Increasing Firing Accuracy of 2A46 Tank Cannon Built-in T-72 MBT

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Abstract

The paper is devoted to possibilities of increasing 2A46 tank cannon firing accuracy built-in T-72 MBT, i.e. decreasing its technical dispersion. The paper deals with the modifications performed which were designed to retain its fighting capacity on the potential battlefield of today and enhance its operational time. In the process of redesigning the tank cannon, we applied the muzzle oscillation process theory. By carrying out several modernization steps, including seating and guidance of the cannon, we achieved sufficient increase of the firing accuracy at the target, mainly by using the first-shot-kill method. The upgraded cannon serial marking is 2A46 MS (prototype marking was YA1). In the paper, we present modernization steps of the cannon and apply the muzzle oscillation theory in order to decrease technical dispersion during firing at the defined target. Firing characteristics for the original and modernized tank cannon (TC) are listed, too. From the parameters we can see that redesigning the original cannon led to substantial decrease of effects of forces and moments on the barrel in its seating. In addition, instantaneous general muzzle oscillation in the moment when the shell leaves the barrel was decreased. As a result was, firing accuracy was achieved.

Key-Words: Tank Modernization, Main Battle Tank, Accuracy of Firing, Dispersion Pattern, Barrel Guidance, Turret Spherical Bearing, Recoil System, Modified Mounting, Moment of Inertia, First-Shot-Kill

1. Introduction

The Slovak Government and the Army of the Slovak Republic (ASR) decided to carry out the MBT T-72 upgrade to be able to operate under the current challenging battle conditions while meeting the identified rigorous tactical and technical requirements.

As a chief design engineer, I was tasked to take the lead of the project from the initial phase up to its successful completion. In the initial phase, I worked out a comprehensive plan of the MBT T-72 modernization, consequently proposed all main configurations and sections and I also made calculations for the specific construction patterns (drives, aggregates, mechanisms, bearings, etc.).

Following the acceptance of the technical documentation, including calculations, a team of specialists (mechanics, electronics, programming, etc.) was built and individual stages of the project were supervised by myself.

The T-72 M2 main battle tank (new marking for an upgraded original T-72 tank) was twice awarded a gold medal at international defense exhibitions two years in a row.

Even though many armed forces of different countries are currently equipped with T-72 MBTs, their comprehensive modernization was performed only in a few of them, e.g. in the Czech Republic, Croatia, Serbia, the Slovak Republic, etc.

Out of these comprehensive modernization programs performed by their own industry in the countries mentioned, the biggest and most complex modernization was performed in the Slovak Republic under my supervision.

The Czech Republic and its T-72 MBT modernization program was placed second relating to the extent and types of modernization. Upgraded combat armored tanks developed from original T-72 tanks are able of meeting the most challenging requirements and from this perspective they have not been outclassed.

2 Dynamics of Barrel Movement during the Firing Period

a) Angular acceleration, angular velocity and angular deviation in the time period $t \in \langle 0, t_U \rangle$ in elevation plain ρ_φ.

The dynamics of barrels movement in the elevation plain is shown in Fig. 1 based on which the equation of movement barrel inclination around the center of gravity of recoiling parts within the allowance between the barrel and its cradle can be written [1]:

$$J_\varphi \cdot \ddot{\varphi} = M_e + M_b + M_v + M_{tb} + M_{tv} + M_s . \qquad (1)$$

The formula for angular acceleration [1]:

$$\ddot{\varphi}(t) = \frac{1}{J \cdot \varphi}\left(M_e + M_b + M_v + M_{tb} + M_{tv} - M_s\right), \quad (2)$$

angular velocity:

$$\dot{\varphi}(t) = \int_0^t \ddot{\varphi}(t)dt , \qquad (3)$$

and angular deviation:

$$\varphi(t) = \int_0^t \dot{\varphi}(t)dt , \qquad (4)$$

where:

J_φ – moment of inertia of recoiling parts to the axis which crosses their center of gravity perpendicularly to elevation plain ρ_φ.

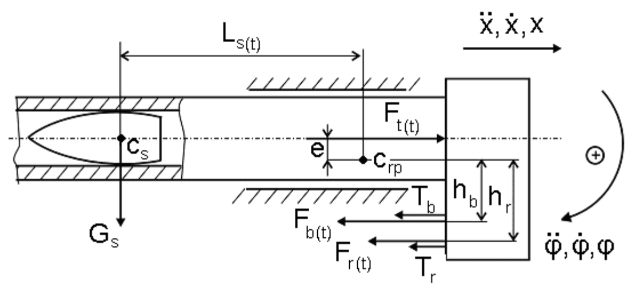

Fig. 1 Action moments acting on recoiling parts in elevation plain ρ_φ [2]

Where:

$\ddot{x}, \dot{x}, x$ - acceleration, velocity and displacement of the recoil,

$\ddot{\varphi}, \dot{\varphi}, \varphi$ - angular acceleration, velocity and deviation in elevation plain,

$F_{H(t)}$ – force from fire, ,
T – passive resistances (friction forces),
$F_{b(t)}$ – resistance of the recoil buffer,
$F_{v(t)}$ – resistance of recuperator,
G_s – force of shell,

e – the arm of force from fire,
hb – arm of recoil buffer resistance in elevation plain,
hv – arm of recuperator resistance in elevation plain,
$\check{T}_s$ – center of gravity of the shell,
$\check{T}_{zc}$ – center of gravity of recoiling parts.

M_e– moment of force from fire:
The values of moment M_e are listed in Table 3. The following holds true for moment of force from fire:

$$M_e = F_H(t) \cdot e, \quad (5)$$

where the force from fire is:

$$F_H(t) = S \cdot p(t), \quad (6)$$

where:
e – distance of center of gravity of the recoiling parts from the barrel axis,
S – basic cross-section of the barrel bore,
$p_{(t)}$ – the course of pressure in the barrel bore (p_s) resulting from internal ballistic calculations.

