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TRENDS IN THE MODERNIZATION OF ARMoured WEAPONS. THE PT-91M2 TANK

Abstract. The article describes the project to modernize the tanks of the T-72 series, presented for the first time at the International Defence Industry Exhibition - Kielce 2017 (MSPO 2017). The specifications of the proposed versions of the modernization of the T-72 tank are referred to and compared with those of other types of tanks (T-72B3, M1A2 ABRAMS). The article presents mainly a technical approach: extensive technical analyzes of the parameters of the offered package in comparison to those of key MBTs. In conclusions, reference is made to essential considerations in favour of the implementation of the industrial manufacture of the presented modernized version of the PT-91M2.

Keywords: modernization, modernization package, T-72 tank, PT-91M2 tank.

1. INTRODUCTION

The article describes the concept of the proposed modernization and analyses the technical implementation possibilities and presents the modernization package. The package was dubbed "M2" after the prototype of the PT-91M2 tank presented at the MSPO International Defence Industry Exhibition in 2017 [1]. The stimulus for the development of this prototype was the ongoing technical discussion on the modernization of armoured equipment of the Polish Armed Land Forces. Despite the two modernization concepts presented in the form of demonstrators of the PT-16 and PT-17 technologies [2], it has become clear that none of these solutions could be implemented in less than 24 months. Considering the proposed technological leap between the T-72 tank and the PT-16 and PT-17 concepts, BUMAR-ŁABĘDY started to work on a compromise solution. The work was aimed at maximizing the tactical parameters of the vehicle within a minimum implementation time. The PT-91M2 tank and its subsequent equipment versions were in fact the realization of a cost-effective programme [3].



Fig. 1. The Polish T-72M1 tank
(photo by ZM "BUMAR-ŁABĘDY" S.A.)

It is worth mentioning that the T-72 tank, which was the starting point for the development of the Polish modernization package projects, is one of the most distinguishable combat vehicles in the world [4]. It is a II+ generation vehicle, but its equipment was already ahead of its time when the tank was put into service. Low silhouette, well-laid out armour and the powerful 125mm cannon provided an advantage in the battlefield. It is a tank created for aggressive operations (assault and/or counterattack) in manoeuvre warfare. The T-72 tank is still an excellent starting base for upgrades. However, it is necessary to retain the basic purpose of the tank - manoeuvre warfare. However, it is uneconomical to design a tank identical to the LEOPARD 2, MERKAVA or AMX-56 Leclerc vehicles starting from the T-72 tank.

Areas for optimal modernization based on the PT-91M2 tank are outlined further in the article.

2. THE PT-91M2 TANK. SPECIFICATIONS AND DESCRIPTION OF THE SYSTEMS

The PT-91M2 tank, as a modernization variant for the T-72 series vehicles, is a very important element in the Polish industry's approach to the issue of modernization of the Polish Armed Forces. Many years of experience in the field of construction of tracked combat vehicles, as well as knowledge and skills in developing new concepts of the T-72 tank by ZM "BUMAR-ŁABĘDY" S.A. have set out the approach to the presented issue. Tank upgrades (including the concept of building a vehicle from scratch) were developed taking into account not only the life cycle of the product as a whole, but also the life cycles of its components, which has never been done before.

At the stage of designing and configuring the tank equipment, an analysis of areas that required modernization was carried out. These areas were split into groups: obsolete and/or discontinued elements, elements of the modernization package and variant/optional elements. The results of the analysis are shown in Table 1.

Table 1. Analysis of the T-72 tank equipment divided into modernization groups [5, 6]

Item	Equipment compliant with 3rd generation (and more recent) combat vehicle standard requirements	Existing T-72 equipment (group)
1	Composite and/or multi-layered armour [7].	Depends on version (modernization option)
2	Reactive armour or NERA (Non Explosive Reactive Armour)	None (included in modernization package)
3	Additional armour protecting the sides of the hull and turret, including the drive compartment [8]	None (included in modernization package)
4	No ammo in crew compartment	None (included in modernization package / partial)
5	Tank gun adapted for firing high-power kinetic energy (muzzle energy > 10MJ) and programmable ammunition	None (obsolete – included in modernization package)
6	Drive in the form of an integrated system	None (modernization package option)
7	2-axial gun stabilization, with line of sight follow up system	None (included in modernization package)
8	Independently stabilized 2-axial aiming devices of the	None (included in

Item	Equipment compliant with 3rd generation (and more recent) combat vehicle standard requirements	Existing T-72 equipment (group)
	gunner	modernization package)
9	Independently stabilized 2-axial aiming devices of the commander	None (included in modernization option)
10	Hunter-Killer operation mode	Limited (included in modernization option)
11	Automatic gun loading system	Yes (obsolete – included in modernization package)
12	Chassis/turret fire suppression system	Yes (obsolete – included in modernization package)
13	Chassis/turret explosion protection system.	None (included in modernization package)
14	Additional power generator / air conditioning	None / None (modernization package / option)
15	Systems: self-concealment, Soft-Kill and/or Hard-Kill [9, 10, 11]	None / None / None (included in modernization package / package / option)
16	Passive night vision systems, 3rd generation thermovision systems, imaging cameras for the driver	None (included in modernization package)
17	Digital electrical systems and power distribution systems	None (obsolete – included in modernization package)

The solutions proposed by ZM "BUMAR - ŁABĘDY" S.A. for the PT-91M2 tank cover all areas listed in Table 1. This gives a picture of the technological level and scope of the modernization offered.

