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Technical Diagnostics of Tank Cannon Smooth Barrel Bore and Ramming Device

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ABSTRACT

The technical diagnostics of 125 mm tank cannon 2A46 smooth barrel and ramming devices are discussed respectively. Focuses on barrel diagnostics and suggests new procedures based on reconstructed BG20 Gun Barrel Bore Gauge System, measuring internal diameter of the barrel bore. The new system measures throughout the whole barrel bore the inner diameter not only at the beginning of barrel bore as it was usually measured before. Different nature of barrel wear was revealed between barrels firing sub-calibre and high explosive projectiles. A method for ramming device diagnostics is presented. An accurate method was proposed, determining projectile extraction force from barrel, as one of the main ramming device parameters for weapons that are used in all areas of armed forces. Results are based on experimental methods assessing the extraction forces from barrel after projectile loading. These tests were performed as a series of tests with consequent technical diagnostics according to the new Czech Defence Standards (derived from NATO standards). The results are presented as the new methodologies for diagnostics of 125 mm barrel 2A46 and ramming devices of tank T-72 for use by technical logistic units in the Czech Republic Armed Forces.

Keywords: Barrel bore wear, diagnostics, tank cannon, ramming device, extraction force, force gauge, and displacement gauge

1. INTRODUCTION

Barrel bore wear varies along the barrel. From the point of change in ballistic parameters, the most important parts of the barrel bore are the forcing cone and the space behind it; that is why the inspection of the barrel bore diameter focuses on these areas in all methods of checking barrel bore wear. The easiest way to observe these changes is to measure the length of the forcing cone, which is, however, not usually checked in smooth tank barrels. The increase of barrel bore wear during the barrel's life time is not linear since it is affected by various different initial conditions in the barrel. In the Armed Forces of the Czech Republic, and also in other countries, barrel bore wear of the tank cannon 2A46 is measured by mechanical device PKI-26[1]; see Fig. 1. The cannon manufactured under license in Czechoslovakia had the designation D-81. According to the Directive[2] this device is designed to measure the real diameter of the barrel bore within the distance of 850 mm from the breech end of the tube. The recorded value must be lower than the allowed diameter of 128.3 mm. Moreover, it is also defined that the diameter in other parts of the barrel bore must be lower than the allowed diameter of 128.0 mm. Knowing the principles of tank barrels wear when using sub-calibre projectiles, the data obtained by PKI-26 are inadequate. The other drawback of the PKI-26 equipment is that it is not possible to find the wear along the whole barrel bore. It is the main reason why the new procedures and the new equipment of barrel diagnostics were proposed.

The barrel bore wear significantly influences the projectile seating after its ramming. Mainly it influences driving band engraving which prevents the risk of projectile fall-back before the charge loading, and breech closing. Determination of barrel bore dimensional changes and reliability of projectile inserting will be further discussed using the new methods of ordnance technical diagnostics. Third part of this paper deals with original application of the Czech Defence Standard 109002 for the 125 mm tank cannon 2A46 when the new measurement device was used for determination of forces necessary to extract the engraved projectile into the forcing cone from the barrel after their ramming.

2. TECHNICAL DIAGNOSTICS OF 125 MM TANK CANNON SMOOTH BARREL

The barrel bore technical diagnostics in the course of a defence research project 'Gun[3] (Delo in Czech)', used a modified system BG20 to measure the inner diameter of barrel bore, see Figs. 2 and 3. Unlike in western calibres, the modified system used for 125 mm barrel consists of a new measurement

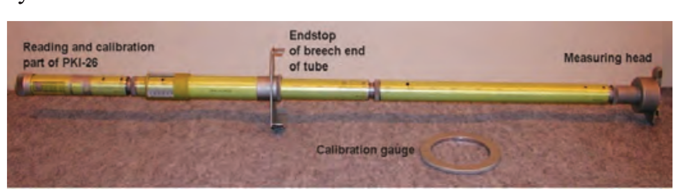

Figure 1. PKI-26 device ready for measurement.