M_b– moment of recoil buffer resistance:
The values of moment M_b (see Fig. 2 and Fig. 3) are listed in Table 2. The following holds for the moment of recoil buffer resistance:

$$M_b = F_b \cdot h_b, \quad (7)$$

where the resistance of recoil buffer is :

$$F_b = S_b\,(x, \dot{x}), \quad (8)$$

where:
h_b – distance between the axle of recoil buffer and center of gravity of recoiling parts,
$x, x^{\cdot}$ - displacement and velocity of the recoil resulting from recoil differential equation.

M_v– moment of recuperator resistance:
The following holds for the moment of recuperator resistance:

$$M_v = F_v \cdot h_v, \quad (9)$$

where the resistance of recuperator is:

$$F_v = F_v(x), \quad (10)$$

where:
h_v – distance between the axis of recuperator and center of gravity of recoiling parts,
x – displacement of the recoil.

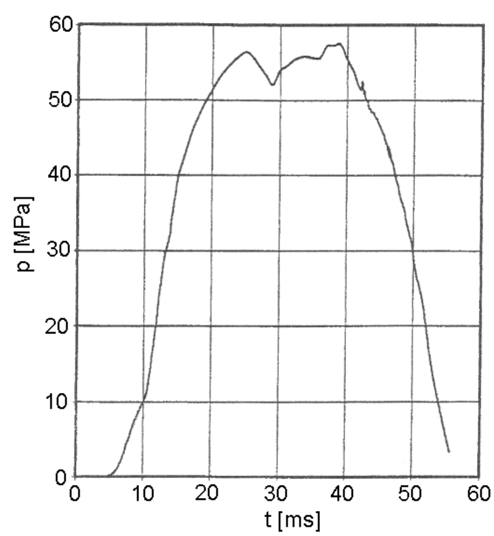

Fig. 2 The pressure in TC YA1 recoil buffer calculated for firing with HE-FRAG shell

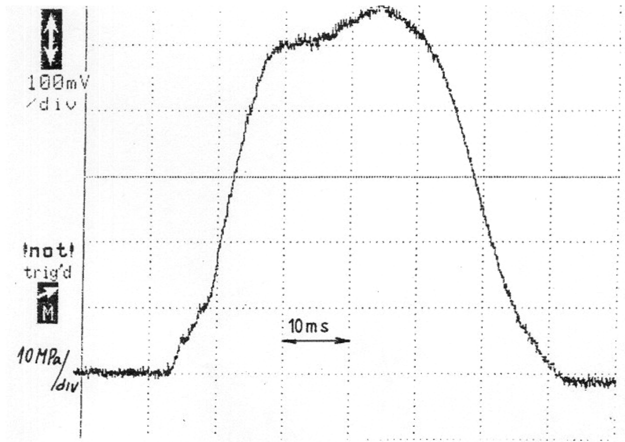

Fig. 3 The pressure record in TC YA1 recoil buffer for firing with HE-FRAG shell [5]

M_{tb}, M_{tv}– the moments of passive resistances of recoil buffer and recuperator:
The following holds for the moment of recoil buffer passive resistance:

$$M_{tb} = T_b \cdot h_b, \tag{11}$$

where the recoil buffer friction force is given by:

$$T_b = m_z \cdot g \cdot f_b, \tag{12}$$

The following holds for the moment of recuperator passive resistance:

$$M_{tv} = T_v \cdot h_v, \tag{13}$$

where the following holds for the recuperator friction force:

$$T_v = m_z \cdot g \cdot f_v, \tag{14}$$

where:
m_z – mass of recoiling parts,
g– gravitational acceleration,
f_b – friction coefficient in recoil buffer,
f_v – friction coefficient in recuperator.

Note:
The arms of momentse, h_b and h_v are positive (+) when the relevant moment deviates the muzzle upwards and negative (-) when the relevant moment deviates the muzzle downwards (see Fig. 1 and formula (1)).

M_s– moment of shells force:
The following formula holds for the moment of shell's force:

$$M_s = m_s \cdot g \cdot l_s, \tag{15}$$

where:
m_s – mass of the shell,
$l_s = l_o + l_{(t)}$, where $l_{(t)}$ – trajectory of shell in the barrel bore,
l_o – the initial distance of shell's center of gravity from recoiling parts' center of gravity. The l_o value is negative (-) when the initial position of shell's center of gravity is beyond the recoiling parts' center of gravity (see Fig. 1 and formula(1)).

Having carried out several experiments, we have obtained courses of angular acceleration $\ddot{\varphi}(t)$, angular velocity $\dot{\varphi}(t)$ and angular deviation $\varphi(t)$ and value of muzzle oscillation in elevation plain in the time period $t_U : \ddot{\varphi}_U = \ddot{\varphi}(t_U), \dot{\varphi}_U = \dot{\varphi}(t_U)$ and $\varphi_U = \varphi(t_U)$.

The values which were obtained by measurements during the experiments for modernized TC YA1 tank cannon are shown in Fig. 4, Fig. 5 and Fig. 6 -

$\ddot{\varphi}(t)$, $\dot{\varphi}(t)$, $\varphi(t)$ and listed in Table 1.