In accordance with the materials available [1,3] the following objectives were targeted in the development of the modernization packages:

- improved firing accuracy, power and range;
- improved crew safety in the battlefield;
- increased mobility;
- improved working comfort and extended mission times;
- improved ergonomics of equipment operation.

The modernization package in its base version contains (Table 2) components and systems available on the domestic market and provided mainly by Polish manufacturers.

Table 2. List of units and systems provided mainly by Polish manufacturers

Item	Unit/system	Manufacturer
1.	Upgraded 850 hp engine with modified power transmission system	ZM "BUMAR-ŁABĘDY" S.A.
2.	Stronger suspension with elastomer bumpers	ZM "BUMAR-ŁABĘDY" S.A.
3.	Stronger hull bottom in driver's compartment	ZM "BUMAR-ŁABĘDY" S.A.
4.	Additional 5 kW power generator	OBRUM sp. z o.o.
5.	ERAWA II reactive armour and light version ERAWA	ZM "BUMAR-ŁABĘDY" S.A.
6.	Bar armour for protecting the engine compartment	ZM "BUMAR-ŁABĘDY" S.A.
7.	Digital supply, control and power distribution systems	ZM "BUMAR-ŁABĘDY" S.A.
8.	Modernization kit for the power transmission system	OBRUM sp. z o.o.
9.	New cannon 2A46MS 125mm/L48	ZTS Special, Slovakia
10.	Advanced fire suppression and explosion protection system	Kidde Deugra, Germany
11.	OBRA-3 vehicle self-concealment system [9]	Przemysłowe Centrum Optyki S.A.
12.	Driver's day and night front and rearview camera KDN-1T [12]	Przemysłowe Centrum Optyki S.A.
13.	Independently stabilized dual-plane integrated day and night gunner's sight	ELBIT, Israel or SAFRAN, France
14.	Electrical weapons stabilization system	ELBIT, Israel or SAFRAN, France
15.	Digital fire control system [13, 14]	ELBIT, Israel or SAFRAN, France
16.	Passive night-time observation instruments	Przemysłowe Centrum Optyki S.A.
17.	Modernized cannon autoloader system	ZM "BUMAR-ŁABĘDY" S.A.
18.	Digital internal and external communication systems	Depends on customer

The PT-91M2 (A1) and PT-91M2 (A2) vehicles, which were presented at the MSPO 2018, were proposals of two possible configurations, adapted to the different requirements of the potential customer.

Table 3 shows comparative tactical and technical specifications for the T-72M1 tank before modernization and for the two presented variants of the final product PT-91M2 with A1 and A2 equipment.

Table 3. Comparison of specifications of T-72 and PT-91M2(A1) and PT-91M2(A2)

Parameter	T-72M1 (T-72M1D)		
	Before modernization	Modernized A1	Modernized A2
Weight [T]	43.4	≤47	≤49
Power to weight ratio [kW/t]	13.2	≥13.3	≥15
Unit of fire [pcs.]	44 / 37 (M1D)	40	40
Average resistance to penetration at an angle of +/-35° by antitank/high energy missile: [mm]	410 / 520	≥600 / 900	≥600 / 900
Commander's observation instrument: - type - magnification [x] - range [m]	Passive/active 5 400	Passive 3.5 900	Thermal imaging 3.5 900 In addition: PASEO – Commander's instrument Hunter-Killer) Magn. 12x Range: (W / R / I)[m] 18k / 9k / 4.5k
Driver's observation instrument: a) Forward travel: - type - range [m] b) Rearward travel: - type - range [m]	TWNE-4B Passive 100 None - -	TWNE-4B / KDN-1T Passive-active / passive 60 – 100 / 200 KDN-1T Passive 200	TWNE-4B / KDN-1T Passive-active / passive 60 – 100 / 200 KDN-1T Passive 200
Fire control system – ballistic computer – laser distance meter (range) [m] – sight: • daytime • night time • type – firing distance at night [m] – fire effectiveness [m] of projectile: • subcalibre • shaped charge • high explosive	Electromechanical up to 3000 TPD-K1 TPN-1-49-23 (active) 500 1500 1400 1300	Digital up to 6000 TIFCS TIFCS (thermal imaging) 2500 2500 2000 2000	Digital up to 9995 SAVAN-15 SAVAN-15 (thermal imaging) 4000 4000 2500 2500
Crew protection means: – self concealment system – anti-explosion system – fire suppression system – driver's seat fastened to roof – improved protection against napalm – enlarged escape hatch – stronger bottom	- - + - - - -	+ + + + + + +	+ + + + + + +
Radio set: – type	Analog	Digital	Digital