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Figure 2. BG20 MkII with 2 m feeder tube. (Aeronautical & General Instruments Limited production)

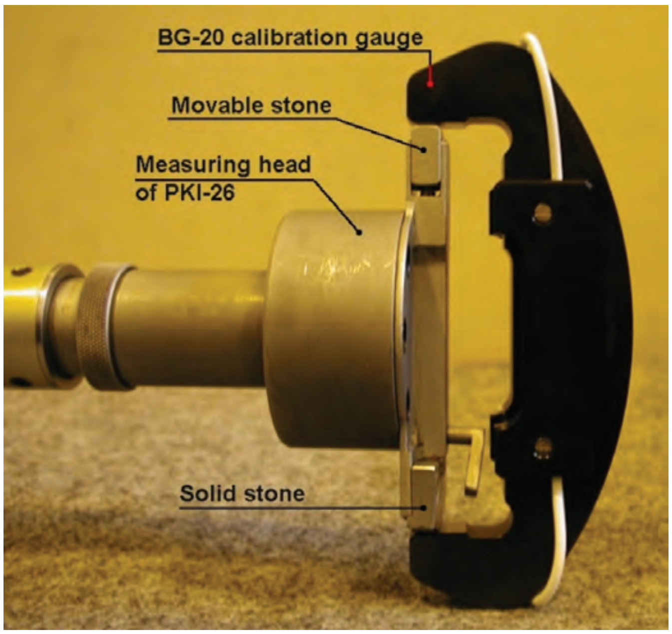

Figure 3. BG20 Calibration gauge as a standard of true value.

head, a new calibration gauge, longer 6 m feeder tube, and other parts relevant to 125 mm calibre.

To evaluate the appropriateness of measuring the dimensions of tank cannon barrel bores, using the PKI-26 or the BG20, indexes[4,5] of the gauge capability C_g and C_{gk} were introduced.

The index of the gauge capability C_g expresses precision of the gauge as follows:

$$C_g = \frac{0.2T}{6s_g}, \tag{1}$$

where T is a specified tolerance range, and s_g is a standard deviation of the measured values.

Index of the gauge capability C_{gk} expresses accuracy of the gauge as follows:

$$C_{gk} = \frac{0.1T - \left|\overline{x}_g - x_e\right|}{3s_g}, \tag{2}$$

where $\overline{x}_g$ is mean measured value, and x_e is standard true value (etalon).

Tolerance range was determined by value $T = 0.15$ mm, according to the barrel production drawing.

We may conclude[1] that the PKI-26 is not suitable for evaluating copper layer of the barrel bore since indexes of capability are significantly lower than 1.33.

On the other hand, the BG20 is suitable (fully useable) not only for the purpose of technical inspections in accordance with the directive[2], but also as a gauge for evaluating quality of barrel bores in full length of their guiding parts.

The 125 mm tank cannon 2A46 fires three types of projectiles, each influencing the barrel bore lifespan differently. The first types are high explosive anti-tank (HEAT) projectiles with cumulative effect and high explosive (HE) projectiles, both very similar in design of guiding part and their round bodies create one solid structural unit. Their muzzle velocity is about 850 m/s. The second types are projectiles with kinetic energy penetrator (armour-piercing fin-stabilised discarding sabot (APFSDS)), guided in a barrel by three-piece sabot and stabilisation fins. Their muzzle velocity is about 1800 m/s. The third types are new APFSDS TAPNA type projectiles, with kinetic energy penetrator and new larger and lighter discarding sabot, made of aluminium alloy. Their muzzle velocity is also approximately 1800 m/s.

The measurements depicted in Fig. 4 were carried out on three worn and discarded barrels of 2A46, using the new modified measuring apparatus BG20. The number of shots varied from 222 to 830. The first two barrels were discarded as their guiding part diameter of the barrel bore, exceeded the allowed maximum in the distance of 850 mm from the breech end of the tube. The third barrel had a short lifespan left and the diameter in that required distance was 127.4 mm. During the measurements, all the barrels were dismantled and placed in a heated hall. Figure 4 illustrates dimensions of all three measured barrel bores. The greatest wear was recorded in the barrel number 1, from which 188 projectiles APFSDS were fired.

