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Original article

Modern weapon systems equipped with stabilization systems: division, development objectives, and research problems

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INFORMATION

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ABSTRACT

The paper presents the results of theoretical analyses and literature review in the field of construction of remotely and manually controlled weapon systems used by the Polish Armed Forces as well as foreign turret systems. The paper also contains information, not available in the teaching literature, concerning division of weapon systems and development objectives in terms of weapon stabilization systems used in manually and remotely controlled turret systems.

KEYWORDS

weapon systems, turret systems, weapon modules

Introduction

The basic component of weapons used in modern combat vehicles is remotely or manually controlled weapon modules, in which one of the main elements that determine the correct implementation of the hit process, including the effectiveness of dynamic shooting (in motion), is the weapon stabilization system.

Since the introduction in the Polish Armed Forces of the Rosomak APC with the OTO Melara turret system, which is equipped with a 30 mm automatic MK44 Bushmaster cannon stabilized in two planes, it can be seen that the needs of land forces indicate that stabilization systems are becoming an integral part of weapon modules. This is also confirmed by the project implemented in the Polish weapons industry, where the final product is to be a remotely controlled 30 mm turret system (ZSSW) (Fig. 1).

1. Weapon module characteristics

Weapon modules (Fig. 2), also called turret modules, which can be controlled manually or remotely are also called unmanned and manned. Both manually and remotely controlled turret systems can be equipped with a weapon stabilization system.

Fig. 1. ZSSW
Source: Prepared by the author.

Manually controlled weapon systems are controlled by personnel using similar manipulators as in remotely controlled systems, but the personnel are located in the turret basket and control signals are transmitted directly to the controlled devices by means of cable harnesses [1].

Remotely controlled weapon systems are also controlled by personnel using manipulators, but control signals are sent to the actuators via, for example, a rotary contact or optical connector and the design of a remotely controlled system does not include a turret basket, since the operator's seat (control compartment, sighting compartment) may be anywhere in the vehicle [1].

The basic elements of an example remotely controlled weapon system are listed below:

a) a base (turret base plate) that integrates the turret with the vehicle body,
b) a rotary-contact connector for transmitting signals from inside the vehicle to external components or vice versa (technologically advanced systems, optical links are used),
c) a cradle, a structural element used for mounting weapons; an optoelectronic head can also be fitted to it,
d) a reloading mechanism,
e) main and auxiliary weapons,
f) optoelectronic heads for detecting, recognizing, and identifying objects (targets) in different weather conditions and for measuring distances,
g) a power supply module, a unit that supplies components of the system, also enabling the components to work with voltage peaks within a fixed range,
h) a drive unit, electric motors (or hydraulic drives) for rotating the turret in the azimuth and elevation planes, and auxiliary drives for changing the position of the auxiliary weapons,
i) a monitor,
j) a control unit, a manipulator component used by the operator to guide the weapons to the target,
k) the stabilization system is a system mounted inside the vehicle and the turret; the operator uses the manipulator while guiding the weapon to the target with

the stabilization system has the ability to conduct a more accurate and effective fire while the vehicle is moving on uneven ground.

As a result of an analysis of literature and the weapons market, it can be concluded that the division and classification of medium and large-caliber turret systems in terms of ballistic protection has also been made (Fig. 2). This division is due to the fact that in manned turret