Parameter	T-72M1 (T-72M1D)		
	Before modernization	Modernized A1	Modernized A2
– power [W]	20	50	50
– internal communication means: – type	Analog	Digital	Digital
Additional equipment			
– APU	-	+	+
– air conditioning	-	-	+
– additional bins	-	+	+
– battlefield management system BMS	-	-	+

2.1. Solutions proposed by ZM "BUMAR-ŁABĘDY" S.A.

As part of the T-72M1 tank modernization package, ZM "BUMAR-ŁABĘDY" S.A. prepared solutions based on many years of experience in designing, servicing and modernizing tanks of various versions, especially the T-72 series vehicles. Solutions already implemented, e.g. in the PT-91 "Twardy" tanks, PT-91M [15], such as a suspended seat or bottom strengthening, will not be discussed here.

2.1.1. Electrical systems

Modern systems that manage the operation of the electrical system in the tank, of solid state technology, ensure stable and trouble-free operation, and most importantly, the ease and comfort of using the equipment.

The modernization includes, among others, a microprocessor-based starting system (replacing the previously used PUS, PAS, BSP), a new digital voltage regulator, battery protection system, fuse arrays in the turret, as well as a new battery holder, using compact modules operating at a standard voltage of 12VDC or increased 26.4VDC.

The driver's console (Fig. 2) is used to display the necessary parameters of the vehicle in motion and at a standstill, such as temperature, pressure, amount of fuel, travel speed, engine speed, desired operating hours, voltage and current of batteries, etc. Indicators display parameters in different colours - green for normal values, yellow for warning values, red for critical values. The device also allows recording selected data in the event of a malfunction. The console concentrates the management of the chassis electrical system in one device. It is also provided with a portable panel which enables readout of key data when driving with the hatch open.



Fig. 2. The driver's console with portable panel - illustrative view

The basic modernization package includes a control system for the autoloader. The modernized control system has ammunition programming functionalities and a diagram of its

distribution in the ammo carrier. In addition, the system, working with the FCS, automatically calls a dedicated ballistic table after loading the projectile into the gun.

The modernization of the control system also improves the rate of fire of the cannon. The new control system rotates the carrier in the direction of the desired shell type as soon as it is selected by the operator on the panel. The original cyclogram for the current solution presented in Figure 3 has been shortened (marked in red) by about 1.2 s (the carousel turns automatically and regardless of the loading procedure, the only selected item is the lower position of all shell cases).

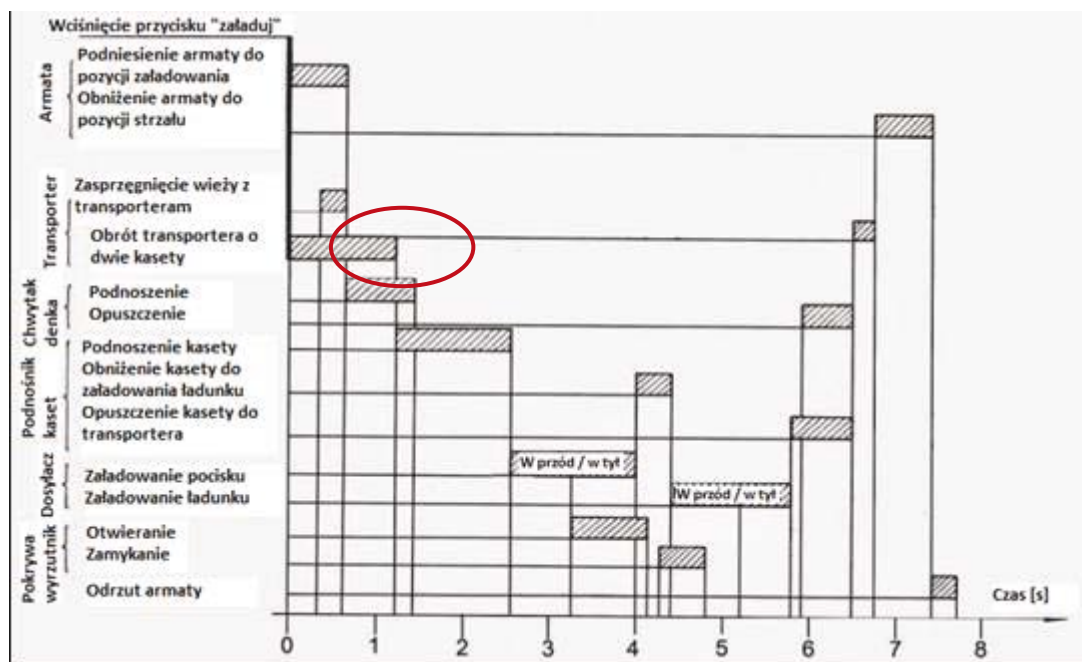


Fig. 3. Autoloader operation cyclogram of the PT-91M tank with marked area subject to modernization

2.1.2. Armour – ERAWA-ALU reactive armour and bar armour [7, 8]

In order to increase the ballistic resistance of the tank, the ERAWA-2 reactive armour was installed to protect the armour surface within the angular range of ± 30 degrees relative to the tank axis. Compared to the PT-91 tank, the resistance of the hull side plates was increased using the ERAWA-2 aluminium armour instead of the ERAWA-1 single-layer steel armour. Installation of aluminium modules does not require changing the design of the fenders above the tracks, and also does not increase the weight of armour compared to the PT-91 tank.

