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MODEL TESTINGS OF TANK GUN STABILISER

The subject of this paper is a real stabilising and tracking control system-namely, the tank gun horizontal stabiliser.

The simulation investigations of the influence of regulation potentiometers settlings on stabilisation exactness and transient processes quality were carried-out using a verified mathematical model of the system.

The author analysed 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-turret) on stabilisation exactness of a given position.

In the result of model investigations, it was found that it would be impossible to improve significantly the stabiliser performance quality with its present structure. For this reason, one investigated the possibilities of adding new feedbacks and their influence on the stabilisation quality. The introduced feedbacks improved performance parameters of the stabiliser by about thirty to fifty percent.

1. Introduction

High demands for increased battlefield mobility of tanks inevitably lead to the requirement that they be able to fire on the move, instead of having to stop every time they engage a target. This requirement calls, in turn, for gun control systems which minimise the effects of vehicle motion on the main armament of tanks and in particular on its ability to hit targets.

The subject of discussion is an electro -mechanic control system which makes it possible to aim at a target, track a target and stabilise a given gun turret angular position.

The systems devised to make tanks capable of firing on the move involve the use of two closed-loop servo systems, one operating about the elevation axis of the gun and the other about the traverse axis of the turret. Each loop

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incorporates gyroscopes to sense angular position and angular velocities of the gun in elevation and in azimuth, respectively. Any difference between actual velocities and those commanded by the gunner causes the elevation and traverse servomotors to rotate the gun and the turret in appropriate direction in order to nullify the difference or "error" and so to stabilise the gun. Thus, if the gunner holds his controls steady $\psi_0 = 0$ (Fig. 1), the two-axis stabilisation system will automatically maintain the position of the gun ψ_W at a fixed bearing in space. It is fixed in spite of any motion of the vehicle (in which it is mounted): in roll (γ_K – hall transversal vibration), pitch (hall longitudinal vibration) or yaw (ψ_K – hall „snake-like" vibration). In other words, the two-axis stabilisation system compensates for the angular velocities disturbances of the vehicle so that, in theory, the gun is unaffected by them.

Those basic two-gyroscope control systems have proved reasonably effective and even if they do not always make it possible for gunners to aim accurately on the move, they can at least aim roughly, so that only relatively small adjustments have to be made when the tank stops to fire. However, in the nature of things, the response of the basic systems is not sufficiently rapid to reduce gun-pointing errors to a sufficiently low level when tanks move at average speed over rough ground.

However, recent developments have resulted in new, more advanced gun control systems, which are greatly superior to the original type. In consequence, tanks can be provided with much greater ability to fire on the move than they have possessed so far.

The second-generation systems [9], [12], [27] are equipped with an additional gyroscope in feedback open loop which responds to angular velocities of the vehicle, and provides anticipatory commands to the elevation and traverse drives, thereby approximately it stabilises the gun. Thus, one additional gyroscope is mounted in the hull to sense the angular velocity of the hull in the plane of rotation of the turret, and to generate feedback commands to the traverse drive.

The considered electro-mechanic control system has a primary closed-loop with a rate integrating (free) gyroscope and a second feedback, closed-loop with a rate gyroscope (Fig. 1).

To improve performance characteristics of tank gun stabiliser, more elaborate systems should be brought into practice. It is possible by adding additional feedbacks [21], [22], [24], [27].

2. Mathematical model

In order to simplify the identification process, the system was divided into appropriate functional parts. Then, via laboratory tests, dynamic and static characteristics of those parts were obtained, and numerical values of coefficients of suitable mathematical models were determined [1], [2], [3], [10], [11], [12].