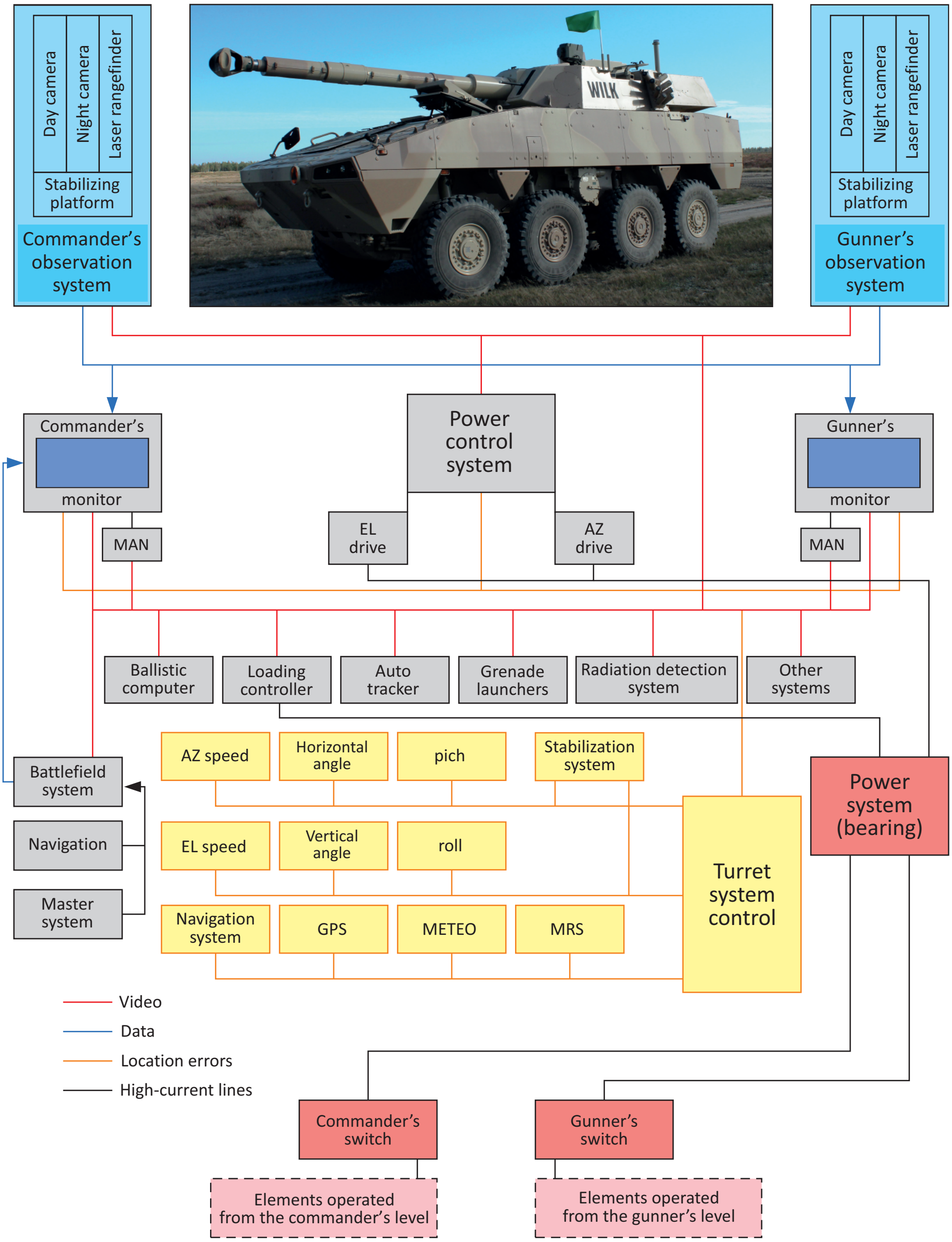

Fig. 2. ZSSW Block diagram of the structure of the turret system
Source: Prepared by the author.

systems, the operator is often above the top plate of the vehicle body and it was the operator who was protected, while in unmanned systems the operator is under the surface of this plate; however, the use of control units on the top plate of the vehicle body also required additional armoring of the external elements of the turret system.

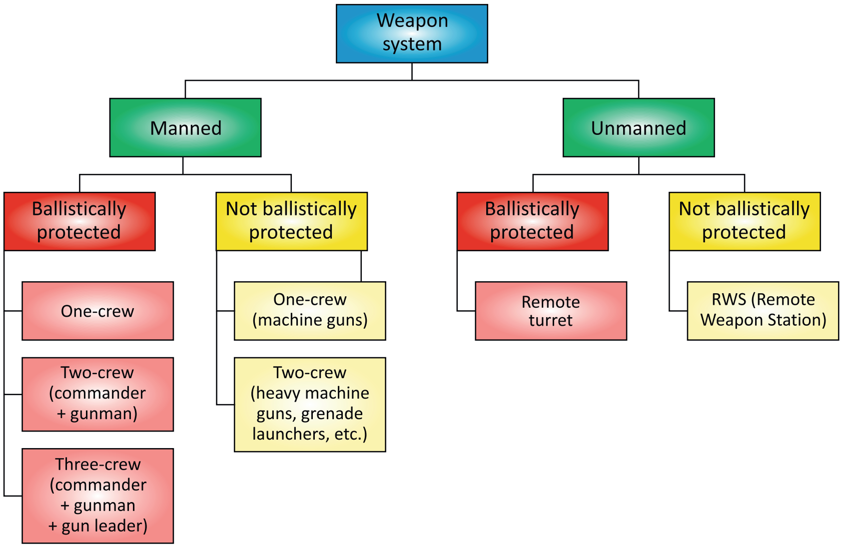

Fig. 3. Classification of turret systems
Source: [2].

The presented division was developed in 2009 and did not qualify remotely and manually controlled weapon systems of smaller caliber e.g. 5.56 mm, 7.62 mm, and 12.7 mm, which are always located on the upper plate of the vehicle body, as ballistically protected. However, it can now be concluded that they meet the criteria to be considered as protected, as most manufacturers ensure that the required armoring can be added to protect system equipment outside the vehicle body. The additional armoring of the system significantly increases the weight of the system, thus increasing inertia mainly in the azimuth plane; the final effect is deterioration of technical parameters (e.g. maximum armor guidance speeds and stabilization system performance, which also limits the possibility of making full use of the firing performance that the system should have).