The bar armour that protects the rear portion of the tank is a popular, widely used protection against shaped charge warheads, e.g. PG-7, but also against the more modern RPG-27. The high effect to cost ratio means that this type of armour is now an integral element of additional tank armour. See Fig. 4 for an example of a bar armour.



Fig. 4. Bar armour installed on the PT-91M2 tank

(photo by ZM "BUMAR-ŁABĘDY" S.A.)

The bar armour for the chassis is designed to counteract shaped charge warhead hits, while the turret has a new stowage bin for carrying vehicle equipment.

2.1.3. Equipment containers – turret box and bins

Increasing the luggage space available for the tank crew is one of the effects of modernization (extended mission duration). The current design does not allow the crew equipment to be transported in an orderly manner. The introduction of an additional sealed turret bin allows the transport of sensitive items, and the additional turret box allows the transport of even bulky items. The turret box is adapted to the requirements of the customer and, in addition to its purely transport functions, it can also act as an additional turret bar armour.

2.2. Solutions offered by OBRUM sp. z o.o.

2.2.1. Modernization of the power transmission system with a comprehensive auxiliary power unit

The modernization of the power transmission system is aimed at improving the driver's work comfort. Replacing the hydraulic valve blocks used to control the operation of gearboxes with solenoids allows for integration of the steering wheel. Control of the above valve blocks through a digital system allows the introduction of new functionalities to the system, such as:

- automatic brake in gear "0" facilitating the driver to start moving the tank uphill;
- steering the tank using one hand only;
- automatic gear selection or use of gear shift buttons on the driver's wheel;
- ability of making a turn with many radii.

The above range of modifications is set up so as to introduce maximum number of functionalities at the lowest possible cost. The possibilities of the modernized system are partly convergent with the functionalities of a Power-Pack system, but implemented at much lower cost.

The auxiliary power unit offers a comprehensive module for delivering power to the tank, when the tank is not moving, from a 5 kW generator, for driving the air conditioning compressor and supporting the modern preheating system. Heating is effected by two new independent systems - for the crew compartment and for the engine compartment. The high

heat output warrants that the operating temperature is attained quickly at low ambient temperatures. The air conditioning system ensures optimal working conditions for the crew at elevated ambient temperature. As all these systems are installed in an easily accessible compartment, they can be conveniently maintained by the tank crew ensuring low failure rate.

2.3. Other subsystems manufactured by the companies of the PGZ S.A. group

The idea of component manufacture ‘polonization’, as well as the selection at the design stage of technically competitive solutions from the domestic market, ensured the integration of a wide range of solutions implemented and provided by companies of the PGZ S.A. capital group. The main integrated systems of the M2 package are described below. The communication system offered as part of the M2 package is available in accordance with the customer's requirements, while domestic solutions JASMIN - TELDAT and FONET - WB Electronics are the favoured ones.

2.3.1. All-around observation system (Fig. 5) – SOD „ATENA” - PCO S.A.

The all-around observation system from PCO S.A. consists of 4 optical modules, a concentrator and a display. It enables observation of the close surroundings of the vehicle. The system is operated by the commander, whereas the image can be relayed to the gunner's display. The mode of image display is selectable only on the commander's panel. The image can be displayed as:

- panoramic view set up from four modules;
- modular view – selected view – one of four modules;
- directional view – selected views from two modules (front, rear, right, left).

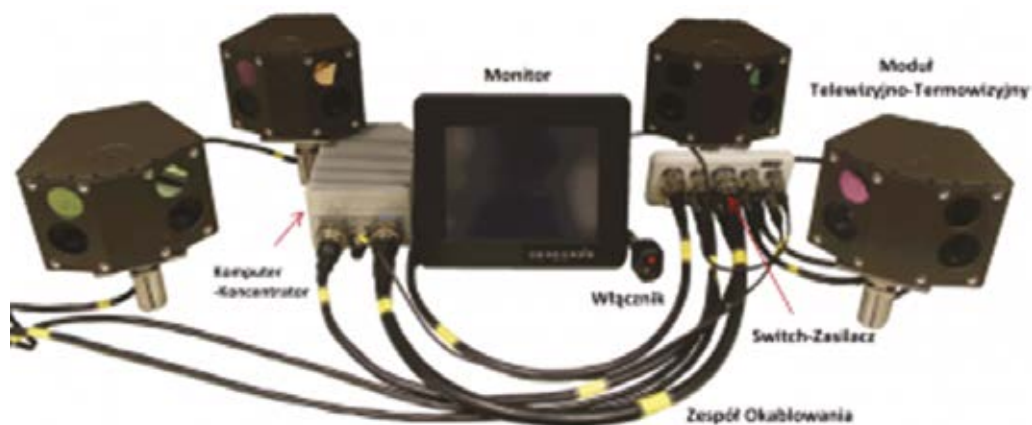


Fig. 5. All-around observation system – SOD "ATENA" - PCO S.A.
(photo by PCO S.A.)