The graph curve of the guiding part dimensions measured for barrel bore number 3 clearly shows common wear character of the forcing cone front part and the part before muzzle. The wear is symmetrical in both horizontal and vertical planes. In comparison with standard trends of wear, there is an atypical increase of wear in the second third of the barrel guiding part. The wear caused by shooting APFSDS projectiles as shown in Fig. 4, curve 1, is of significantly different character. By comparing both wear graphs, it became clear that significant

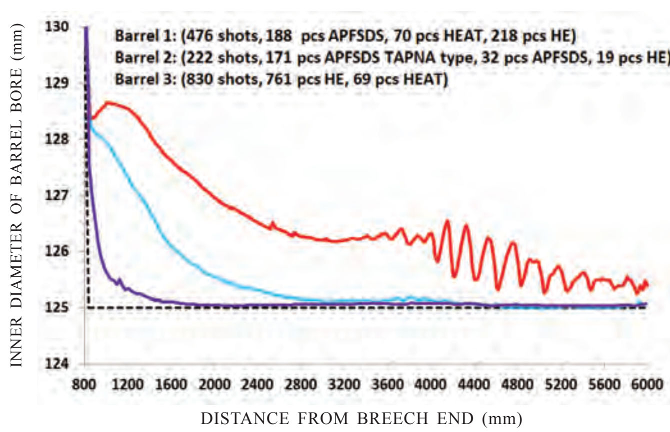

Figure 4. Diameter of guiding parts of worn barrel bores 2A46.

wear of the forcing cone and wear of the front end of the barrel bore guiding part was caused by higher velocity of APFSDS projectiles and the steel sabot vibration. The effect of HE projectiles on this kind of wear was, even at high rapidity of fire, negligible. Curve 2 in Fig. 4 shows barrel bore dimensions worn predominantly by new APFSDS TAPNA projectiles with aluminium guide elements. In his case the vibration almost disappeared. Significantly bigger wear was caused by steel APFSDS and aluminium APFSDS TAPNA projectiles, not only by high projectile velocity, but also by sabot material and sabot vibrations. The distinctive wear near bottom of the barrel bore guiding part was not eliminated even by construction of more appropriate sabots on new APFSDS TAPNA projectiles. Also, in sabots of this round, seal ring was placed in its front part. That could be the reason why the sabots could have been spread by gas pressure. Reduction of contact pressure occurred after certain travel of projectile when the spreading was hindered by sabot fins. Reduction of the bore diameter in the barrel in front of the muzzle was probably caused by abrasive wear of aluminium sabot fins.

Article[5] mathematically formulates conditions of possible increased barrel wear occurrence at the beginning of its guiding part, caused by sub-calibre projectiles. The contact pressure between the barrel wall and the sabot seal ring could overcome the maximum gas pressure in the barrel p_G . The gas pressure p_G together with pressure between the barrel wall and seal ring p_{NWSR} and pressure between the barrel wall and edge of the sabot p_{NWES} all depending on the projectile travel of the projectile (or let us say seal ring travel), are shown in Fig. 5.

Based on a barrel bore wear analysis, it is recommended to measure the barrel bore diameters in the following new positions, see Fig. 6.

