Wear of cannon 2A46 barrel bore

Robert Jankovych and Stanislav Beer

***Abstract*—**The paper provides information about a successful evaluation and also an analysis of character of bore wear of the barrel of T-72 tank, which is still in service in number of armies throughout the world. Three types of the wear of driving parts of the barrel bore were documented. There are in original way mathematically formulated conditions of formation of a specific type of wear caused by firing the armour piercing discarding sabot 3BM-9 and 3-BM-15 projectiles in the paper.

***Keywords*—**Barrel bore wear, T-72 tank projectiles.

I. Introduction

THE gun barrel is one of the most important parts of gun and determines both gun power and gun lifetime. Contemporary theories of barrel lifetime match the wider theory of the propellant gases erosion and limit states of barrel material. The study of barrels lifetime enables to manage practically not only the lifecycle of barrel itself but moreover the whole gun. Therefore the very wide range of theoretical and practical tasks of the evaluation of the technical condition of barrels during its service has to be solved.

Available literature, e.g. [1], [7], [8], [12] describes rifled bore wear of cannon barrels in dependence on cannon power and the number of rounds shot. As far as smooth bore wear is concerned, the literature almost does not deal with it. In contrast to rifled barrels, smooth barrels use for shooting rounds of various construction types which cause different character of wear.

The aim of the contribution is to report on successful measurement and analysis of the character of the process of D-81 cannon barrel wear of T-72 tank which is used in several armies.

Basic types of cartridges used in T-72 tank are cartridges with fin stabilized projectiles of the following types: 3BK-14M (high-explosive anti-tank fin stabilized with tracer - HEAT-T), 3OF-19 (high- explosive - HE), 3BM-9, 3BM-15 (both armour-piercing fin-stabilized discarding sabot with tracer -APFSDS-T) and TAPNA (APFSDS-T).

The mechanical instrument PKI-26 is determined for the measurement of the barrel bore driving parts of the 2A46 tank cannon. With PKI-26 it is possible to carry out the measurement only within the distance of maximally 1050 mm from the back end of the tube as well as from the muzzle. Based on the knowledge of the principles of wear of tank barrels using sub-calibre projectiles, it is necessary to monitor and evaluate the information on dimensions of the whole barrel bore [10].

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II. Measurement of T72 Tank Barrel with BG-20 MkII

Measurement was conducted in three 2A46 cannon barrels by BG-20 MkII measuring equipment. The purchased BG-20 measurement system produced by Aeronautical and General Instruments was adjusted also for the 125 mm calibre in 2010.

Fig. 1 shows the photograph of BG-20 system prepared for measuring with a 2 m long feeder tube. For the measurement on T-72 tank, a 6 m feeder tube is also available at the University of Defence.

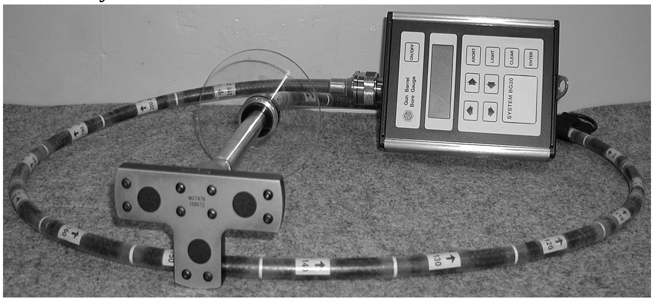

Fig.1 Photo BG-20 MkII with 2 m feeder tube

III. Measurement Conditions

To analyze the character of wear process, three 2A46 cannon barrels were selected from which from 222 to 830 different types of projectiles were shot. However, in each of the barrels, the number of one type of projectile prevailed. A survey of projectiles shot from individual barrels is given in Table I [9]-[11].

TABLE I
Survey of Types and Numbers of Projectiles Shot

Barrel	Type of projectile	Number	Frequency
B0507	3OF-19 (HE)	761	91.7 %
	3BK-14M (HEAT-T)	69	8.3 %
	Total	830	-
C0164	3BM-15 (APFSDS-T)	188	39.5 %
	3BK-14M (HEAT-T)	70	14.7 %
	3OF-19 (HE)	218	45.8 %
	Total	476	-
D0034	TAPNA (APFSDS-T)	171	77.0 %
	3BM-15 (APFSDS-T)	32	14.4 %
	3OF-19 (HE)	19	8.6 %
	Total	222	-

IV. Types of Tank T-72 Barrel Wear

On the basis of accomplished measurements it is possible to say that three basic types of tank T-72 barrel bore wear exist. The first type of barrel bore wear is caused by HE projectiles mainly, the second by 3BM-15 projectiles and the third by a new type of sub-calibre projectiles TAPNA.

