ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1168476

MODEL TESTING OF STABILISING AND TRACKING CONTROL SYSTEM IN MAIN BATTLE TANK

Krzysztof M. Papliński

Military University of Technology, Faculty of Mechanical Engineering
Gen. S. Kaliskiego Street 2, 00-908 Warszawa, Poland
tel.: +48 261 837403, fax.: +48 261 837370
e-mail: krzysztof.paplinski@wat.edu.pl

Abstract

The subject of discussion is a tank gun stabiliser (in azimuth and elevation). For the investigation of the considered control system one applied a method of computer simulations. The mathematical model and its numerical implementation were experimentally verified. The results of experimental and model simulation investigations showed that the mathematical model and its numerical implementation were worked-out correctly.

Using the verified mathematical model of the system, the simulation investigations of the influence of regulation potentiometers settlings on stabilisation exactness and transient processes quality were carried-out. The possibilities of improving performance characteristics of the stabiliser via altering of feedback's gain coefficients as well as the influence of disturbing inputs amplitude and frequency (propagated from the hull on the gun and turret) on stabilisation exactness of a given position were also analysed.

The presented technique is quite general and may be applied to any type of vehicle to study dynamic effects of several rigid bodies, which move relative to each other (when displacements are small) and are connected by constraint equations.

Keywords: *main battle tank, stabilising and tracking control system, tank gun stabiliser, model testing*

1. Introduction

The battle tanks are equipped with two-axis stabilisation systems. The stabilisation system compensates the velocities of the vehicle and automatically maintains the position of the gun at a fixed bearing in space.

In order to simplify identification, the system was divided into appropriate functional parts. Then, via laboratory tests, dynamic and static characteristics of those parts are obtained, and numerical values of coefficients of suitable mathematical model of the system were determined.

The structural scheme of the overall system was derived because of the obtained static characteristics and transfer functions of individual parts of the system. Because of obtained system of differential and algebraic equations as well as of the knowledge about the system feedbacks, the overall structural scheme of the system has been found (see Fig. 1).

2. Force acting on a tracked vehicle from the ground

Tracked fighting vehicles move over rough ground where ups and downs are about 4-10 meters long and 0.05-0.4 meters high. The investigated vehicles are able to fire on the move (stabilisation system automatically maintains the position of the gun and turret at a fixed bearing in space) only at speed of 5-20 km/h. In that circumstances, average frequency of the hull motion in roll (γ_K) is about 0.8 Hz, in yaw (ψ_K) it is about 0.6 Hz and in pitch (φ_K) it is about 1.1 Hz. Therefore, the investigations were carried-out for such amplitude and frequency values of disturbing signals.

Determined force can be obtained while moving the tank around obstacles on a specially selected shape, size and arrangement. The study stabilizer in the determined obstacles conditions used obstacles of all shapes and markings of the dimensions shown in Figure 2. The test stabilizer used two types of obstacles: a low – H1 and high – H2. These obstacles were different dimensions. The dimensions used obstacles are given in Table 1.

Tab. 1. Dimensions of obstacles used in research stabilizer under conditions determined excitations