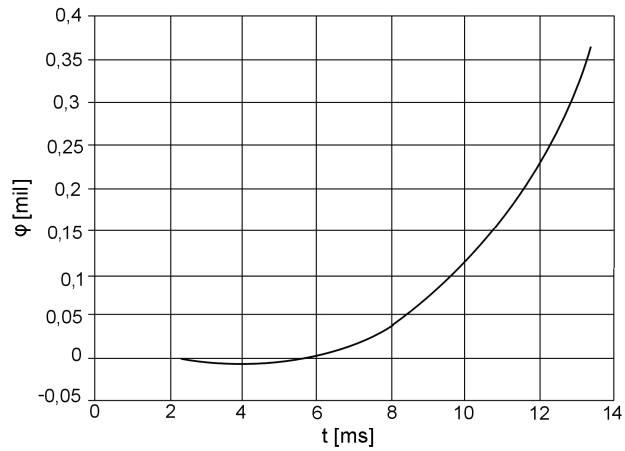

Fig. 4 TC YA1, the course of angular deviation in elevation plain for HE-FRAG shell [5]

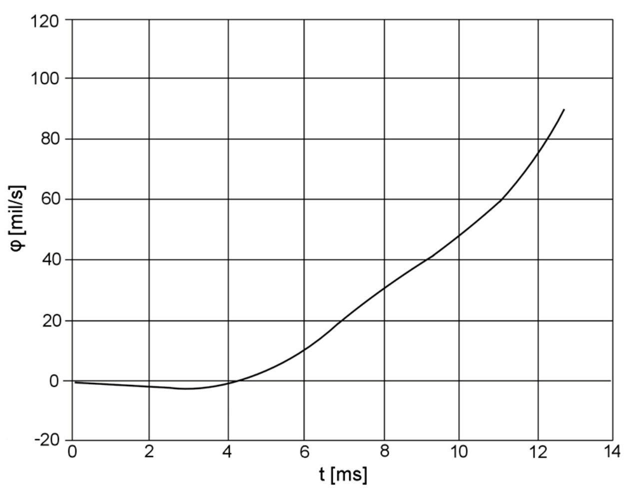

Fig. 5 TC YA1, the course of angular velocity in elevation plain for HE-FRAG shell [5]

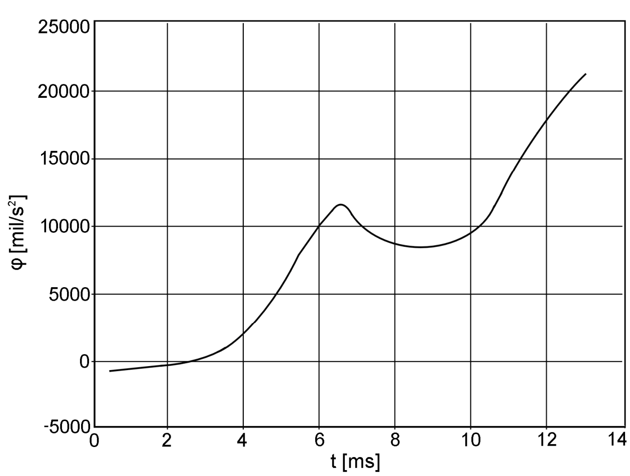

Fig. 6 TC YA1, the course of angular acceleration in elevation plain for HE-FRAG shell [5]

b) Angular acceleration, angular velocity and angular deviation in the time period $t \in \langle 0, t_U \rangle$ in deflection plain ρ_φ.

Dynamics of barrels movement in deflection plain is figured in Fig. 7, on the basis of which we can write the equation of barrel movement deviation to the side [1]:

$$J_{\sigma} \ddot{\sigma} = M_{e1} + M_{b1} - M_{v1} + M_{tb1} - M_{tv1} . \qquad (16)$$

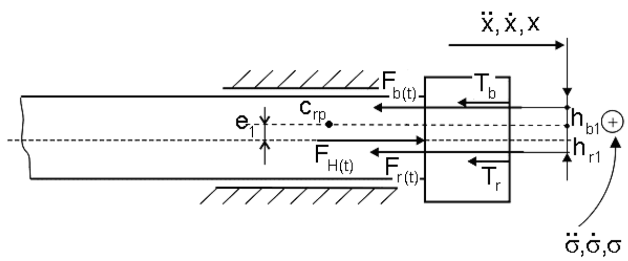

Fig. 7 Action moments acting on the recoiling parts in deflection plain ρ_σ [2]

Where:

$\ddot{x}, \dot{x}, x$ - acceleration, velocity and displacement of the recoil,

$\ddot{\sigma}, \dot{\sigma}, \sigma$ - angular acceleration, velocity and deviation in deflection plain,

$F_{H(t)}$ – force from fire,
$F_{b(t)}$ – resistance of the recoil buffer,
$F_{v(t)}$ – resistance of recuperator,
e_1 – arm of force from fire to Ť$_{zc}$ in deflection plain,
hb_1 – arm of the recoil buffer resistance in deflection plain,
hv_1 – arm of the recuperator resistance in deflection plain,
Ť$_{zc}$ – center of gravity of recoiling parts,
T_b – friction force of the recoil buffer,
T_v – friction force of recuperator.

The following formula holds for angular acceleration [1]:

$$\ddot{\sigma}(t) = \frac{1}{J \cdot \sigma}\left(M_{e1} + M_{b1} - M_{v1} + M_{tb1} - M_{tv1}\right), \qquad (17)$$

angular velocity:

$$\dot{\sigma}(t) = \int_0^t \ddot{\sigma}(t)\, dt , \qquad (18)$$

and angular deviation:

$$\sigma(t) = \int_0^t \dot{\sigma}(t)\, dt , \qquad (19)$$

where:

J_σ – moment of inertia of the recoiling parts to the axis which crosses their center of gravity perpendicularly to the deflection plain ρ_σ. The following holds for muzzle oscillation : $\ddot{\sigma}_U = \ddot{\sigma}(t_U)$, $\dot{\sigma}_U = \dot{\sigma}(t_U)$ and $\sigma_U = \sigma(t_U)$.

2 Weapon Construction in terms of the Theory of Muzzle Oscillation

Having analyzed differential equations (1) and (16), it follows that the following can minimize muzzle oscillation:

1. maximizing moment of inertia of the recoiling parts,
2. minimizing the resultant moment acting on the recoiling parts.