The course of measured internal dimensions of barrel No B0507 worn by shooting 3OF-19 projectiles whose number significantly prevails is shown in Fig. 2 (nominal dimension of a new barrel bore is marked by dotted line).

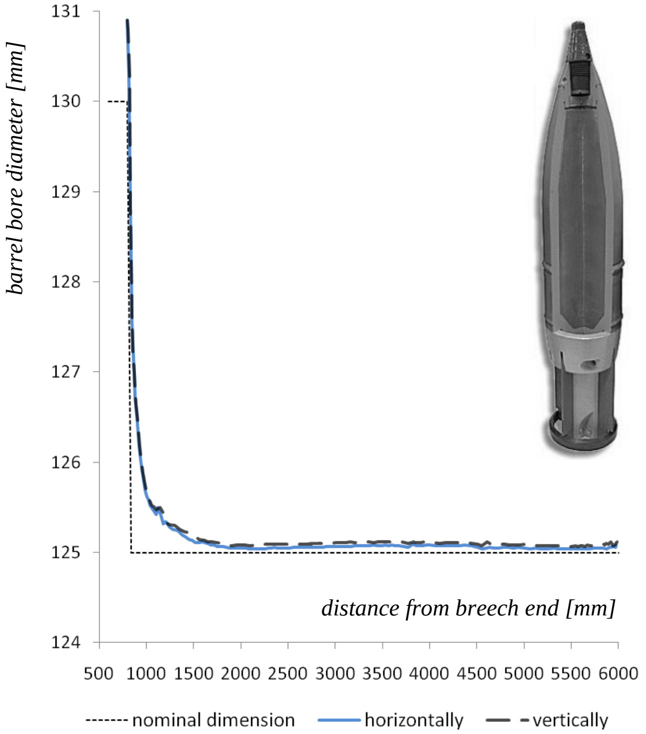

Fig. 2 Barrel No B0507 – wear caused mostly by 3OF-19 projectiles

The course of the measured dimensions of guiding part of B0507 barrel bore obviously shows common character of wear of the forcing cone beginning and the part before muzzle. The course of wear is symmetrical in horizontal and vertical plain. Thus, some statements about asymmetric (eccentric) wear of forcing cone and beginning of guiding part occurring at loading projectiles have not been proven true. In comparison with standard courses of wear, there is an atypical increased wear in the second third of the guiding part of the barrel [7].

Taking into account that 3BK-14M projectiles are similar in the design of driving parts to 3OF-19 projectiles; it can be assumed that the character of wear caused by them will be similar.

The wear caused by shooting 3BM-15 projectiles shown in Fig. 3 is of essentially different character. From the comparison of the wear courses shown in Figs. 2 and 3 it is obvious that a significant wear of forcing cone and of the beginning of the barrel bore guiding part is caused by 3BM-15 rounds. The influence of 3OF-19 rounds on this kind of wear is even at high frequency of their shootings negligible.

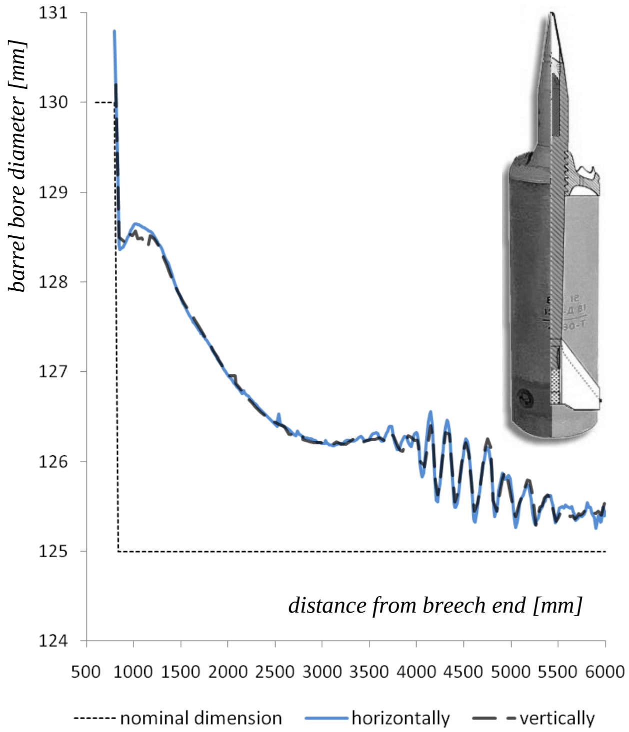

Fig. 3 Barrel No C0164 – wear caused by shooting mostly 3BM-15 and 3OF-19 projectiles

Fig. 4 shows the measured course of barrel bore dimensions where the wear is caused predominantly by TAPNA projectiles.