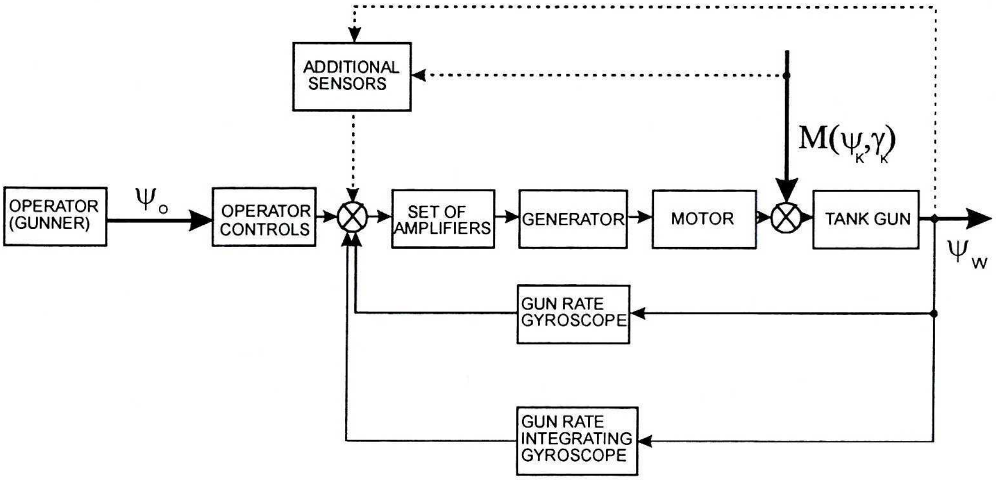

Fig. 1. The block diagram of tank gun stabiliser

The structural scheme of the overall system (with three inputs and one output) was derived on the basis of the obtained static characteristics and transfer functions of individual parts of the system, and based on the knowledge about the system feedbacks.

The input signals are (Fig. 6):

U_{PK} – the reference signal given by the operator,

ψ_K – the disturbing signal caused by the hull "snake-like" movements,

γ_K – the disturbing signal caused by the transversal angular displacements of the hull around the longitudinal axis.

The gun turret angular displacement ψ_w represents the output signal.

The system of differential and algebraic equations was formulated [13], [16], [17], [19], [20], [25], [26] on the basis of the structural scheme. The system of equations constitutes a mathematical model of the stabilizer. The differential equations constitute mathematical description of stabilizer modules, rate and current feedbacks and turret. These are ODE's of first or second order with constant coefficients. The algebraic equations describe nonlinear characteristics and summing nodes.

The system of differential and algebraic equations, formulated on the basis of the structural scheme, has the form:

$$T^2_{01}\ddot{U}_P + T_{02}\dot{U}_P + U_P - \dot{\psi}_W T_0 k_{SP} = 0, \tag{1}$$

$$\dot{\psi}_0 = U_{PK}k_{EM}, \tag{2}$$

$$(\psi_0 - \psi_W)k_{ST}c_K - U_K = 0, \tag{3}$$

$$(U_K - U_P)c_0 - U_{SU} = 0, \tag{4}$$

$$U_{SU}K_{W1} - U_{WE} = 0 \qquad (\text{for}) \qquad -U_{SU1} \le U_{SU} \le U_{SU1}, \tag{5}$$

$$\begin{gathered}-1244540U^4{}_{SU}+444193U_{SU}{}^3-60957U_{SU}{}^2+4107U_{SU}-15.7-U_{WE}=0\\ \text{(for)}\quad U_{SU1}\langle U_{SU}\le U_{SU2},\end{gathered}\tag{6}$$

$$\begin{gathered}883004U^4{}_{SU}+330272U^3{}_{SU}+48863U^2{}_{SU}+3635U_{SU}+10.3-U_{WE}=0\\ \text{(for)}\quad -U_{SU2}\le U_{SU}\langle U_{SU1},\end{gathered}\tag{7}$$

$$U_{WE}-U_{MWE}=0\quad\text{(for)}\quad U_{SU}\rangle U_{SU2},\tag{8}$$

$$U_{WE}+U_{MWE}=0\quad\text{(for)}\quad U_{SU}\langle -U_{SU2},\tag{9}$$

$$\dot{\psi}_W i_r k_T+U_T=\dot{\psi}\ \ i_r k_T,\tag{10}$$

$$R_I\dot{I}_S-U_I=0,\tag{11}$$

$$U_{WE}+U_I+U_T-U_{SA}=0,\tag{12}$$

$$U_{SA}K_{W2}-U_A=0\quad\text{(for)}\quad -U_{SA1}\le U_{SA}\le U_{SA1},\tag{13}$$