	l [m]	H [m]
low obstacle – H1	4.4	0.17
high obstacle – H2	5.1	0.34

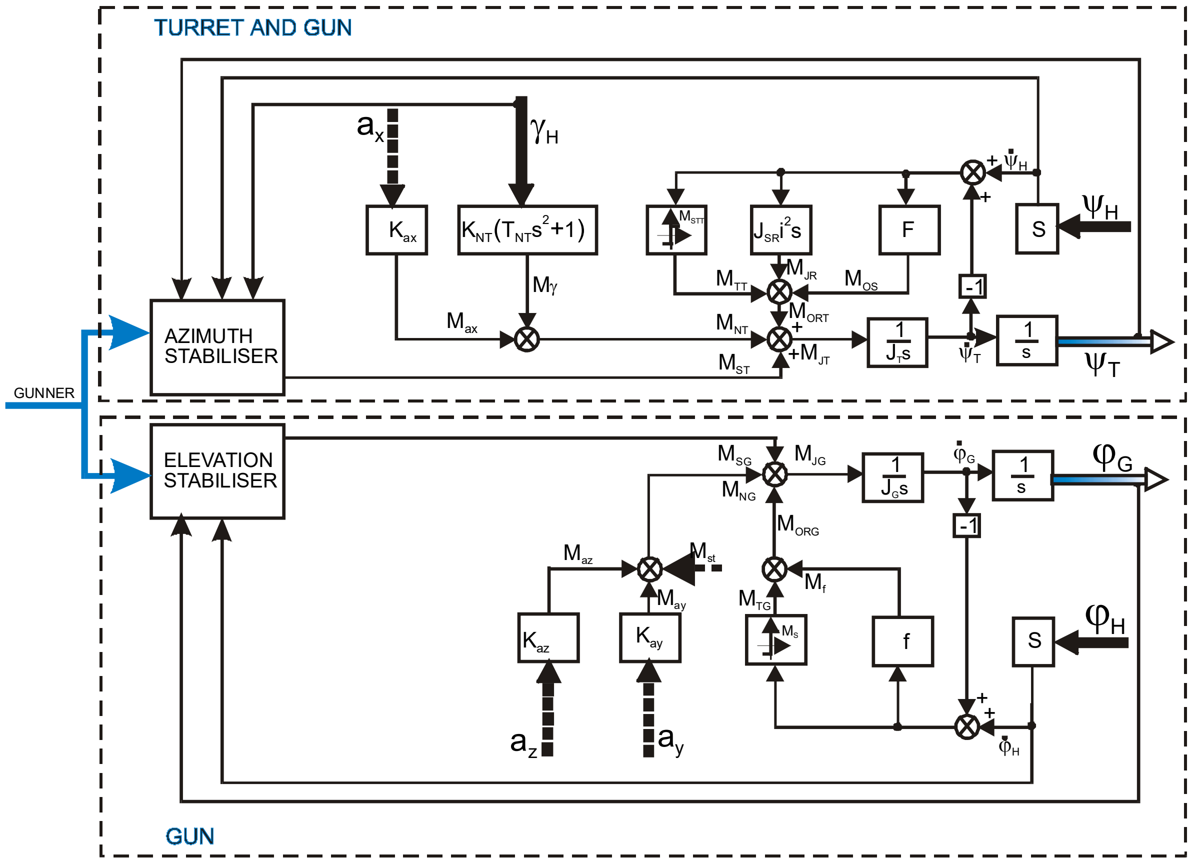

Fig. 1. Structural scheme of stabilised main armament

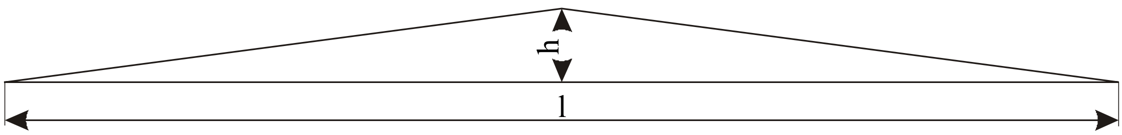

Fig. 2. The shape and dimensions of the applied obstacles

Detailed descriptions of requirements were presented in [*4, 6, 8, 10÷12, 18*].

To obtain values of over-regulations *(h)* and the settling time (t_r), one gives the input function (disturbing signals) the following form:

$$y(t) = \begin{cases} 0 & t < 1, \\ \mathrm{A_w}[1 - (\cos 2\pi f_w t)] \quad for & 1 \le t \le t_i, \\ 0 & t > t_i. \end{cases} \tag{1}$$

It is similar to a single irregularity of road surface flattened by tracks (that make the road for wheels). To obtain attenuation characteristics of the gun and turret angular vibration, one gives the harmonic function as an input function.

3. Model testing

For the investigation of the considered control systems, a method of computer simulations has been applied. Calculations were done using MATLAB-SIMULINK program. The mathematical model and its numerical implementation have been experimentally verified. Mathematical model of the vehicle and the models of gun stabilisers (experimentally verified because of experimental investigations results) were tested in common. To this aim:

- the results of model testing (for open-loop system) have been compared with the existing results of experimental tests carried-out on a real plant;
- tests of the complete closed-loop system have been carried-out and their results have been compared with the results of numerical computations.

The results of experimental and model simulation investigations showed that the mathematical model and its numerical implementation have been worked-out correctly. Using the verified mathematical model of the system, the simulation investigations have been carried-out.

To obtain values of the amplitude of the first over-regulation (h_1) and the settling time (t_r), that are the main parameters that describe transient processes quality, after disturbances caused by the reference signal given by the operator ($\mathrm{U_{PK}}$) the input function was given as a rectangular impulse of voltage.

Using the verified mathematical model of the system the simulation investigations of the influence of regulation potentiometers settings $c_K, c_P, c_N, c_C, p_{WP}, p_{WK}$ (within blocks of the stabilizer in Fig. 1) on stabilisation exactness and transient processes quality (i.e., setting time and magnitude of the first over-regulation) have been carried-out. These investigations show that appropriate settings have essential meaning for obtaining right performance characteristics of the stabiliser. By contraction of the area of admissible regulation settings, the performance characteristics may be improved even about several percent.