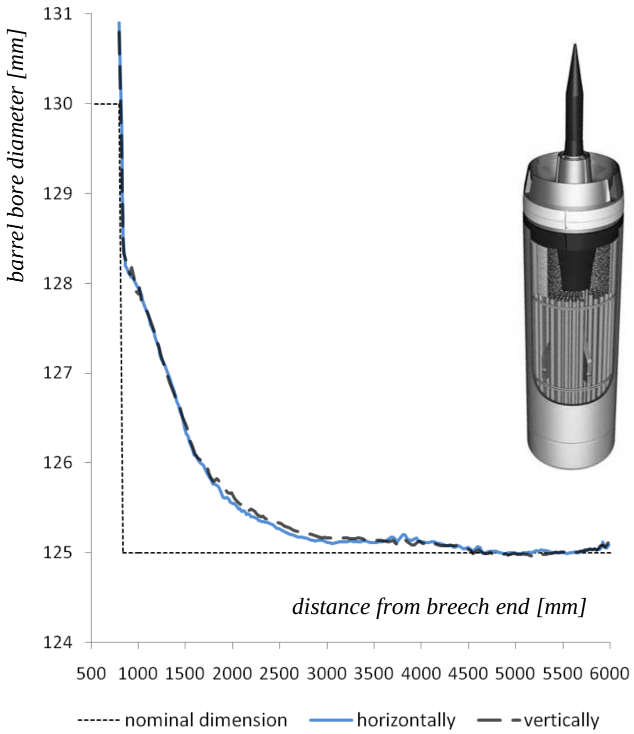

Fig. 4 Barrel No D0034 – wear caused predominantly by TAPNA projectile

Significantly bigger wear caused by 3BM-15 and TAPNA rounds in comparison with 3OF-19 and 3BK-14M projectiles results from sabot.

The position of seal ring in the front part of sabot of 3BM-15 round enables their partial spreading out (swinging) with respect to the penetrator by the force from gas pressure. This causes the increase in contact pressure between the barrel wall and sabot. It is demonstrated by gradual increase in wear approximately in the first and partially in the second third of barrel bore. Thus, also the surface of sabot behind seal ring gets into the contact with the surface of the bore.

This distinctive wear of the beginning of the guiding part of barrel bore has not been eliminated even by the construction of more appropriate sabots of TAPNA projectiles – see Fig. 4. Also in sabots of this round, seal ring is located in the front part. That is why the spreading out of sabots by the treatment of power from gas pressure might occur also in this case. The reduction of contact pressure occurs after certain travel of projectile when the spreading out is hindered by fins of sabots.

Reducing the bore diameter in the barrel part in front of muzzle is probably originated by abrasive wear of aluminum fins of sabots. Aluminized surface of barrel wall is also visually distinct.

The next part of the paper will deal with more detailed description of possible reasons of the wear of the beginning of barrel bore guiding part by shooting sub-caliber armor piercing projectiles of 3BM-9 and 3BM-15 types which is illustrated in Fig. 3. The causes and more detailed description of the course of wear of other parts of bore will be discussed after measuring wear in more barrels. It is necessary to verify the repeatability of this cyclical wear (see Fig. 4).

V. Barrel Wear Caused by Sub-Caliber Projectiles

Now we will mathematically formulate the conditions of possible occurrence of increased barrel wear at the beginning of its guiding part (see Fig. 3). Forces and load affecting the sabot (3BM-12 and 3BM-15 projectiles have 3 sabots) and seal ring are drawn in Fig. 5.

The force from the pressure of propellant gases causes the moment

$$M_{\mathrm{A}} = F_p \left(y_{VS} + e \right), \tag{1}$$

where F_{p} is force of pressure of propellant gases affecting perpendicular projection of surface S_{VS}, y_{VS} is distance of gravity centre of sabot from point A in the direction of axis y and e is eccentricity of point of action F_{p} towards gravity centre of sabot T_{VS}. The force F_{p} is given by the relation $F_{\mathrm{p}} = pS_{\mathrm{VS}}$ and $S_{\mathrm{VS}} = \frac{1}{3}\frac{\pi}{4}\left(d^2 - d_p^2\right)$, where p is momentary pressure of propellant gases, d is caliber and d_{p} is penetrator diameter.