2.3.2. Vehicle self-concealment system – SSP-1 "OBRA-3" - PCO S.A. [9].

The domestic solution, implemented in PT-91 tanks, and in exported tanks (e.g. T-72M4Cz and T-72M2 Moderna) was developed by PCO S.A. Increased awareness of the tank crew of the contact with the enemy extends the time available for taking effective defensive actions/means. The introduction of four or six detector heads ensures uniform 360 degrees coverage of the observation sectors. In addition, the integration of launchers provides automatic (visual and thermal) screening in the threat direction. Providing the PT-91M2 tank with a digital ballistic computer also gives the possibility of introducing additional functionality in the form of automatic turret rotation towards

the threat. Such a rotation could be effected automatically after switching on the "defence" combat mode.

2.3.3. Driver cameras (front and rear) – KDN-1T "NYKS" - PCO S.A [12].

In T-72 type tanks, the driver has a limited field of observation by one main daytime periscope, which can be converted to a night vision periscope. The installation of driver day and night cameras will significantly increase the driver's situational awareness, enabling smooth driving regardless of weather conditions. The low hull of the tank required the driver to take an unnatural crouched position while driving, which increased fatigue. Driving a tank while looking at the image displayed on the monitor will allow the driver to adopt an optimum position, reduce fatigue and improve comfort.

2.3.4. Internal and external communication system

A modern internal and external communication system makes use of digital technology to encrypt and transfer data between military units and disposition centres.

The communication system forms a common module with the battlefield management system. All data sent by the above mentioned systems are used by the FCS to track subsequent targets.

2.4. Subsystems provided by foreign manufacturers

2.4.1. Main armament: 2A46MS 125 mm/L48 cannon; KBA-3 – 125 mm/L48

The **2A46MS** cannon has improved ballistic properties, due to relocated muzzle brake, which eliminates the cannon deviation from the target while firing. In addition, during manufacture, the raw barrel element is subjected to autofrettage which increases the life of the barrel. An optional solution is chrome plating of the barrel tube, which additionally extends its service life.

The **KBA-3** is an equivalent of the Russian cannon **2A46M-5**. It has symmetrically arranged muzzle brakes (diagonally of the barrel axis) that retain the cannon's line of fire while firing. Autofrettage carried out during the manufacturing process, as well as optional chrome plating of the barrel, together with an additional muzzle brake, allow the use of ammunition with higher muzzle energy, which in the case of kinetic (subcalibre) shells directly translates into the penetration ability gained with distance. The mounting system does not require deep modifications in the turret structure of all types of T-72 tanks. An additional solution that facilitates maintenance and workshop work in combat units is the barrel bayonet connector, enabling the replacement of this element without dismantling the cannon from the entire turret system.

Below is a comparison of the dispersion (Fig. 6) of BM-15 shells fired from the **2A46** cannon and from the modernized cannon **2A46MS/KBA-3**.