$$\begin{gathered}0.000311U^6{}_{SA}-0.064278U_{SA}{}^5-5.50826U_{SA}{}^4-250.468U^3{}_{SA}-6373.61U^2{}_{SA}-\\ -86054.3U_{SA}+481662-U_A=0\quad\text{(for)}\quad U_{SA1}\langle U_{SA}\langle U_{SA3}\quad\text{(and)}\quad U_A\langle U_{AM}\end{gathered}\tag{14}$$

$$U_A-U_{AM}=0\quad\text{(for)}\quad U_{SA}\ge U_{SA3}\quad\text{(and)}\quad U_{SA2}\langle U_{SA}\langle U_{SA3}\quad\text{(and)}\quad U_A=U_{AM}\tag{15}$$

$$\begin{gathered}-0.000463U^6{}_{SA}-0.095721U^5{}_{SA}-8.21027U^4{}_{SA}-373.658U^3{}_{SA}+\\ -9516.2U^2{}_{SA}-128584U_{SA}-720209-U_A=0\\ \text{(for)}\quad -U_{SA3}\langle U_{SA}\langle -U_{SA1}\quad\text{(and)}\quad U_A\rangle -U_{AM},\end{gathered}\tag{16}$$

$$\begin{gathered}U_A+U_{AM}=0\quad\text{(for)}\quad U_{SA}\le -U_{SA3}\\ \text{(and)}\quad -U_{SA3}\langle U_{SA}\langle -U_{SA2}\quad\text{(and)}\quad U_A=U_{AM},\end{gathered}\tag{17}$$

$$T_1\ddot{E}_A+T_2\dot{E}_A+E_A-U_A=0,\tag{18}$$

$$\dot{\psi}_W i_r k_E+E_S=\dot{\psi}_K i_r k_E,\tag{19}$$

$$R_\beta I_S-U_\beta=0,\tag{20}$$

$$E_A+E_S-U_\beta-U_S=0,\tag{21}$$

$$T_S\dot{I}_S-U_SK_S+I_S=0,\tag{22}$$

$$k_m i_r I_S-M_S=0,\tag{23}$$

$$\ddot{\psi}_W i^2{}_r J_{SR}+M_{JR}=\ddot{\psi}_K i^2{}_r J_{SR},\tag{24}$$

$$M_T=0\text{(for)}-\delta\le(\dot{\psi}_K-\dot{\psi}_W)\le\delta,\tag{25}$$

$$M_T-M_{TS}=0\quad\text{(for)}\quad(\dot{\psi}_K-\dot{\psi}_W)\rangle\delta,\tag{26}$$

$$M_T+M_{TS}=0\quad\text{(for)}\quad(\dot{\psi}_K-\dot{\psi}_W)\langle\delta,\tag{27}$$

$$M_\gamma = K_{NW} T_{NW} \ddot{\gamma} + K_{NW} \gamma \,, \tag{28}$$

$$M_{JR} + M_T - M_Z = 0 \,, \tag{29}$$

$$M_S + M_Z + M_\gamma - M_W = 0 \,, \tag{30}$$

$$\ddot{\psi}_W J_W - M_W = 0 \,. \tag{31}$$

For the differential equations, one assumed the zero initial conditions:

$$\psi_W = \dot{\psi}_W = \dot{\psi}_0 = U_P = U_K = U_{SU} = U_{WE} = U_T = U_I = U_{SA} = U_A =$$
$$= E_A = E_S = U_\beta = U_S = I_S = M_S = M_{JR} = M_T = M_Z = M_\gamma = M_W = 0$$

In the above equations, the following notation is used:

$T_0, T_{01}, T_{02}, T_1, T_2, T_S$ – denote time constants of rate gyroscop, amplidyne and turret d.c. motor, respectively;