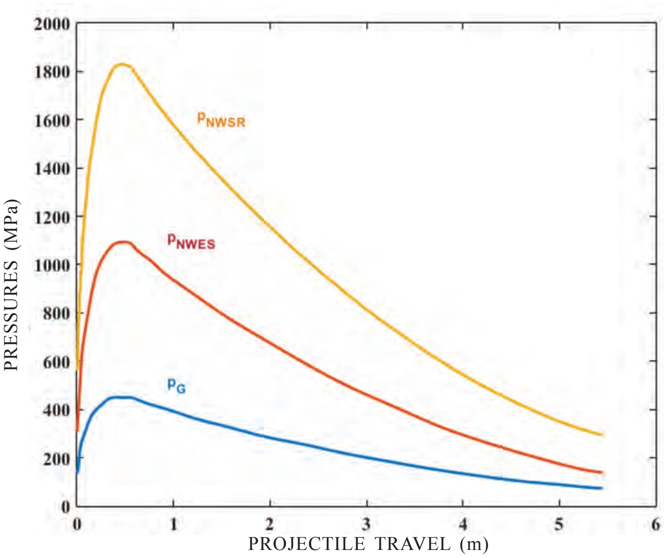

Figure 5. Gas pressure p_G and contact pressures p_{NWES}, p_{NWSR} depending on projectile path inside of barrel.

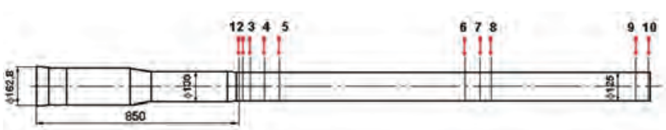

Figure 6. New recommended measurement positions for the 125 mm smooth barrel bore.

These measurement points were included in the new methodology for technical diagnostics of the 125 mm tank cannon barrel bore. The explanation and substantiation of this suggestion is shown in Table 1.

3. TECHNICAL DIAGNOSTICS OF TANK CANNON 2A46 RAMMING DEVICES

It is known that combat efficiency of artillery, especially self-propelled howitzers and tanks, depends on many tactical and technical factors. One of the most important technical parameters in practice is the rapidity of firing and the safety of projectile ramming during unstable motion of fighting vehicles on the battlefield. A very important factor is the safety of projectile ramming while a fighting vehicle in the battlefield is moving fast and over bad terrain, or bad road conditions, when a heavy projectile must not fall down from the cartridge chamber[6]. Therefore, both the rapidity and safety of ramming depends on the quality of loading device that is a very important part of the ramming device. Firstly, the ramming device secures the projectile in the barrel while the projectile is engraved into the barrel forcing cone, thus preventing the risk of projectile fall-back. Secondly, the ramming process creates a deformation field between the driving band and the forcing cone to seal the air-gap between the powder chamber and the guidance section of the barrel, ensuring the powder gas does not leak through this air-gap when firing. Thirdly, an accurate position of the projectile in the chamber after ramming gives a steady movement to the projectile in the barrel and decreases vibration of the projectile. This, together with all the above mentioned factors, increases firing accuracy. Barrels wear and barrel thermal deformation influence the ramming process intensively[7-9], as it is portrayed in Fig. 7.

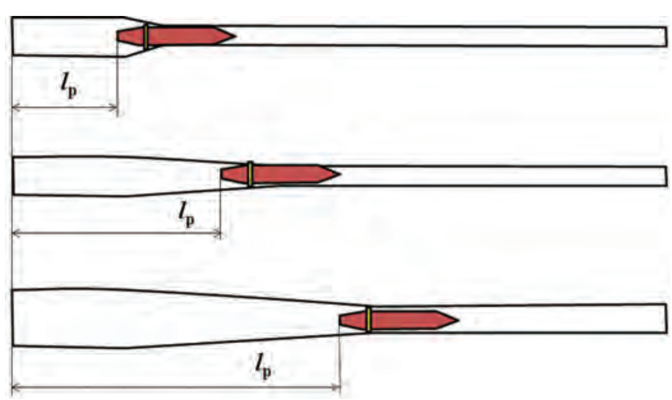

Figure 7. Projectile rammed position in new barrel (above), worn barrel (middle), worn and heated barrel (below).