The possibilities of improving performance characteristics of the stabiliser via changing of internal feedbacks gain coefficients have also been analysed. Although alteration of gain coefficients of these feedbacks does not require essential intervention in construction of individual modules of the stabiliser, however the results show that these attempts are inefficient. On the other hand, it is observed that alterations of construction parameters of the gun-turret as well as cooperating conditions in the interlinking of hull and gun-turret have essential more influence on the quality of stabiliser performance. In the result of investigations, the quantitative and qualitative effects of structural changes of the system have been determined.

Improvement of the turret armour (in order to increase ballistic protection of combat vehicle) lead to an increase of the turret moment of inertia and coulomb friction. Similar effects cause increase of gun calibre (in order to improve firepower of combat vehicle). The ranges of the turret and the gun moments of inertia (J_W, J_A), moments (M_{TS}, M_{st}) acting on the turret and the gun due to coulomb damping between the turret and the hull as well as the gun and the turret were chosen for wide kind scope of tanks (from light tanks to heavy tanks). The main parameters that describe transient processes quality, after disturbances caused by the reference signal given by the operator (U_{PK}) as a rectangular impulse of voltage and after disturbances propagated from the hull on the gun and turret, are the amplitude of the first over-regulation (h_1) and the settling time (t_r).

Figures 3, 4, 5, 6 show the exemplary characteristics of the amplitude of the first over-regulation as well as of the settling time versus turret and gun moment of inertia.

To confirm the simulation results, one can mention the effect of modification of the real tank. After improvement of the turret armour, its moment of inertia increased from 11780 kgm^2 to 13740 kgm^2 and the effect measured in the tank confirmed the simulation results [20].

The influence of input amplitude and frequency of disturbing signals (propagated from the hull on the gun-turret) on stabilisation exactness of a given position was also analysed [4, 6, 8, 12, 18]. The investigations showed that the performance quality of the stabiliser could be essentially improved via a proper choice of the tank suspension characteristics (mainly characteristics of damping elements and shock absorbers). The suspension allows the road wheels to follow the vertical motion of tracks without transferring too much of that motion to the hull and stabilised armament.

All changes leading to increase negative effect of transient processes first over-regulation and increase of settling time are unfavourable.

4. Conclusion

For the investigation of the considered type of control systems a computer simulations method has been applied. Because of the mathematical model an algorithm and computer program has been worked-out. Making use of the MATLAB-SIMULINK program, a scheme for numerical computations has been worked-out.

The author is of the opinion that the proposed methodology of simulations investigations represents a significant level of generality. It comprises a complex analysis of the system of gun and turret stabilisation beginning from identification of individual functional parts of the system, through the algorithm of mathematical model building, up to detailed investigation of system properties.

In technique that has been presented whereby the equations of motion are associated with a military tank. The technique is quite general and may be applied to any type of vehicle to study dynamic effects of several rigid bodies, which move relative to each other (when displacements are small) and are connected by constraint equations.