$k_{SP}, k_{ST}, k_{EM}, c_K, c_0, K_{W1}, K_{W2}, K_S$ – denote gain coefficients of synchro-control-transformers of gyroscopes, aiming electromagnets of gyroscopes, regulation potentiometers of electronic amplifier, amplidyne and turret d.c. motor, respectively;

k_T, R_β, R_I, k_E – feedback gain coefficients;

$J_W, K_{NW}, T_{NW}, k_m, J_{SR}, i_r$ – construction parameters of turret, turret d.c. motor and turret reduction gear, respectively;

$U_{SU1}, U_{SU2}, U_{MWE}, U_{SA1}, U_{SA2}, U_{SA3}, U_{AM}, \delta, M_{TS}$ – characteristic points on non-linear characteristics of electronic amplifier, amplidyne and coulomb friction, respectively;

$\psi \;, \dot{\psi} \;, \dot{\psi}_0, U_P, U_K, U_{\;U}, U_{\;E}, U_T, U_I, U \;, U \;, E \;, E \;, U_\beta, U \;, I \;, M \;, M_{JR}, M_T,$ M_Z, M_γ, M_W – model state co-ordinates;

$U_{PK}, \gamma_K, \ddot{\gamma}_K, \dot{\psi}_K, \ddot{\psi}_K$ – inputs.

The system of equation (1)–(31) constitutes a mathematical model of the stabiliser.

3. Simulation investigations

Using the verified mathematical model of the system, one carried out the simulation investigations of the influence of the regulation potentiometers settlings (c_K, c_0) – see structural scheme on Fig. 6 – on the stabilisation exactness and the transient processes quality (reduction of the amplitude of first over-regulation h_1 as well as reduction of the settling time t_r – see Fig. 7). These investigations show that appropriate settlings have essential meaning for obtaining proper performance characteristics of the stabiliser. By contraction of the area of admissible regulation settlings, the performance characteristics may be improved even by more than ten percent [1], [2], [4], [5], [6], [7]. Setting range of regulation potentiometers are shown in Fig. 2.

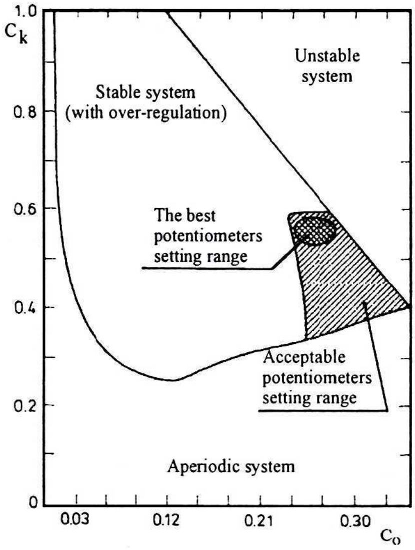

Fig. 2. Setting range of regulation potentiometers in main battle tank

The possibilities of improving performance characteristics of the stabiliser via changing of feedback's gain coefficients were also analysed. Although alteration of gain coefficients of these feedbacks did not require essential intervention in construction of individual modules of the stabiliser, the results showed that this approach was inefficient. On the other hand, it was observed that alterations of construction parameters of the gun-turret as well as improvement of co-operating conditions in the interlinking of hull and gun-turret had more essential influence on the stabiliser performance quality. In the result of investigations, the quantitative and qualitative effects of structural changes of the system were determined [1], [2], [4], [5], [6], [7].

The main parameters that describe transient processes quality, after disturbances caused by the reference signal given by the operator (U_P) as an rectangular impulse of voltage, are the amplitude of the first over-regulation (h) and the settling time (t_r) – see Fig. 7. Figures 3, 4, 5 show the characteristics of the amplitude of the first over-regulation as well as of the settling time versus turret moment of inertia (J_W) referred to the vertical axis of rotation, moment (M_T) acting on the turret due to coulomb damping between the turret and the hull, d.c. motor and gear box moment of inertia (J_{SR}) referred to the axis of rotation, respectively. The investigations were carried out for parameters of the tank before modification.