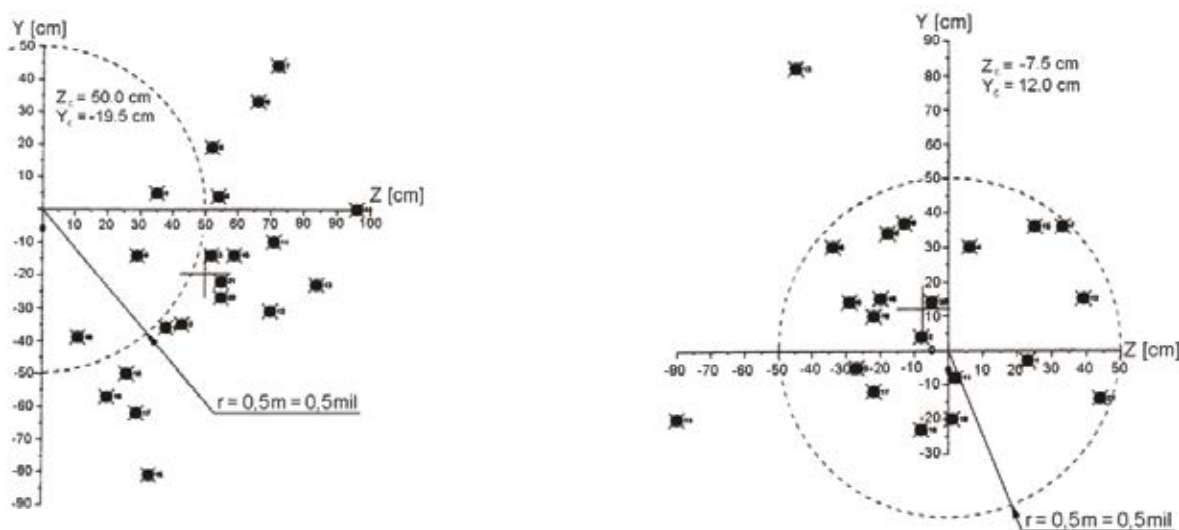


Fig. 6. Dispersion comparison

a) 2A46 cannon

b) 2A46MS/KBA-3 cannon

Basic specifications of the 2A46, 2A46MS and KBA-3 cannons are listed in Table 4.

Table 4. Basic specifications of cannons

Parameter	Cannon type		
	2A46	125MS (2A46MS)	KBA-3
Calibre	125 mm	125 mm	125 mm
•Barrel length	6000 mm	6000 mm	6000 mm
Weight	2675 kg	2500 kg	2500 kg
Recoil	270-320/340 mm	260-300/310 mm	260-300/310 mm
Shell dispersion	0.78 mrad	~0.39 mrad	~0.19 mils
Maximum pressure	450 MPa	560 MPa	650 MPa
Pressure in recuperator	6.18-6.38 MPa	6.18-6.38 MPa	5.79-6.08 MPa
Mean service life of barrel	900 EFC* rounds	1200 EFC* rounds	1200 EFC* rounds

2.4.2. Complete fire control system – ELBIT (TIFCS) or SAFRAN (SAVAN-15)

The fire control system is based on the solution applied in the MERKAVA (ELBIT) [14] or PT-91M//AMX-56 Leclerc [13]. A modern ballistic computer is operated from two panels (gunner and commander) on which all parameters calculated by the computer are displayed. The image is displayed independently on each of the monitors in one of the available modes (daytime – TV and thermal). In both solutions we are dealing with a modern thermal imaging camera with at least high-definition resolution. This makes it possible to strike identified targets at a distance of 2500-4000 m under the conditions of limited visibility. The computer also controls the turret digital stabilization system. The accuracy of the independent biaxial stabilization of the cannon, as well as of the sight, implemented through

speed and angle coincidence (master Line of Sight - slave Line of Fire), allows accurate firing while the vehicle is moving in any direction relative to the target.

3. COMPARISON BETWEEN THE PT-91M2(A2) TANK AND FOREIGN STRUCTURES

Analyzing the current military situation, as well as the geopolitical location of Poland, as tanks of potential opponents we consider those vehicles that are in service in neighbouring countries. While analyzes of the T-72 tanks and of its modernized versions are described extensively in the literature [4, 5, 6, 15, 16, 17, 18, 19] and in publicly accessible web sites [20], the technical parameters of Western tanks and their analyzes have not been made public until recently. Change in the accessibility clause to the results of Western tank tests enables the presentation of previously unknown publications [16], as well as of previously scarcely known technical data (see Figs. 7, 8, 9, 10).

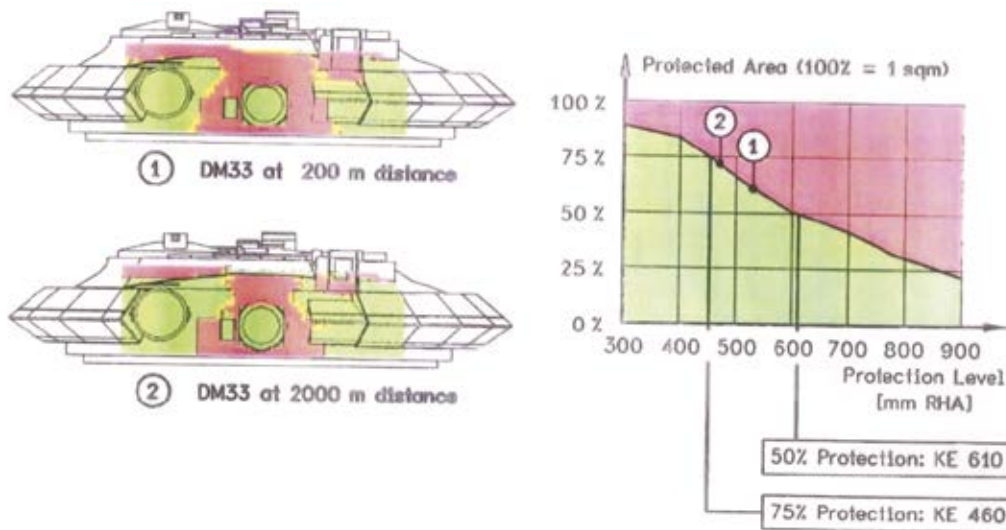


Fig. 7. Resistance of the T-72B3 tank turret against KE projectile hit [16]

The list (Table 5) of basic tactical specifications of selected MBTs is a good illustration of the differences between them.