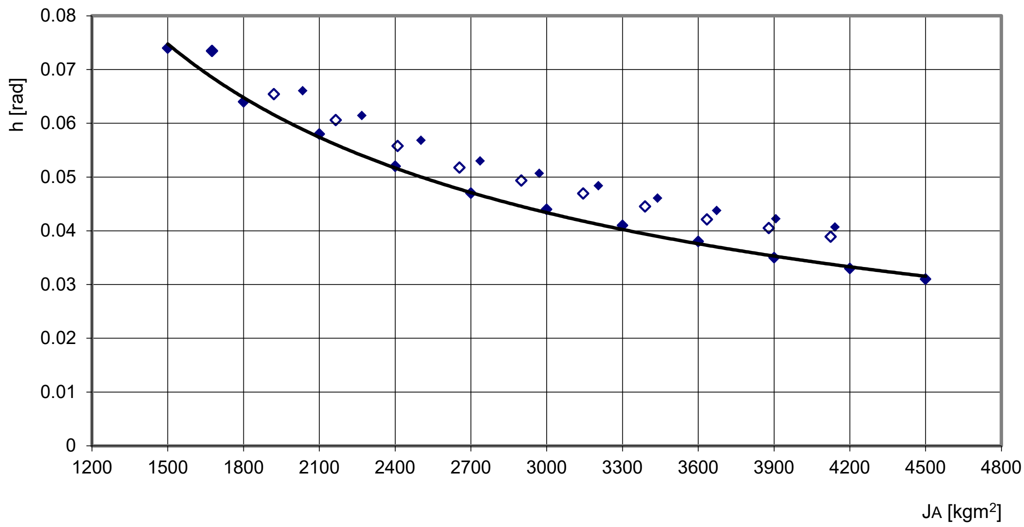

Fig. 3. Amplitude of the first over-regulation versus gun moment of inertia

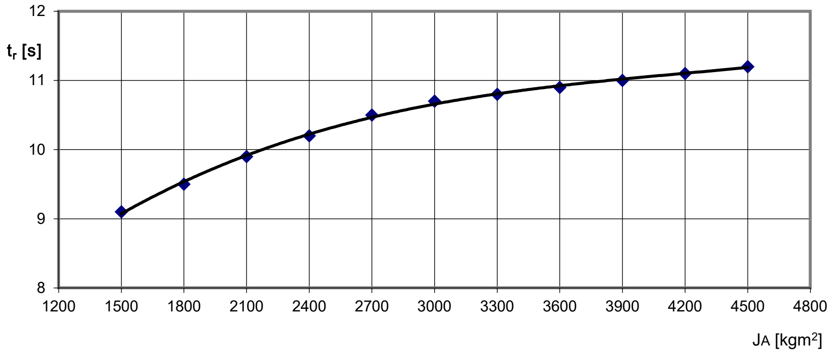

Fig. 4. Settling time versus gun moment of Inertia

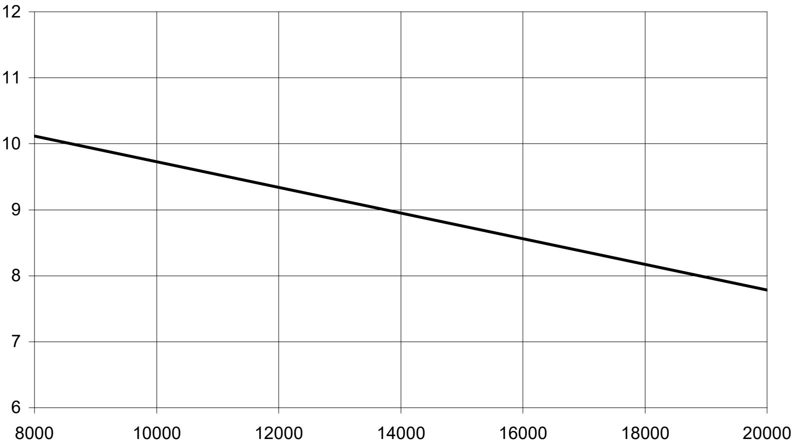

Fig. 5. Settling time versus turret moment of inertia

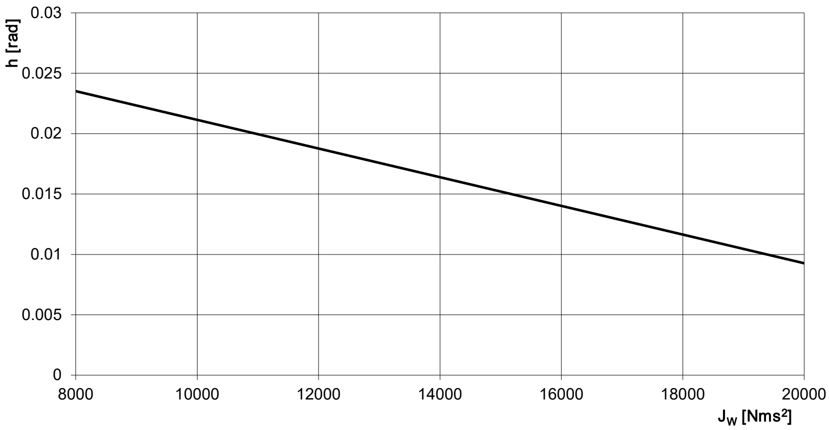

Fig. 6. Amplitude of the first over-regulation versus turret moment of inertia

References

[1] *Czołg śretni T-55A i czołg dowódczy T-55AD*. Opis i użytkowanie, MON, Panc.Sam. 46/68.

[2] Krupka, R. M., *Mathematical simulation of the dynamics of military tank*, SAE , Technical paper series, International Congress & Exposition, Detroit, Michigan 1985.

[3] Tokarzewski, J., Papliński, K., Juszczyk, A., Sobczyk, Z., *Urządzenia elektryczne i osprzęt pojazdów mechanicznych*, część II, Układy stabilizacji uzbrojenia wozów bojowych, Skrypt WAT, Warszawa 1999.