The changes of barrel bore inner diameter, caused by radial deformation, are important input data for the ramming problem, especially the diameter change of the forcing cone, and the diameter change of the beginning of the guiding part. These changes influence the interaction process between the projectile driving band and the forcing cone during ramming. The standard[6] assumes that a rifled bore is used. A different problem occurs when barrel is smooth as it is in modern tank cannons. One example is illustrated in Fig. 8, where the chamber length of 800 mm is followed by a short forcing cone

Table 1. Recommended places for diameter measurements

Measuring position	Distance from the barrel bottom (mm)	Comment
1	850	Basic measurement position, 10 mm behind forcing cone, identical position as stated in Directive (using device PKI-26). Must not exceed diameter of 128.3 mm.
2	1040	In this position, diameter can increase if sub-calibre ammunition (APFSDS-T) if ferrous sabots were used – but must not exceed diameter of 128.0 mm. State of emergency – ramming projectile falling out.
3	1200	The end of maximum wear area for APFSDS-T. For other projectiles the wear decreases.
4	1500	The end of maximum wear area for HE and HEAT-T projectiles.
5	1800	Beginning of minimum wear area for standard projectiles.
6	3720	Beginning of sabot vibration area.
7	4140	Maximum wear amplitude of vibration wear. Only for APFSDS-T with steel sabots.
8	4320	Second maximum wear amplitude of vibration wear. Only for APFSDS-T with ferrous sabots.
9	5875	One calibre from muzzle, wear increase
10	5980	Muzzle. Projectile clearance can be determined.
Except position 1, for the whole bore		Must not exceed diameter of 128.0 mm.

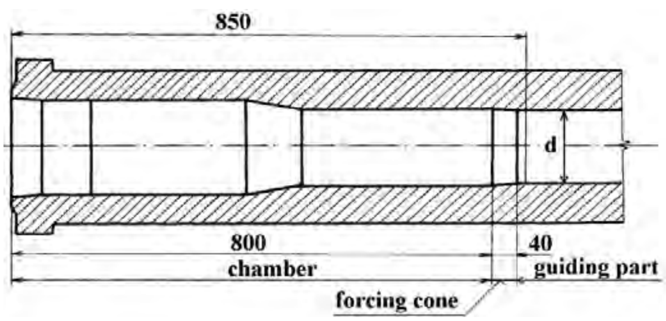

Figure 8. Parts of smooth barrel bore.

having the length of the new barrel only 40 mm. Then, the guiding part continues with a diameter that corresponds to the weapon calibre d . During barrel life, after series of firings, the forcing cone is shifted more and more into the guiding part of the barrel and the projectile is caught deeply after its ramming. Then the distance l_p , indicating the projectile stroke in a barrel when it is rammed, is lengthening, see Fig. 7.

Measurements of the inner barrel bore diameter of 125 mm worn barrels are based on the following assumptions:

- the inner diameter of the new cannon barrel bore is $125^{+0.15}$ mm,
- the limited diameter of barrel behind the forcing cone (850 mm from bottom) is 128.3 mm,
- the projectile diameter tolerance for manufacturing is $129^{-0.4}$ mm.

Then, the projectile diameter should be at least 128.6 mm. Therefore, when the projectile is rammed into a worn barrel– the new projectile does not stop as in the new barrel, but stops deeper in the barrel. According to Fig. 4 it is known that APFSDS projectiles cause different character of wear compared to HEAT and HE projectiles.

Usually, the barrel wear after firing APFSDS projectiles is more than eight times greater than barrel wear firing HEAT and HE projectiles. The prolongation of the ramming displacement leads to a rise in the volume of the barrel chamber causing a change in the development of barrel gas pressure. The place of the maximum value of the gas pressure in the barrel shifts to the place where the barrel thickness is smaller. This phenomenon could cause the risk of barrel chamber elongation. A permanent elongation can occur when the barrel wear is greater than the value specified in the technical documentation of the Czech Defence Standard for requirements of the loading process[6]. Then barrel explosion can occur. This problem is important for APFSDS projectiles whose velocities go beyond 1500 m/s. The increase in resistance forces, caused by the driving band engraving, happens in the region where the worn barrel diameter is smaller than the driving band diameter. In such cases the projectile is rammed deeper than in an unworn barrel and projectile velocity at the beginning of the engraving is lower as a consequence of the projectile movement by inertia. In a new barrel the rammer is designed to stop its movement at the beginning of the projectile driving band, in the forcing cone. If the ramming stroke is greater than it should be, due to the barrel wear, the projectile will be moved by inertia and it has to obtain sufficient velocity to engrave into the forcing cone. For this reason the rammer velocity[9] was increased up to 3 m/s.