Concerning muzzle oscillation, the moment of inertia of recoil parts should be as high as possible. It means that the structure of recoil parts (i.e. barrel and breech ring) has to be most robust, while taking into consideration all the other limiting contexture allowances of the entire weapon system construction .
The size of resultant moment action is mainly influenced by the following three force moments:

I. Moment of force from fire

The following holds for moment of force from fire:

$$M_e = F_H \cdot e . \qquad (20)$$

The size of force from fire *F* can´t be changed as this value specifies the required weapon´s firepower. However, this moment can be influenced significantly by the size of its arm e (e_1) – distance of the center of gravity of recoiling parts from the barrel axis. The arm e (e_1) is getting smaller with the growing symmetry of the cannon´s recoiling parts with regard to both elevation and deflection plains. The ideal symmetric construction has the value of arm of force from fire e = 0 mm (e_1=0 mm) and moment M_e= 0 N.m (M_{e1} = 0 N.m) – see Fig. 8.

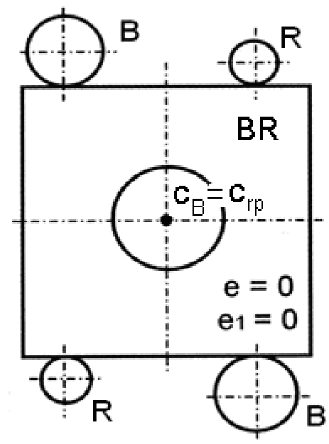

Fig. 8 The example of recoiling parts symmetric construction in elevation and deflection plains – the diagonal symmetric axis [3]

Where:
B – recoil Buffer,
R – recuperator,
Z – breech ring,
$\check{T}_H$ – barrel's center of gravity,
$\check{T}_{Z\check{C}}$ – center of gravity of recoiling parts,
M_e = 0 N.m, M_b = 0 N.m, M_v= 0 N.m,
M_{e1} = 0 N.m, M_{b1} = 0 N.m, M_{v1} = 0 N.m.
(see formulae (1) and (2)).

In terms of the resultant moment acting, it is necessary to orientate the arm of force *e* to the barrel axle. Thus, moment M_e acts against all other moments acting on recoiling parts in the time period $t \in \langle 0, t_U \rangle$.

II. Moment of recoil buffer resistance:

The following holds for the moment of recoil buffer resistance:

$$M_b = F_b \cdot h_b , \qquad (21)$$

The size of moment M_b (M_{b1}) can be reduced by reducing the brake resistance $F_b(t)$ in the time period $t \in \langle 0, t_U \rangle$,by an appropriate design of throttling cross-section dimension positioned in the recoil buffer and decreasing the arm h_b(h_{b1}) by approximating the recoil buffer axis towards the recoiling parts' center of gravity in both elevation and deflection plains (see Fig. 9 - $h_{b1} = 0 \Rightarrow M_{b1} = 0$).

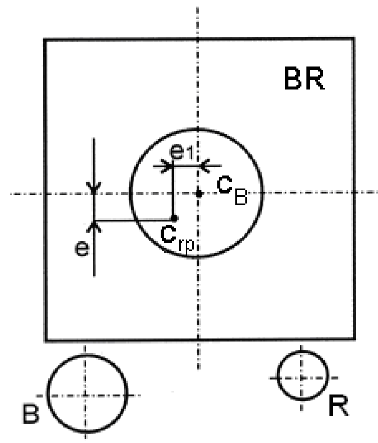

Fig. 9 Example of unsymmetrical construction of recoiling parts [3]

Where:
$M_e \neq 0$, $M_b \neq 0$, $M_v \neq 0$ [N.m],
$M_{e_1} \neq 0$, $M_{b_1} \neq 0$, $M_{v_1} \neq 0$ [N.m].

It is advisable to position the recoil buffer in the recoiling parts structure so that the moment of recoil buffer M_b acts against all other moments acting on recoiling parts. Thus, the resultant acting of moments is decreased (Fig. 10).

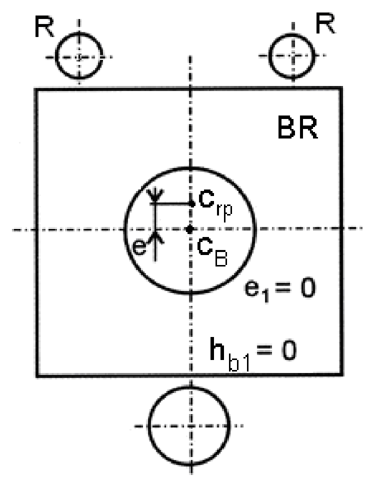

Fig. 10 Example of the symmetrical construction of recoiling parts [3]

Where:
$M_e \neq 0$, $M_b \neq 0$, $M_v \neq 0$ [N.m],
$M_{e1} = 0$ N.m, $M_{b1} = 0$ N.m, $M_{v1} = 0$ N.m,
$M_e + M_v$ againstM_b.

Within the diagonal symmetric construction of recuperator (Fig. 8), doubled recoil buffer (2 pieces) placed diagonally against each other in the same distance from the barrels axis can be used. Thus, the brake moments act in elevation plain and also deflection plain exactly against each other, i.e. $M_b = 0$ N.m.

III. Moment of recuperator resistance:

The following formula holds for the moment of recuperator resistance:

$$M_v = F_v \cdot h_v, \quad (22)$$

The force of recuperatorF_v cannot be changed due to its function of a counter-recoil as well as holding the barrel in its elevation angle. Moment M_v (M_{v1}) can be changed by decreasing the arm h_v (h_{v1}), and approximating the recuperator axis to the barrel axle in both plains.

The position of recuperator axle towards the barrel axis in the construction should be adjusted to the moment of recuperatorM_v (M_{v1}), thus decreasing the resultant acting on the recoiling parts (see Fig. 9).

Fig. 8 illustrates diagonal placement of two recuperators, which eliminates acting of moments M_v and M_{v1} in both elevation and deflection plains.

Fig. 10 shows symmetric recuperator construction action on the recoil buffer. Thus, the elimination of moment M_{v1} in deflection plain is achieved.

3 Muzzle Oscillation and Course of Resistance Against the Recoil

The following holds for the resistance against the recoil:

$$R(t) = F_b + F_v + T \,, \tag{23}$$

where
F_b – resistance of recoil buffer,
F_v – resistance of recuperator,
T – passive resistances (friction forces).