Moment M_{A} tends to swing the sabot around point A. By this, at the place of contact of seal ring with internal surface of barrel bore, the following reaction occurs:

$$N_{\mathrm{VS}} = \frac{M_{\mathrm{A}}}{l_x}, \tag{2}$$

which increases contact pressure between barrel and seal ring. Against this swinging of sabots around point A, circumferential forces N_{TOt} take effect. They are a reaction of seal ring to its extension by the influence of force N_{VS}. Against this swinging affects also moment of friction force T.

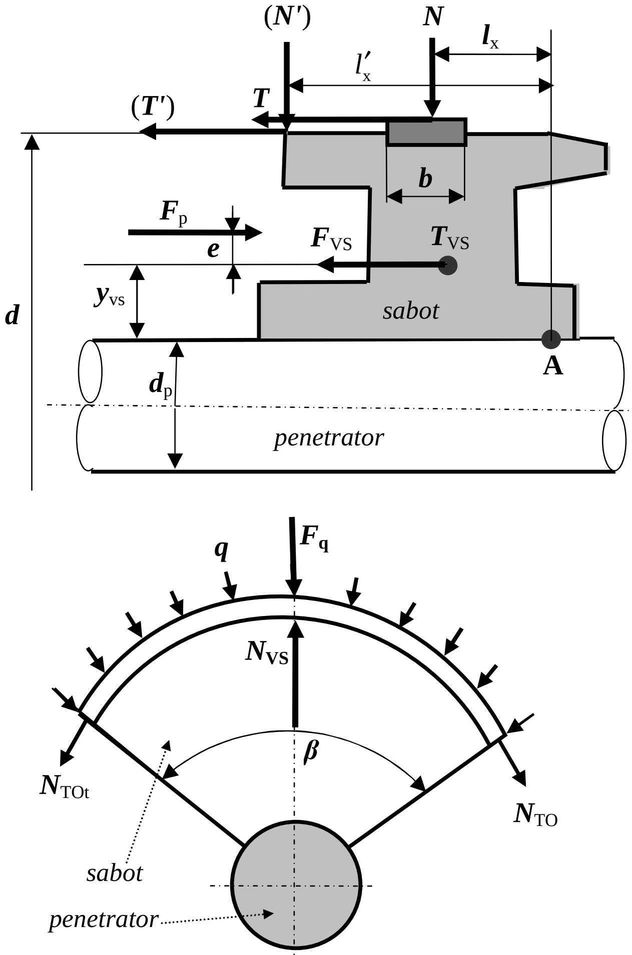

Fig. 5 Simplified diagram of forces affecting sabot of 3BM-9 and 3BM-15 projectiles

Force N_{VS} causes the highest pressure $p_{\mathrm{N,max}}$ in the direction of its activity. In the direction diverted by angle β, it will interact by the following pressure: $p_N = p_{N,\max} \cos\beta$.

The elementary circumferential surface of seal ring of the width b and size $\mathrm{d}S = \frac{bd}{2}\mathrm{d}\beta$ will be affected by corresponding part of reaction $\mathrm{d}N_{\mathrm{VS}}$ for which it is valid that:

$$\mathrm{d}N_{\mathrm{VS}} = p_{\mathrm{N}}\mathrm{d}S = p_{\mathrm{N,max}} \cos\beta \frac{bd}{2}\mathrm{d}\beta. \tag{3}$$

By the integration of the equation (3), we will get the relation between force N_{VS} and internal pressure reacting with the seal ring of the shape as follows:

$$N_{\mathrm{VS}} = \frac{bd}{2} p_{\mathrm{N,max}} \int_{-\frac{\pi}{3}}^{\frac{\pi}{3}} \cos\beta \mathrm{d}\beta =$$

$$= \frac{bd}{2} p_{\mathrm{N,max}} \left[\sin\beta\right]_{-\frac{\pi}{3}}^{+\frac{\pi}{3}} = 0.866 bd p_{\mathrm{N,max}},$$