[4] Papliński, K., Rybak, P., *Rozwój systemów zwiększających siłę ognia prowadzonego z armaty czołgowej*, Zeszyty Naukowe WSO WP nr 1 (09), pp. 75-93, Poznan 2001.
[5] Juszczyk, A., Papliński, K., Sobczyk, Z., *Układy stabilizacji uzbrojenia wozów bojowych*, Zeszyty Naukowe AON, Nr 4/96, pp. 260-275, Rembertów 1996.
[6] Papliński, K., Sobczyk, Z., *The tank gun elevation stabiliser as a second – order multi-loop servomechanism*, UEES'99, Vol. 3, pp. 1377-1382, St. Petersburg (Russia) 1999.
[7] Papliński, K., *Modelling and simulation of a multi-loop servomechanism*, AVCS'98, pp. 57-62, Amiens (France) 1998.
[8] Borkowski, W., Papliński, K., *Simulation of a second-order multi-loop servomechanism*, International Conference MMAR'94, pp. 221-226, Międzyzdroje 1994.
[9] Papliński, K., Sobczyk, Z., Tokarzewski, J., *Badanie obciążeń dynamicznych działających na uzbrojenie czołgu*, II Konferencja Odporność Udarowa Konstrukcji, pp. 267-276, Rynia 1998.
[10] Papliński, K., *Uzbrojenie czołgu jako obiekt regulacji dla układu stabilizacji położenia kątowego*, Archiwum Motoryzacji Nr 1-2, pp. 19-30, PWN Warszawa 2001.
[11] Nikitin, A. O., Cergeev P. B., Tarasov B. B., *Teoriya Tankov*, Moskva 1956 (in Russian).
[12] Korneev, B. B., *Elektroavtomatika i Elektrooborudovaniye tankov,* Moskva 1964 (in Russian).
[13] Korneev, B. B., *Osnovy avtomatiki i tankovye avtomaticheskiye sistemy,* Moskva 1978 (in Russian).
[14] Belanovckiy, B. A., *Elektroavtomatika i Elektrooborudovaniye tankov,* Moskva 1963 (in Russian).
[15] Belanovckiy, B. A., Popov, E. P., *Teoriya sistem avtomaticheskogo regulirovaniya,* Nauka, Moskva 1975.
[16] Belanovckiy, B. A., *Dinamicheskiy analiz sistem avtomaticheskogo regulirovaniya,* Nauka, Moskva 1970 (in Russian).
[17] Missala, J.,Missala, T., *Elektryczne pomiary wielkości mechanicznych*, PWN, Warszawa 1971.
[18] Papliński, K., Sobczyk, Z., *Modelling of a tank gun stabiliser*, IASTED International Conference, Innsbruck, pp. 186-189, Austria 1997.
[19] Papliński, K., *Modelling of a Nonlinear Second-Order Multi-Loop Servomechanism*, IASTED International Conference, pp. 18-21, Grindewald, Switzerland 1998.
[20] Papliński, K., *Badania możliwości polepszenia układu stabilizacji wieży czołgowej*, Rozprawa doktorska, Warszawa 1994.
[21] Gibson, J. E., Tuteur, F. B., *Człony układów regulacji*, WNT, Warszawa 1961.
[22] Kaczorek, T., *Teoria sterowania*, PWN, Warszawa, T. 1 1977, T. 2 1981.
[23] Pląskowski, A., *Eksperymentalne wyznaczanie własności dynamicznych obiektów regulacji*, WNT, Warszawa 1965.
[24] Bubnicki, Z., *Identyfikacja obiektów sterowania*, PWN, Warszawa 1974.
[25] Burdziński, Z., *Teoria ruchu pojazdu gąsienicowego*, WKŁ, Warszawa 1972.
[26] Borkowski, W., Papliński, K., *Simulation of a second-order multi-loop servomechanism*, Symposium MMAR'95, pp. 389-394, Międzyzdroje 1995.
[27] Papliński, K., Tokarzewski, J., *Badania symulacyjne układu stabilizacji położenia kątowego wieży wozu bojowego*, Konferencja Kazimierz Dolny'97, pp. 141-146, Kazimierz Dolny 1997.
[28] Borkowski, W., *Dynamiczna analiza konstrukcji metodą elementów skończonych*, Dodatek do Biuletynu Nr. 5 (381) WAT, Warszawa 1984.
[29] Borkowski, W., Konopka, S., Prochowski, L., *Dynamika maszyn roboczych*, WAT, Warszawa 1992.
[30] Paszkowski, S., *Analiza przyczyn niedokładnej pracy automatyki czołgu oraz ustalenie wniosków i zaleceń*, Sprawozdanie z pracy naukowo-badawczej, Warszawa 1967.