Based on the listed forces and in terms of decreasing muzzle oscillation, it is possible to reduce the course of recoil buffer resistance $F_b(t)$ in the time period $\langle 0, t_U \rangle$. Ideal situation would be if the recoil buffer resistance F_b were zero during the firing interval. This option, however, cannot be adopted due to the physical principle of the hydraulic recoil buffer, because the following holds true [3]:

$$F_b = F_b\left(x, \dot{x}\right), \tag{24}$$

where $x, \dot{x}$ is displacement and velocity of the recoil and it is true that $x \neq 0$ and $\dot{x} \neq 0$.

In addition to the recoil system design option, it is advisable to optimize (minimize) the course of force $F_b(t)$ during the firing interval in terms of the size of muzzle oscillation, while the main boundary condition is the size of the necessary throttling's cross-section for braking the recoil and counter-recoil in relation to the other construction parameters of the buffer recoil (see Fig. 11).

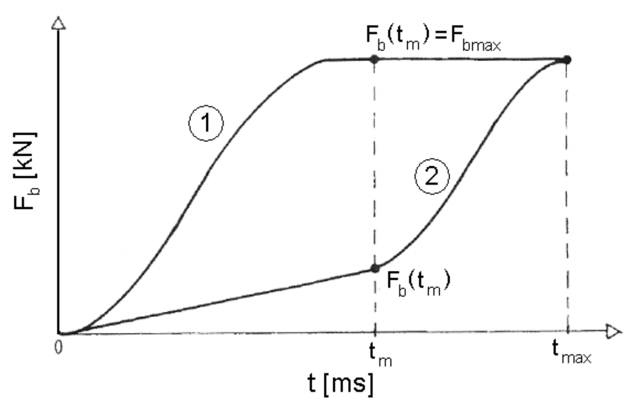

Fig. 11 The course of buffer recoil resistance of 2A46 original recoil system ① and YA1 reconstructed recoil system ② [2]

Where:
R_b – resistance of recoil buffer,
t_u – time at which the shell leaves the barrel,
R_{bm} – maximum resistance of the recoil buffer.

① - cosine batter of F_b to the maximum value in time period $\langle 0, t_U \rangle$,

② - minimized course of F_b in the time period $\langle 0, t_U \rangle$ considering the muzzle oscillation and cosine batter of F_b to the maximum value in the time period $\langle t_U, t_m \rangle$.

4 Muzzle Oscillation and Dynamic Firing Stability

The following formula holds for the barrels muzzle condition of the dynamic firing stability [4]:

$$Z + H \leq Y, \qquad (25)$$

where:

Y – half-height of the target.

Z – accession of the vertical deviation at the target area with the height target of $2Y$ at the distance L, which is given by the deviation of the entire weapon in the time when shell leaves the barrel and the following formula holds [4]:

$$Z = \varphi_{UZ} \cdot L + \dot{\varphi}_{UZ} \cdot l_Z \cdot \frac{L}{v_o}, \qquad (26)$$

where:

φ_{UZ} – angular deviation of the weapon,

L – distance of the target in direct firing,

$\dot{\varphi}_{UZ}$ – angular velocity of the weapon,

l_z – distance of the weapon's center of gravity from the muzzle,

v_o – initial velocity of the shell.

H – accession of the vertical deviation at the target area, which is given by the barrel movement towards its cradle within the guidance allowance between the barrel and its cradle [4]:

$$H = \varphi_{UH} \cdot L + \dot{\varphi}_{UH} \cdot l_H \frac{L}{v_o}, \qquad (27)$$

where:

φ_{UH} – angular deviation of the barrel,

L – distance of the target in direct firing,

$\dot{\varphi}_{UH}$ – angular velocity of the barrel in time t_U,

l_H – distance of the recoiling parts' center of gravity from the muzzle,

v_o – initial velocity of the shell.

φ_{UH} and $\dot{\varphi}_{UH}$ - result of the differential equation solution of the barrel oscillation (1).

Note:

Proportional relation between H and Z parameters depends on the quality of both recoiling parts structure and recoil system (H parameter) and design of the entire weapon system (Z parameter). For instance, for T-72 MBT, the Z parameter is lower when compared to H parameter, which is caused by the robustness of this tank (high value of the moment of inertia J) and its low firing height (low value of the arm H_r low value of resistance against the recoil R) and by such construction of recoiling parts (Fig. 10 and Fig. 12), in which all action moments acting on the recoiling parts are nonzero. In the course of firing tests with HE-FRAG shells, the following values were obtained:

φ_{UH} = 1,0 mil, $\dot{\varphi}_{UH}$ = 244 mil/s – from equation (1),

φ_{UZ} = 0,05 mil, $\dot{\varphi}_{UZ}$ = 10 mil/s – from equation (3).

5 Upgrading T-72 Tank in Order to Increase its Firing Accuracy

Firing accuracy is one of the most important parameters of all weapon systems, whose quality and impact effectiveness is affected by the following basic factors [7]:

1. *Target characteristics* – moving and stationary targets, pointed and planar targets, etc.
2. *Firing conditions* – range of fire, weather and climatic effects, day or night firing, etc.,
3. *Human factor* – quality and training of weapon system operators,
4. *Technical factor* – quality specifications of the system: ammunition + sight + weapon itself.

Increasing the probability of hitting the target by the first-shot-kill method as a part of T-72 MBT upgrade was achieved by the following modifications [6]:

1. new design of tank cannon and its seating in the cradle,
2. redesigning the recoil system,
3. reconstructing the turret bearing,
4. new option for stabilization and aiming as well as firing system.

The tactical and technical weapon quality in terms of technical accuracy of firing can primarily be affected by its design configuration, which should ensure the minimal value of the muzzle oscillation at the moment, when the shell leaves the barrel [1].