from which the internal pressure is expressed as

$$p_{\mathrm{N,max}} = \frac{N_{\mathrm{VS}}}{0.866 bd} . \tag{4}$$

For force N_{VS} and pressure $p_{\mathrm{N,max}}$ it is still valid that $\mathrm{d}N_{\mathrm{VS}} = p_{\mathrm{N,max}} \frac{bd}{2} \mathrm{d}\beta$ and at the same time $\mathrm{d}N_{\mathrm{VS}} = N_{\mathrm{TOt}} \mathrm{d}\beta$, from which we will get

$$N_{\mathrm{TOt}} = p_{\mathrm{N,max}} \frac{bd}{2} . \tag{5}$$

After substituting $p_{\mathrm{N,max}}$ from the relation (4) we will get

$$N_{\mathrm{TOt}} = \frac{N_{\mathrm{VS}}}{0.866 bd} \frac{bd}{2} = \frac{N_{\mathrm{VS}}}{1.732} . \tag{6}$$

The increase in contact pressure between the barrel wall and seal ring will result from force

$$N = N_{\mathrm{VS}} - 2N_{\mathrm{TOt}} \cos\frac{\beta}{2} = N_{\mathrm{VS}} - N_{\mathrm{TOt}} = = N_{\mathrm{VS}} - \frac{N_{\mathrm{VS}}}{1.732} = 0.423 N_{\mathrm{VS}} . \tag{7}$$

Using Fig. 5, we can now express the condition of balance of moments of forces affecting point A as follows

$$N l_{\mathrm{x}} + F_{\mathrm{VS}} y_{\mathrm{VS}} + T\left(\frac{d}{2} - \frac{d_p}{2}\right) - M_{\mathrm{A}} = 0 , \tag{8}$$

where l_{x} is distance of point of action N from point A in the direction of axis x, F_{VS} is inertial force affecting sabot and given by the relation: $F_{\mathrm{VS}} = m_{\mathrm{VS}} \ddot{x}$, m_{VS} is weight of one sabot, $\ddot{x}$ is acceleration of translation motion of sabot (identical with projectile acceleration).

Acceleration $\ddot{x}$ can be expressed from motion equation of projectile by the following relation $\ddot{x} = \frac{\pi d^2}{4 m_{\mathrm{q}}} p$, where m_{q} is weight of the whole projectile ($m_{\mathrm{q}} = m_{\mathrm{p}} + 3 m_{\mathrm{VS}}$) and m_{p} is weight of penetrator.

After substitution to relation (8) and arangements, we will get the relation for determination of force N_{VS} increasing contact pressure between barrel wall and seal ring as follows:

$$N_{\mathrm{VS}} = \frac{\frac{\pi d^2}{4} p \left[\frac{1}{3}\left(y_{\mathrm{VS}} + e\right)\left(1 - \frac{d_p^2}{d^2}\right) - \frac{m_{\mathrm{VS}}}{m_{\mathrm{q}}} y_{\mathrm{VS}}\right]}{0.423 l_x + 0.5 f_{\mathrm{TO}} \left(d - d_{\mathrm{p}}\right)} , \tag{9}$$

where f_{TO} is friction coefficient between seal ring and barrel wall.

The magnitude of reaction N_{VS} is, according to relation (9), proportional to the pressure of propellant gases; thus, the maximum is reached in the place of maximal pressure. In case of D-81 cannon and 3BM-15 projectile, the maximal pressure $p_{\mathrm{N,max}}$ is reached in the distance of 0.53 m from the beginning of forcing cone. The maximum measured wear of the beginning of barrel bore is according to Fig. 3 caused in the distance of approx. 0.25 m. This difference can be explained by the fact that we do not know the real course of gases' pressure (measured course of pressure at shooting by 3BM-15 projectile is not available), and that as a result of high surface pressure and its rapid increase, significant compression of seal ring occurs already at the beginning of projectile movement. By this, also the back edge of sabot gets into contact with the surface of barrel.

Initial reaction q achieves its maximum at the moment of full compression of seal ring by barrel wall, i.e. on the trajectory 0.40 m maximum. Providing that the material of seal ring behaves as ideally elastic and plastic material, $q_{\max}$ will equal yield value (in case of seal ring made of annealed copper, yield value is about 60 MPa). Thus, it is apparent that the rear part of the surface of sabots will get into contact with internal surface of barrel bore even before the place of maximal pressure $p_{\mathrm{N,max}}$. Significant wear is partly caused by friction resulting from friction force T' (see Fig. 5).