Table 5. Basic technical specifications of selected tanks

Parameter	Main battle tanks (MBTs)				
	PT-91M2 (A2)	T-72B3 [21]	M1A2 Abrams	Leopard 2A5+	AMX-56 Leclerc
Weight [T]	49	47	65	62.5	62
Power to weight ratio [kW/t]	18	17.68	16.92	17.6	17.74
Unit of fire [pcs.]	40	45	42	42	40
Average resistance to penetration at an angle of +/- 35° by antitank/high energy missile: (mm)	600/900	610/900	600/750	700/1300	500/700
Effective fire distance: (m)	4000	3000/ 5000(ppk)	4000	4000	4000
Crew protection means:					
– self concealment system	+	-	-	+	-
– anti-explosion system	+	+	+	+	+
– fire suppression system	+	+	+	+	+

Parameter	Main battle tanks (MBTs)				
	PT-91M2 (A2)	T-72B3 [21]	M1A2 Abrams	Leopard 2A5+	AMX-56 Leclerc
- Hard-Kill system	-	-	-	-	-
- anti-spall lining	+	+	+	+	+
- ammunition separated from the crew	-	-	-	-	-
- stronger bottom	+	+	+	+	+
Additional equipment					
- APU	+	-	+	+	-
- air conditioning	+	-	+	+	+
- additional bins	+	+	+	+	+
- battlefield management system BMS	+	+	+	+	+
- automatic fire extinguishing system	+	-	-	-	+

The comparison of parameters shows that the A2 configuration of the PT-91M2 is equivalent to, or even exceeds in some aspects the technical parameters of competing designs [16]. While the modernization of the PT-91M2 does not allow a significant increase in the armour strength, the level achieved does not differ from other world solutions (Figs. 8, 10, 11).