6 Applying the Theory of Muzzle Oscillation in the Course of 2A46 TC Upgrade

Modification of the main 2A46 gun was carried out as a part of T-72 main battle tank modernization. The goal of this modernization was to increase the firing accuracy of the 2A46 tank cannon (TC).

In order to increase TC firing accuracy, we first performed the proportion analysis on TC 2A46 in terms of muzzle oscillation. Following the results, a new design was developed to decrease muzzle oscillation [8].

Muzzle oscillation is defined as a barrel movement at the moment, when the shell leaves it and its size is given by values of angular deviations φ_m, σ_m, angular velocities $\dot{\varphi}_m$, $\dot{\sigma}_m$ and angular accelerations $\ddot{\varphi}_m$, $\ddot{\sigma}_m$ at the moment when the shell leaves the barrel t_m, in both the elevation ρ_φ and deflection plains ρ_σ [4][9].

The results of comparative calculations of muzzle oscillation in original TC 2A46 and upgraded TC having YA1 (2A46 MS) prototype marking are listed in Table 1.

Tab.1 Comparison of the muzzle oscillation in the elevation plain ρ_φ (obtained by calculations)

TC:	Parameter:	Shell:	**APFSDS**	**HE-FRAG**
2A46	φ_m [mil]		0,315	1,039
	$\dot{\varphi}_m$ [mil/s]		122,5	243,9
	$\ddot{\varphi}_m$ [mil/s^2]		23 138	36 455
YA1	φ_m [mil]		0,122	0,359
	$\dot{\varphi}_m$ [mil/s]		50,5	103,0
	$\ddot{\varphi}_m$ [mil/s^2]		8 929	22 232

Where:

$\varphi_m, \dot{\varphi}_m, \ddot{\varphi}_m$ – Angular deviation, angular velocity, angular acceleration – parameters of muzzle oscillation,

APFSDS – armor piercing fin stabilized discharging sabot,

HE-FRAG– high explosive – fragmentation.

Where the conversion degrees [º] to the artillery mils [mil]:

$$1° = \frac{6000}{360°} = 16{,}666\ \text{mil} \qquad (28)$$

Muzzle oscillation decrease in TC YA1 was achieved by redesigning the entire recoil system and symmetrical mounting of the recoil buffer and recuperator in the breech ring, in order to decrease the resultant moment effects on the barrel during the time, when the projectile is moving in this barrel (during the firing interval) [2][3]. The attained decrease moment from the brake force F_B of the recoil buffer is presented in Table 2 [6].

Tab.2 Moments from brake force M_{Bm} at the moment, when the shell leaves the barrel in the elevation plain ρ_φ

TC:	**2A46**	**YA1**
Type of shell:	M_{Bm}[kN.m]	M_{Bm}[kN.m]
APFSDS	75,8	36,4
HE-FRAG	147,7	102,5

Fig. 12 and Fig. 13 illustrate the breech ring design and position of the recoil system of TC A246 and YA1 (as seen from behind in the direction of fire). The illustrations show the symmetric mounting of the parts of recoil system in the TC YA1 breech ring in terms of decreased moment effects in both the elevation and deflection plains.

To clarify the TC YA1 construction, we should note that diagonal symmetrical option [1] couldn´t be used due to turret compartment limitations.

By decreasing the arm $e$of force from fire $F_{F(t),}$ we managed to decrease substantially the moment of force from firing M_{eF} [5]. The values obtained by calculating and comparing the moments $M_{eF}$of tank cannon 2A46 and YA1 are listed in Table 3.

Tab.3 The values of moment of force from fire M_e for the 2A46 and YA1 cannon [6]

TC:	**2A46**	**YA1**
Type of shell:	**APFSDS**	**APFSDS**
Force from fire $F_F(t)$ [kN]	6 000	6 000
Arm$e$ [mm]	0,0236	0,0094
Moment of force from fire M_{eF} [kN.m]	141.6	56,4

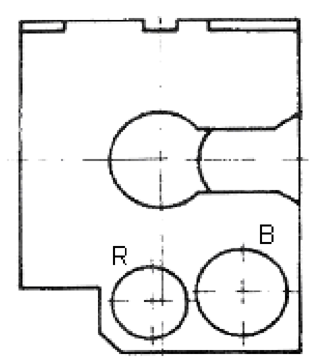

Fig.12 The breech ring of the original TC 2A46,
R – Recuperator, B – Recoil buffer

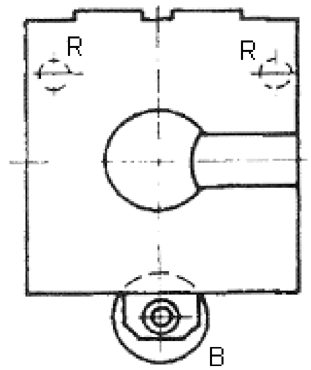

Fig.13 The breech ring of modernized TC YA1
R – Recuperators (2 pcs), B – Recoil buffer

Results of moment of recuperatorM_R obtained by experimental measurements and tests are listed in Table 4.

Tab.4 The values of moment of recuperator$M_R$obtained in experiments [6]

TC:	**2A46**	**YA1**
Type of shell:	M_R [kN.m]	M_R [kN.m]
APFSDS	3,68	1,87
HE-FRAG	7,18	5,26

Moment effects decrease in redesigned TC YA1 was achieved by:

- decreasingthe arm *e* of force from fire $F_{F(t)}$,
- decreasing the reverse of the recoil buffer $F_{B(t)}$during the firing interval (see Tab.2),
- displacing the recoil buffer axis under the barrel axle (in deflection plain),
- by using doubled recuperators effect against each other and changing their positions above the barrel´s axle, so now they act against moment of the recoil buffer M_B.

YA1 tank cannon prototype mounted on the T-72 MBT underwent firing tests whose results were compared with the T-72 series with the original 2A46 cannon. Results obtained in firing tests are shown in Table 5.