A very important criterion for the division, which has not been taken into account, and should be, as it is very important from the point of view of crew safety, is the possibility of loading ammunition from inside and outside the vehicle. This function has a very significant impact on the protection and safety of the crew. This parameter was taken into account by the Polish consortium implementing the ZSSW project.

Therefore, according to the author of the division, protection, considered only in terms of ballistic protection, is insufficient and should be considered mainly in terms of protection of crew members. Ballistic protection of only the elements of the system does not seem to be fully justified, because people are the most important link [3].

2. Purpose of the weapon stabilization system

The weapon stabilization system (Fig. 4) is the main element of the turret system responsible for the correct implementation of the process of hitting while in motion. Generally speaking, it is an automatic aiming line control system whose task is to maintain the aiming line set by the operator while entering ballistic information at the controller input.

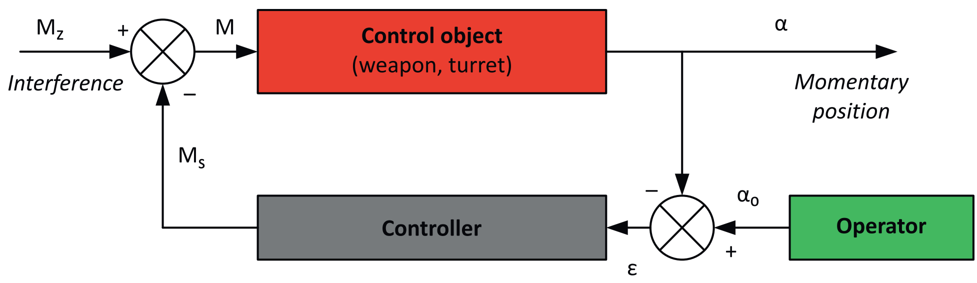

Fig. 4. Basic diagram of the stabilization/regulation system
Source: Prepared by the author.

An analysis of the basic diagram of the stabilization system indicates that the parameters important for the assessment of the implementation of the hit process while maintaining the required effectiveness of the incapacitating fire are [4]:

a) changes in the angular inclination of the barrel in elevation over time αl(t),
b) changes in the angular deviation of the barrel in azimuth over time βl(t),
c) changes in the angular inclination of the body in elevation over time αk(t),
d) changes in the angular deviation of the body in azimuth over time βk(t).

3. Development of weapon stabilization systems

The progressive development of weapons stabilization systems has made it possible to divide them according to the generation of the stabilization system used. However, there is only one aim of using stabilization systems in military vehicles, regardless of their generation: to achieve the lowest possible deflection of the weapon from the aiming line. Thus, achieving the smallest value of:

a) angular inclination of the barrel in elevation over time αl(t) from the expected value;
b) angular deviation of the barrel in the azimuth in time βl(t) from the expected value.

Originally stabilizers were used in ship guns. In the tank technology, initially immature designs of stabilizers were used in the M2A2E3 American light tanks in 1938, in the M3 tanks in 1941, and later in the M4 medium tanks [5]. Some of the M4 tanks were also equipped with azimuth cannon stabilization. However, the first recognized double-plane stabilization system was the one used in the British high-speed tank Centurion manufactured in the years 1945-1962.

The development of weapon stabilization systems from 1938 to the present day has allowed for its division into generations. Despite the generally accepted division of automatic control systems (differentiating, proportional-differentiating, proportional-differentiating-integrating), the division of weapon stabilization systems is the following [6]:

a) 1st generation systems,
b) modified 1st generation systems,
c) 2nd generation systems,
d) modified 2nd generation systems,
e) 3rd generation systems,
f) modified 3rd generation systems,
g) 4th generation systems.

The above-mentioned division from first generation systems to third generation systems was first proposed in [6].

The proposed division results mainly from the development of generations of tanks, which the author of [6] did not mention in his dissertation, but the chosen direction is clearly justified because it is mainly the weapons and their capabilities that determine the tank's fire performance. Therefore, this division is continued with the modified 3rd generation systems and the 4th generation systems.

In principle, it can be assumed that the basic differences between the different generations result from the type of sensors and the number of measured values used to support the weapon guidance process.

Because 4th generation systems are modern systems, they will be described in this article.

4th generation stabilization systems implement two types of combat readiness, in which the gunner is able to use the so-called two "stabilization loops". The first is "to attach the weapon to the aiming device", the second is "to attach the sights to the weapon (barrel axis)". Of course, 4th generation systems also have image stabilization systems, an auto tracker, and a "hunter-killer" mode.

