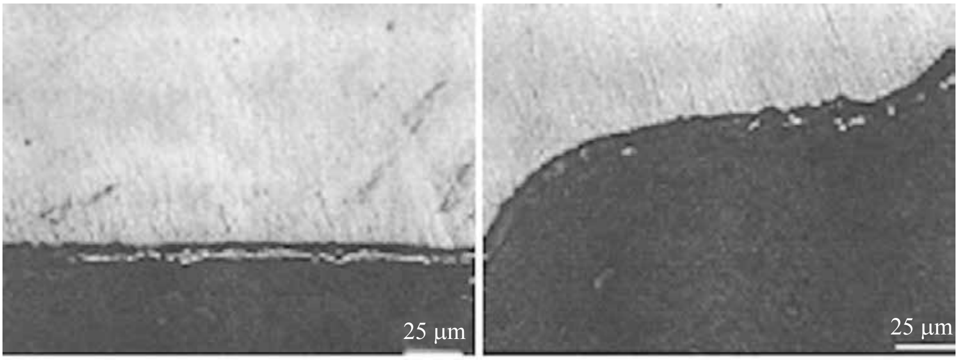
(*a*) before treatment (*b*) immediately after treatment (*c*) after treatment and 200 fired bullets

Fig. 4. Look of barrel AP M70 7.62×39 mm



(*a*) immediately after treatment (*b*) after three-months storage

Fig. 5. Micrographic cut of sample 1



(*a*) immediately after treatment (*b*) after three-months storage

Fig. 6. Micrographic cut of sample 2

times[15]. According to certain examinations, using this device for improving the condition of barrel interior line on a firearm at the beginning and in the middle of its lifetime, weapon precision is improved up to 45% on unchromed barrels and 30% on chromed barrels, compared to barrels not treated with gel[16]. Results of these examinations show improvement of precision parameters on firearm to approximately 31% when it comes chromed barrel interior line.

CONCLUSIONS

As any other product, firearm also has its lifetime, which is determined by the degree of wear of barrel interior line. Criteria which determine it refer to the method of determining barrel condition over precision demand of a weapon or the value of bullet initial speed. Although developing new materials and technologies for manufacturing barrel with improved characteristics are constantly progressing, it is necessary for both manufacturers and weapon users to particularly pay attention to the condition of barrel interior line. One of the methods for improving condition of barrel interior line and for improving its ballistic characteristics is the use of special gels for surface modification. These devices improve tribological characteristics of barrel interior line on a firearm, as well as the precision parameters and also lengthen weapon lifetime, both new barrels and the ones that has been in the exploiting process, but has not reached the wear limit. Formed metalloceramic coating on barrel interior line protects it from gunpowder gases effect, makes it more resistant to corrosion, dust and damp.

Examinations have shown that the results are not always positive on barrels with chromed interior line which is at the end of its lifetime, because of the further decreasing in bullet speed and the increased data dispersion.

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