Let us assume that against force N_{VS}, force F_{q} interacts from the reaction q of seal ring, given by the relation

$$F_{\mathrm{q}} = q \frac{bd}{2} \int_{-\frac{\pi}{3}}^{+\frac{\pi}{3}} \mathrm{d}\beta = q \frac{\pi bd}{3} . \tag{10}$$

For the known force N_{VS}, we will now formulate the condition of moments balance

$$N' l'_{\mathrm{x}} + F_{\mathrm{q}} l_{\mathrm{x}} + \left(T_{\mathrm{q}} + T'\right)\left(\frac{d}{2} - \frac{d_p}{2}\right) - N_{\mathrm{VS}} l_{\mathrm{x}} = 0 ,$$

from which after substitution and operations we will get

$$N' = \frac{N_{\mathrm{VS}} l_{\mathrm{x}} - F_{\mathrm{q}} \left[l_{\mathrm{x}} + 0.5 f_{\mathrm{TO}} \left(d - d_{\mathrm{p}}\right)\right]}{l'_x + 0.5 f \left(d - d_{\mathrm{p}}\right)} ,$$

where l'_{x} is distance of point of action N' from point A in the direction of axis x

This force results in contact pressure at the edge of sabot

$$p'_{\mathrm{N,max}} = \frac{N'}{0.866 bd} . \tag{11}$$

Force N', or better to say pressure $p'_{\mathrm{N,max}}$, thus will cause high contact load of internal barrel surface which is just the reason of big wear of this part of bore.

As a conclusion and for better judging the effect of sabots swinging on the wear of barrel bore we will depict pressure caused by force N_{VS} using the relations (4) and (11). The both dependence of pressure $p_{\mathrm{N,max}}$ between the barrel wall and seal ring and also pressure $p'_{\mathrm{N,max}}$ between the barrel wall and edge of the sabot on the travel of projectile, or let us say travel of seal ring, are shown in Fig. 6.

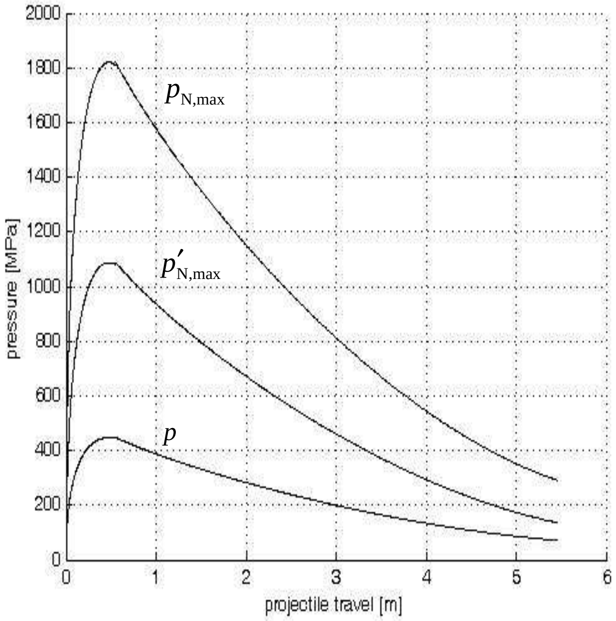

Fig. 6 Course of pressure of gases *p*, pressures $p_{\mathrm{N,max}}$ and $p'_{\mathrm{N,max}}$ in dependence on travel of seal ring in barrel

VI. Conclusion

The contribution shows the suitability of the use of BG-20 MKII equipment for the measurement of wear of smooth barrels bore. Measured courses of wear, or let's say the changes in the diameter of barrels caused by shooting of various types of projectiles and then also demonstrate the suitability of used constructions of projectile sabots.

From the point of view of bore wear it seems obvious that sabots of 3BM-9, 3BM-15 and TAPNA projectiles are inappropriately designed.

For comprehensive description of causes of wear resulted from 3BM-9 a 3BM-15 projectiles, it is necessary to conduct measurements on more barrels and consequently to analyze the causes of occurrence of cyclical wear in the last third of barrel bore. On the basis of this analysis it is recommended to determine the dependence of amplitude and length of wear on construction characteristics of sabots and barrel.

A new sub-calibre projectile of APFSDS type with a longer driving part of sabots and seal ring located on rear driving band has been introduced in the Czech Armed Forces recently. In this construction of projectile it is possible to assume significantly lower wear in both driving cone and beginning of barrel sabot. The assessment of wear caused by shooting these projectiles will be dealt with in the future.

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