The hunter-killer mode consists in the fact that the commander locates and identifies the target and, once he decides to destroy it, passes on its captured image to the display of the gunner who continues to track it accurately and has the ability to use fire at it. Having the hunter-killer mode is a distinctive feature of the most modern tanks. It is also important to have an auto-tracking function, i.e. automatic tracking of the selected target. The auto-tracking function in modern systems is available to the commander as well as to the gunner, so the commander can pass the target captured in the auto-tracking mode to the gunner for further tracking.

In the cannon-to-sight linking mode, the sighting line movement functions are generated automatically as a response to all unintended changes in the spatial orientation of the sighting line. The two-axis stabilization of the sighting line is controlled by an internal servocontrol built into the control unit. The control loop is driven by the reaction to the dynamics of directional gyros which measure angular deflections of the sighting line and angular velocity changes of the main weapon.

In the case of an angular deviation greater than the required value, the gunner is not able to fire. Additionally, during the implementation of the hitting process, the angular velocity of the cannon and the turret is measured; if the velocity is higher than the required one and there is no coincidence of the aiming line with the axis of the barrel, the gunner is also unable to fire or can do so but the shot will be ineffective.

Stabilization in the above-mentioned systems is achieved by sending the speed signal to the control loop as compensation for the interference measured by gyroscopes. The signals for the movement of weapons in the azimuth and elevation are derived from information related to the change of target sighting lines and information from gyroscopes. The cannon to sight linking mode is the main mode of operation of the 4^{th} generation weapon stabilization systems and is more accurate due to lower inertia of the optical elements and better balance.

The sight to barrel linking mode is an additional mode and is used in case of malfunction of the first mode. In this mode, the sighting line follows the weapon, making only corrections related to ballistic compensation.

3.1. Principal development objectives for arms stabilization systems

Continuous development of weapon stabilization systems has been and is related to the requirements that are placed on these systems [7]:

a) accuracy of stabilization of the set position (small angular vibrations of the turret with known ground forces),
b) short adjustment time,
c) quick run-up,
d) quick braking,
e) large range of guidance speeds (low speeds for precision, high for quick fire maneuvers),
f) simplicity and ease of use,
g) reliability during operation,
h) safety during use,
i) small size and weight.

An analysis of the requirements presented in the dissertation [7] leads to the conclusion that for the purposes of identifying the parameters, the main objective of the development of weapon stabilization systems is to achieve:

a) the smallest possible angular inclination of the barrel in the elevation αl(t) from the set aiming line,
b) the smallest possible angular deviation of the barrel in the azimuth βl(t) from the set aiming line,
c) the shortest possible response times of the stabilization system to forced action tresp(t)

using the largest and most accurate amount of information about the angular position of the vehicle body, which are caused by [7]:

a) the properties of the terrain,
b) the speed of movement of the object,
c) the dynamic properties of the suspension,
d) the characteristics of the suspension system (adhesion to the ground),
e) the drive train and the engine vibrations.

Conclusions

Continuous development of weapon stabilization systems is determined by the continuous development of technology used in the construction of weapon modules.

For many years, there have been no publications on fire-free methods, adequate and applicable in the process of verification of modern systems without the use of combat ammunition. The lack of the above mentioned testing methods makes it necessary to undertake works that may result in new testing devices as well as innovative testing methods enabling the evaluation of these systems or the use of technical parameters to assess their functioning.

The fact that research work was stopped a dozen or so years ago, although unjustified from the scientific point of view, was caused by the high costs of research on such systems.

This fact and the undertaking of pioneering work by the Polish weapons industry on the development of a modern remotely controlled turret system justifies the development of innovative testing methods that enable comprehensive verification of turret modules while maintaining relatively low research costs.

The research carried out in the years 2009-2017 by the employees of the Military Institute of Armor and Motor Vehicle Technology enabled the preparation of analytical and theoretical background and precise measuring equipment enabling the assessment of the hit process within the framework of dynamic shooting on the basis of the identified weapon stabilization system operation parameters without the use of combat ammunition.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

The author contributed to the interpretation of results and writing of the paper. The author read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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Biographical note

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Współczesne systemy uzbrojenia wyposażone w układy stabilizacji: podział, cele rozwoju i problemy badawcze

STRESZCZENIE Artykuł przedstawia wyniki przeprowadzonych analiz teoretycznych oraz badań poznawczych w zakresie budowy zdalnie i ręcznie sterownych systemów uzbrojenia będących na wyposażeniu polskich Sił Zbrojnych jak również systemów wieżowych zagranicznych. W artykule zawarto również informacje niedostępne w literaturze dydaktycznej dotyczące podziałów systemów uzbrojenia, celów rozwoju w aspekcie systemów stabilizacji uzbrojenia będących wyposażeniem ręcznie i zdalnie sterowanych systemów wieżowych.

SŁOWA KLUCZOWE systemy uzbrojenia, systemy wieżowe, moduły uzbrojenia

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