Tab.5 Firing test results with APFSDS shell at the target in the distance of 1 000 m [6]

Parameter:	n_{500}[%]		n_{250}[%]	
TC:	**2A46**	**YA1**	**2A46**	**YA1**
Y	81	95	48	67
Z	43	95	10	62

Where:
Y – evaluation in vertical direction – altitude
(see Fig.3 and Fig.4),
Z – evaluation in horizontal direction – longitude,
n_{500} – percentage of target hits which are placed up to the 500 mm distance from the aiming point in the respective y direction, z of the target,
n_{200} – percentage of target hits which are placed up to the 250 mm distance from the aiming point in stated y direction, z of the target.

Based on the results obtained in firing tests, the first shot hit probability by both TC 2A46 and TC YA1 was evaluated (a target was T-72 tank). Results obtained in firing tests are listed in Table 6.

Tab.6 Probability of hitting T-72 tank by first round at range 2000 m with APFSDS shell

Probability with TC:		Ratio:
2A46	**YA1**	**YA1/2A46**
0,57	0,70	1,23

Dispersion of APFSDS BM-15 shells impact at target in the distance X = 1 010 m for 2A46 - Fig. 14.

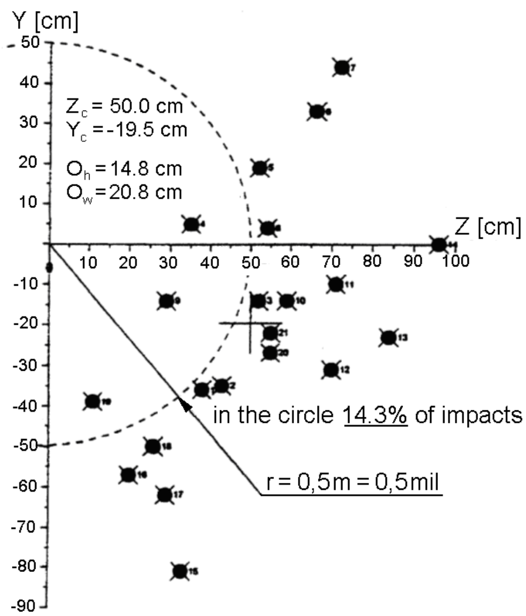

Fig.14 Firing 21 rounds from the original 2A46 tank cannon [6]

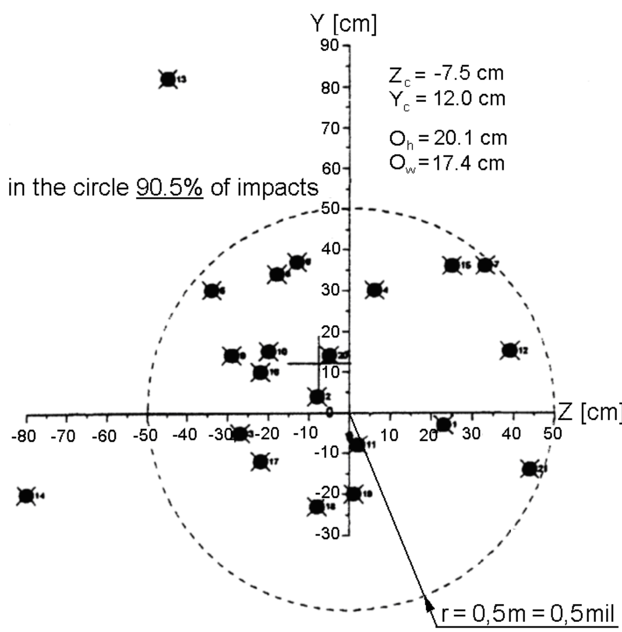

Fig.15 Firing 21 rounds from the modernized YA1 tank cannon [6]

It has been experimentally confirmed that the upgraded YA1 TC (future serial production marking 2A46 MS) has a higher probability of hitting the target when compared with the original 2A46 one (see Tab. 5). The probability of hitting the target by first round with TC YA1 increased about 23% (see Tab. 6).

Dispersion of impact APFSDS shells BM-15 at target in the distance X = 1 010 m for YA1 – see Fig.15.

7 Major Scientific Contributions

It follows from theoretical analyses and experimental measurements (see above) that the following parameters have major impact on muzzle oscillation [4]:

1. Moment of inertia J_i[kg.m^2],
2. Moment of force from fire M_{eF} [N.m],
3. Moment of recoil buffer reverse M_B [N.m],
4. Moment of recuperator reverse M_R[N.m].

Concerning muzzle oscillation, the moment of inertia of recoil parts should be as high as possible. It means that the structure of recoil parts (i.e. barrel and breech ring) has to be most robust, while taking into consideration all other limiting contexture allowances of the entire weapon system construction. [1].

The following modifications in design were carried out to decrease the muzzle oscillation in elevation plain:

- The moment of force from fire $M_{eF}$was decreased by reducing the arm of force from fire from the value$e = 23,6$ mm to the value of $e = 9,4$ mm by redesigning the breech ring,
- the moment of force from fire $M_{eF}$was decreased by reducing the arm of force from fire from the value$e = 23,6$ mm to the value of $e=9,4$ mm by redesigning the breech ring,
- recoil buffer reverse was decreased by modifying the brake design during the time of firing interval until the moment the shell leaves the barrel, ,
- repositioning the recuperators above the horizontal plain crossing the barrel axis, the moment of recuperator reverse M_R effects against the other action moments $M_{eF}$and alsoM_B.

The following modifications in design were carried out to decrease the muzzle oscillation in deflection plain:

- breech ring construction is symmetrical towards the vertical plain crossing the barrel axle,
- similar recuperators are doubled, symmetrically situated in the upper section of breech ring,
- recoil buffer is symmetrically placed in the bottom section of the breech ring,
- barrel guidance in the cradle was extended.

Comparison of firing tests results obtained by the original TC and its upgraded version:

Having analyzed and compared both muzzle oscillation and technical accuracy of firing by the original tank cannon and modernized 2A46 MS tank cannon, options to improve firing accuracy emerged. It should, however, be born in mind that all inputs are of random nature, such as muzzle oscillation and dispersion. The designed option of TC modernization is to decrease the values of the actuating input random variables which results in decreasing values of output random parameters and muzzle oscillation and decreasing dispersion at the target.