According to recommendation[6,9] the main two ramming characteristics are as follows: the ramming velocity at the end of the ramming process, when the projectile engraves into the forcing cone; and the ramming force that secures the projectile in the barrel before firing. The ramming velocity for howitzers and tank cannon was discussed[7-9], however, determination of any forces during ramming and the projectile engraving is difficult as the nonlinear plastic-elastic feature makes the determination of many factors hard. Standard[6] deals with determination of a force needed to hold the projectile in the barrel. Nevertheless, this standard defines the opposite force (of the same value), known as the retention force, when the tested projectile is extracted from the barrel using a special arrangement. First calculated force results were published using FEM models[9]. Similarly, but using of experimental simulations the engraving processes from wear point of view on rifled barrels are published by WU[10,11]. The input projectile velocity equalled to the rammer velocity at its end position, where the ramming device stopped but the projectile moved continuously (by inertia) in the direction of the barrel axis with an initial velocity of 2.9 m/s. Measurements proved that the projectile would also be held in a worn barrel at any elevation angle while loading on the move, where significant inertia forces strongly influenced the loading system.

In a new barrel, the projectile has shorter stroke during ramming compared to a worn barrel and similarly, the engraving time is shorter as well.

Validity of the FEM models were performed indirectly using a unique measuring device designed at Weapons and Ammunition Department of Brno University of Defence during research work on the ‘Gun (Delo)’ Project[3].

In course of research of the ‘Gun (Delo)’ Project, two measuring instruments FV-1 and FV-2 were designed enabling to set the course of the force holding projectiles in the barrel after their ramming. Their mechanical designs were similar, but they used different force gauges and different software for analysis. The first hand driving arrangement FV-1 was equipped with 125 kN HBM (Hottinger Baldwin Messtechnik-www.hbm.de) force transducer, and it used older and simple software PME Assistant.

The second new semi-automatic instrument FV-2, shown in Fig. 9, measured the projectile extraction force from the 125 mm tank cannon smooth barrel 2A46, and 152 mm howitzer rifled barrel, as FV-1[8,9]. Experiences with the previous model have led to a reduction in weight and force sensor up to 50 kN was used. As BG20 and PKI-26, both the FV-1 and the FV-2 were tested for their capabilities. Let us define the ramming process capability as the ability to reach a continual fail-proof engraving of projectiles into the forcing cone. An adoption of this new term enabled to create an unambiguous criterion for assessment of the projectile ramming process and thus the evaluation of the complete loading cycle.

The assessment of the test is as follows:

Assuming that the fall-back occurrence probability takes place if the extraction force F_E is less than 5 times the force of gravity of the projectile ($5G_P$):

$$F_E < 5G_P \,. \tag{3}$$

Then, the $5G_P$ retention force provides sufficient safety to preclude potential dislodgement of the projectile. This minimum force should provide sufficient safety margin to preclude potential dislodgement of the projectile as a result of breech operation or normal laying and operating drills when the ordnance was loaded or laid. This criterion is in accordance with the standard[6].

Figure 9. FV-2 semi-automatic measuring device for determination of extraction forces.

The index of ramming process capability was defined by the formula[9]:

$$C_{RD} = \frac{\overline{F}_E - 5G_P}{3s_{F_E}}, \tag{4}$$

where s_{F_E} is standard deviation.

According to Eqn (3), it is possible to define three examples of the projectile ramming process capability. If $C_{RD} > 1$ then the ramming process is fully capable. If $C_{RD} = 1$, the process is conditionally capable, and if $C_{RD} < 1$, the process is incapable.

The explanation of the C_{RD} conditions is following. The theoretical probability of the projectile fall-back is 0.0013 for $C_{RD} = 1$. That means that one out of 1000 rammed projectiles can fall-back. This level of ramming capability is, from a security risk point of view, very poor (tested on 103/104 rammed projectiles).