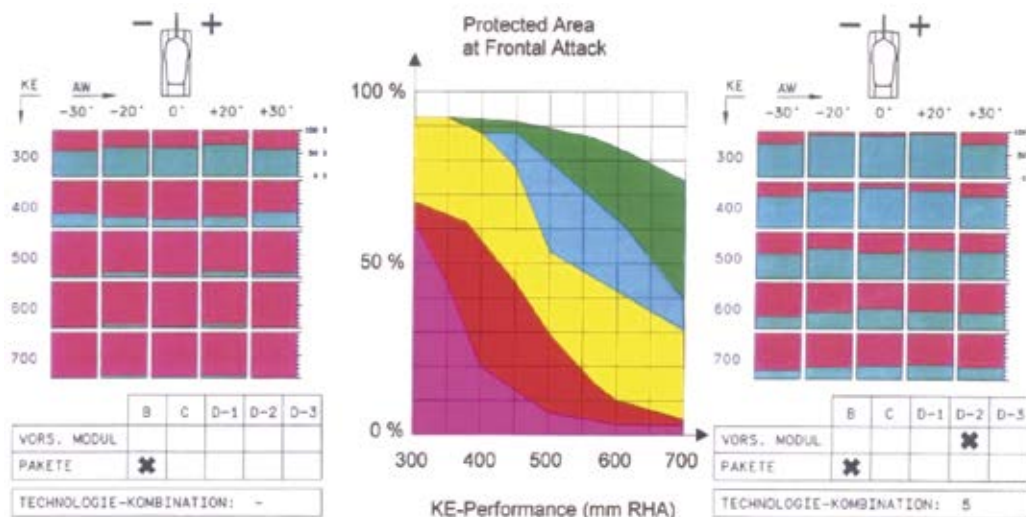


Fig. 8. Resistance of the front panels of tank against KE projectile hit

a) LEOPARD 2A4

b) various LEOPARD configurations

c) Strv-122 tank

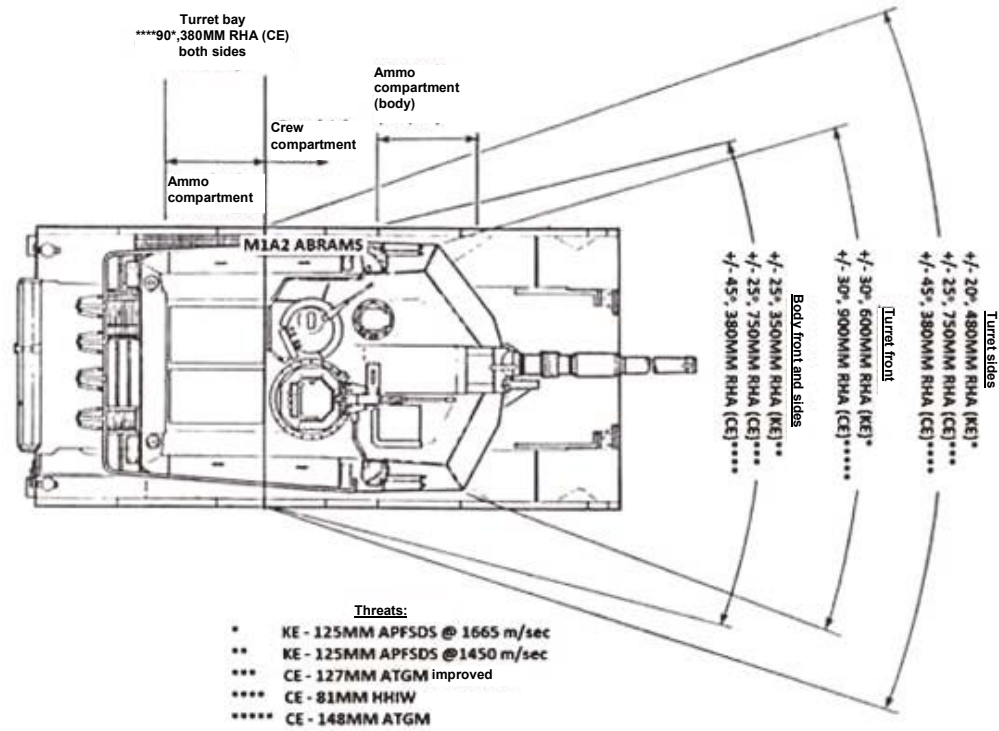


Fig. 9. Resistance of the front panels of ABRAMS M1A2 tank against KE projectile hit

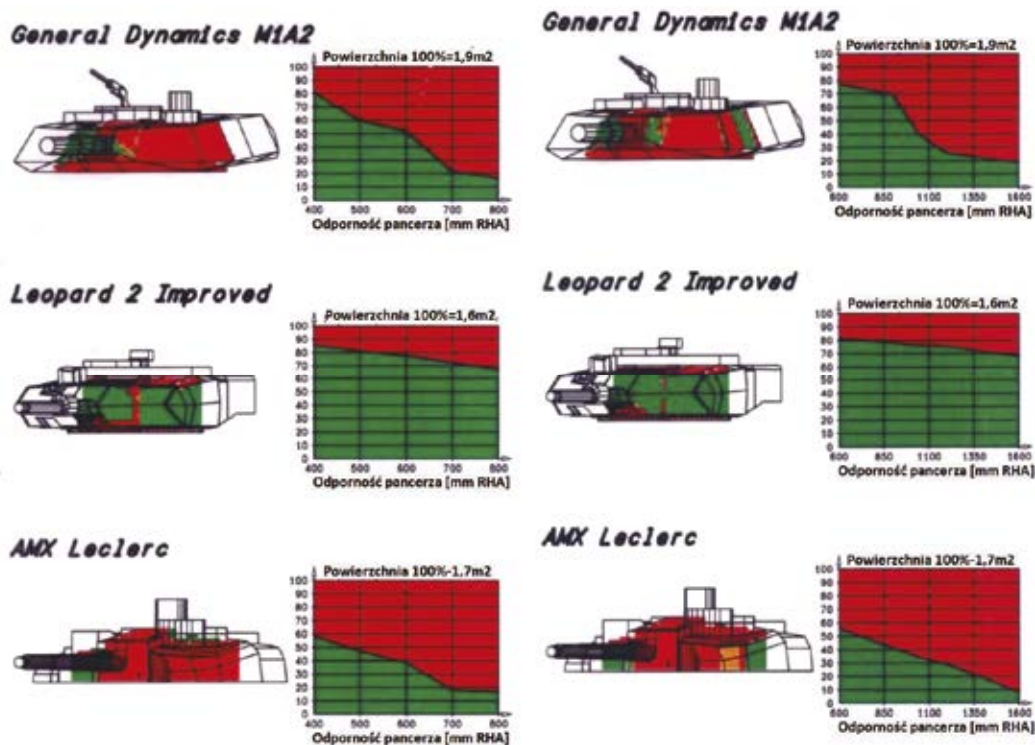


Fig. 10. Comparison of resistance of ABRAMS M1A2, STRV-122, AMX Leclerc turrets to KE projectile hits [16] at a firing angle of +20° in relation to the vehicle axis

a) projectile with 700 mm RHA penetration value

b) projectile with 1200 mm RHA penetration value

4. CONCLUSIONS

The presented solutions, including components and systems from Polish suppliers, which can be used in the PT-91 M2 tank, do not differ in specifications from other solutions used in the ABRAMS M1A2 or LEOPARD 2 tanks.

The Polish industrial defence potential grouped in the Polska Grupa Zbrojeniowa S.A. (Polish Armaments Group) is fully prepared to implement the proposed solutions into industrial practice.

The use of existing technical and technological facilities will have a significant effect on the "cost-effect" relationship and will also significantly improve the logistic support for the future production. At the same time, access to the Polish-made components and systems not only guarantees independence in the event of an armed conflict, but also allows for the further development of defence industry plants related to tracked vehicles and the education of new, indispensable specialists, with the generation gap already present [22].

The proposed modernized tank, the PT-91 M2 version, put into service in the Polish Armed Forces may also become an attractive export offer both for the European market and for other markets.

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