Table 7 lists potential location deviations for APFSDS shells for both compared cannons, i.e. the original 2A46 cannon and modernized one 2A46 MS (YA1) with regard to the target, shell fired from the ideal cannon.

Practical results obtained in firing tests confirmed that the tank cannon modernization was optimal and necessary when using the up-to-date firing control system (and also each of its sub-systems) within the T-72 MBT comprehensive upgrade.

Tab.7 Location deviations when firing at targets with APFSDS shells [6]

X_Z [m]		100	500	1000	1500	2000
TC 2A46	ΔY [m]	0,065	0,306	0,569	0,793	0,972
	ΔZ [m]	-0,011	-0,053	-0,106	-0,159	-0,213
TC YA1	ΔY [m]	0,026	0,110	0,180	0,210	0,202
	ΔZ [m]	0,000	0,000	0,000	0,000	0,000

8 Conclusion

The demand for a complex upgrade of T-72 MBT within the ASR (Army of Slovak Republic) stems from the needs of the modern battlefield of 21st century. The modernization project consisted of various modernization stages, including increasing firing accuracy and first-round hitting probability (first-shot-kill). Moreover, the project was designed to increase mobility, enhance passive and active tank protection, modify electronic and optical and electronic devices within the FCS (fire control system) (sensors, detectors, stabilizers, sight and aiming optical devices, etc., and to mount the 30mm automatic cannon 2A42 (as an anti-aircraft defense cannon) and integrate its controls into the main tank FCS. Decreasing technical dispersion through redesigning the TC 2A46 mounted on T-72 MBT and its seating in the cradle (in the chassis of the vehicle through changing the turret spherical bearing) by applying the muzzle oscillation theory process in the scope of this paper, fully meet enhanced tactical and technical requirements for firing accuracy in modernized armored combat vehicles for the needs of the ASR [7].

The scientific contribution of the paper lies mainly in understanding force and moment effects on elevating parts of the weapon and other parts of the weapon system and their influences on technical dispersion during firing.

Since 2A46 muzzle oscillation effects many factors, specific construction changes were made, thus leading to higher firing accuracy.

It was proved that by installing recoil buffer and two recuperators symmetrically to the rear section of the tank cannon (breech ring), the moment of force from fire M_e was decreased by reducing the arm of force from fire (excentricity) from its original value e 23,6 mm to the value of 9,4 mm. It means that the distance of the center of gravity of recoiling parts from the barrel axis was reduced by 14,2 mm in vertical plain. This construction modification made the moment of force from fire M_e decrease from the original value of 141,6kN.m to the value of 56,4 kN.m during firing with APFSDS projectile.

The research results, which emerged from reconstruction project are the following:

During firing with APFSDS shell, the decrease of the brake force moment M_{bs} from the value of 75,8kN.m to the value of 62,4 kN.m was observed. Regarding the recuperator symmetric, it was shown that the moment of recuperatorM_R was decreased from the value of 3,68kN.m to the value of 1,87 kN.m.

By the reconstruction of 2A46 tank cannon lodgment in its cradle, consisting of an extension of the cannon´s rear section (breech ring) guidance and centering, the allowance in guiding was eliminated to the acceptable value and the exact tank cannon position before each fire was defined, which is an extremely important indication for FCS (Fire Control System) of the weapon system. Firing accuracy of the new reconstructed 2A46 MS (YA1) tank cannon was also enhanced by complete reconstruction of the turret transverse bearing spherical path, by which inconvenient allowances in the turret bearing were eliminated.

In addition, up-to-date sights, aiming and warning systems and devices were installed in the fire control system. Based on the facts presented, experimental firing tests with the reconstructed 2A46 MS (YA1) cannon were carried out. The tests proved that the probability of hitting the target was increased by 23% in comparison with the original 2A46 tank cannon. Improvements can also be attributed to the new fire control system devices.

Acknowledgement

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Note:
In case ISSN of some quoted literature is missing, it is because the research and technical bulletins and other documents in question were published merely for internal needs of the company. Thus, it was guaranteed that reconstruction activities and work for the needs of the ASR were categorized as classified.

References

Balaštík, P. *Gun Carriage*. Textbook. Brno: Military Academy in Brno, Czech Republic, 1984, pp. 30-270.

Čech, V. *Recoil System of the Gun I*. Textbook. Brno: Military Academy in Brno, Czech Republic, 1991, pp. 25-105.

Čech, V. *Recoil System of the Gun II*. Textbook. Brno: Military Academy in Brno, Czech Republic, 1991, pp. 76-212.

Balaštík, P., Tvarožek, J., Galeta, A. *Basis of special techniques design – gun carriage*. Textbook. Trenčín: Alexander Dubček University of Trenčín, Slovak Republic, 2006, ISBN 80-8075-181-1, pp. 17-148.

Research-Development Project of ZTS – Modernization of T-72 MBT.*Research- Development Work.* Martin: Research and Development institute (VVÚ), Slovak Republic, 2004, pp. 20-55.

Technical and Tactical Specifications for Special Techniques, *Development Work* , Martin: Research and Development Institute (VVÚ), Slovak Republic, 2002, pp. 40-65.

Kollar, S. Dynamic Firing Stability of the Self-Propelled Gun Howitzer. *The Proceedings of 2th Conference on Ways of Ground Forces Techniques Development*, LiptovskýMikuláš: Military Academy of Armed Forces, Slovak Republic, 1997, pp. 23-34.

Kollar, S. The Oscillation at the Barrel´s Muzzle at Instant, in Which the Shell Leaves the Barrel. *The Proceedings of 2th Conference on New Technologies and Materials Used for the Special Techniques Manufacturing and Services*, Trenčín: Alexander Dubček University of Trenčín, Slovak Republic, 1998, pp. 62-73.