An acceptable security risk during a gun service life is considered for fall-back probability only one out of one million rammed projectiles. This probability level matches the capability index of $C_{RD} \geq 1.583 \cong 1.6$.

Ramming device is considered fully capable when capability index (determined from 25/30 projectile ramming cases) is greater than 1.583 (practically greater than 1.6). This value of capability index ensures stable and safe ramming projectile process.

During tests, the projectiles were pulled out of the barrel using DC electric motor and a gearbox. Then, the extraction force was independent on the technical crew operation. Special measuring arrangement enabled to record both the extraction force and the projectile displacement (and the time as well). The evaluation Catman®Easy software that was used enables data transformation into ASCII format for further analyses by any software, MATLAB® for example.

The DC motor was equipped with a control unit, and a stop button for emergencies.

Comparison of the experimental results (red colour) and the calculated results (blue colour) is depicted in Fig. 10. The graph shows extraction forces dependency on projectile strokes.

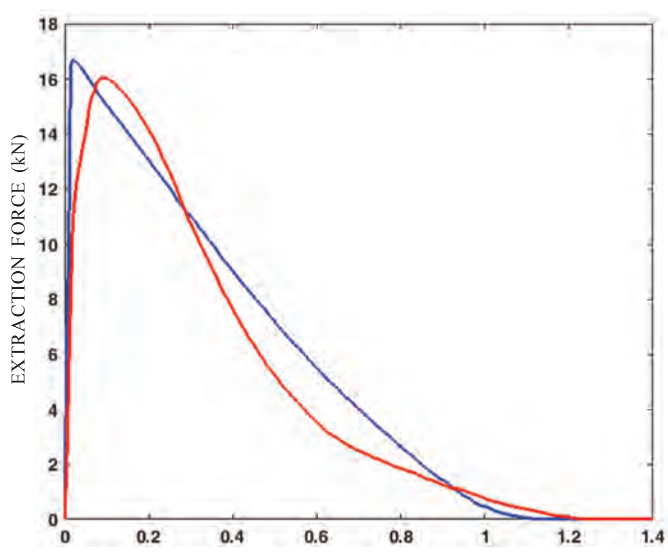

Figure 10. Extraction force from 125 mm barrel.

4. CONCLUSION

During the defence research Project ‘Gun (Delo)’, suitability analysis of PKI-26 for measuring barrel bore 2A46 dimensions were carried out. Its gauge is suitable only for measuring barrel bore wear within the distance of 850 mm from the tube breech end. With respect to construction of this gauge, we were not able to diagnose the important part of the barrel bore behind the forcing cone. Based on the experiments and suitability analysis of the purchased reconstructed gauge BG20, we may conclude that BG20 MKII Gun Barrel Bore Gauge (Aeronautical & General Instruments Limited production) is fully suitable not only for the purpose of technical inspections in accordance with the Directive Del-30-72, but also as a gauge for evaluating barrel production quality within the full length of the barrel bore guiding part. It can be also used for measuring copper layer in the barrel bore. Above mentioned procedure improved the quality of technical diagnostics of the cannon barrel 2A46 and allowed to prognosticate the barrel’s lifetime. This prevents undesired cannon 2A46 breakdown.

The presented methods used for technical experiments with 125 mm tank cannon 2A46 showed practicality of such experimental work in the ramming device domain and they can be included into either the existing systems or future systems of armed forces around the world.

The procedures published in this paper are applicable to gun technical diagnostics and will be taken into consideration when preparing new Czech Defence Standards dealing with loading devices.

Very important contribution of the research project ‘Gun (Delo)’ to the educational process is utilisation of the project results in improving quality of courses at University of Defence, mainly distance studies. Our experience have shown that all theoretical lectures, practical laboratory exercises, special trainings, seminars and published articles essays have to be linked and have to comprise theoretical and practical parts with applications ‘in-service’ during firing, on the move and during storage.

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