The ranges of the turret moment of inertia (J), moment (M) acting on the turret due to coulomb damping between the turret and the hull as well as d.c. motor and gear box moment of inertia (J_{SR}) were chosen for wide scope of kinds of tanks (from light tanks to heavy ones).

Improvement of the turret armour (in order to increase its combat resistance) lead to an increase of the turret moment of inertia. This had a negative effect on transient processes quality, and caused sharp increase of the first over-regulation (h) and the settling time (t) – see Fig. 3.

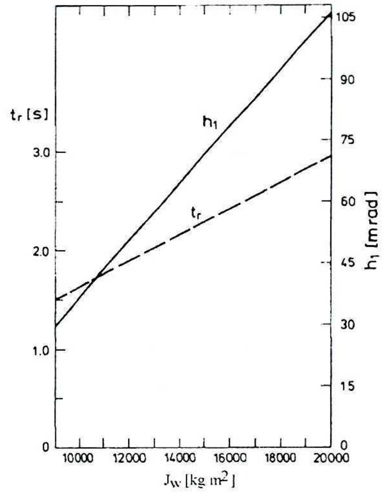

Fig. 3. Characteristics of the amplitude of first over-regulation (h_1) and of the settling time (t_r) versus turret moment of inertia (J_W) referred to vertical axis of rotation

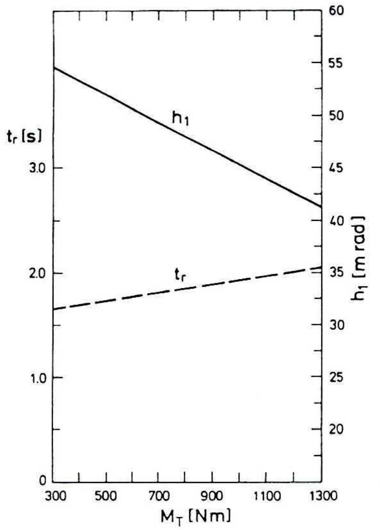

Fig. 4. Characteristics of the first over-regulation ( ) and of the settling time ( ) versus moment (M_T) acting on the turret due to coulomb damping between the turret and the hull

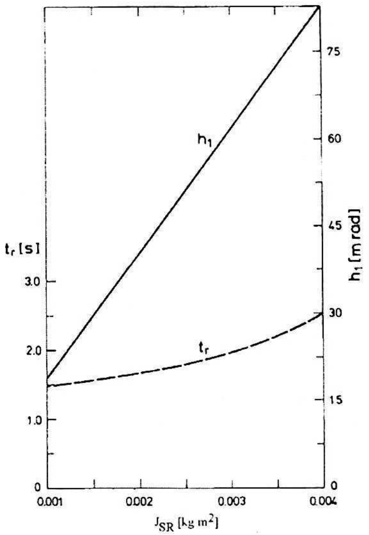

Fig. 5. Characteristics of the first over-regulation ( ) and of the settling time ( ) versus d.c. motor and gear box moment of inertia (J_{SR}) referred to the axis of rotation

To confirm the simulation results, one can mention the effect of modification of the tank T-55A. 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 [12].

Though we can observe a decrease of the first over-regulation for greater M (see Fig. 4), greater M makes it impossible to traverse the main armament more quickly and track the target at low but steady speed.

We can obtain good results by a decrease of d.c. motor and gear box moment of inertia (see Fig. 5). It may be reached by applying modern (lighter and more compact) constructions of the gear box and d.c. motor insted of the old ones built in the late fiveties.

The influence of disturbing of input amplitude and frequency (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.

4. Additional feedbacks

In the result of model investigations, it was found that it would be impossible to improve significantly the stabiliser performance quality with its present structure. For this reason, the possibilities of adding new feedbacks and their influence on the stabilisation quality was investigated. To this aim: additional feedbacks were introduced in the mathematical model of the system and appropriate modifications of computer program were performed; the most advantageous values of gain coefficients of these feedbacks were chosen.
The structural scheme of the overall system was then developed – see Fig. 6.

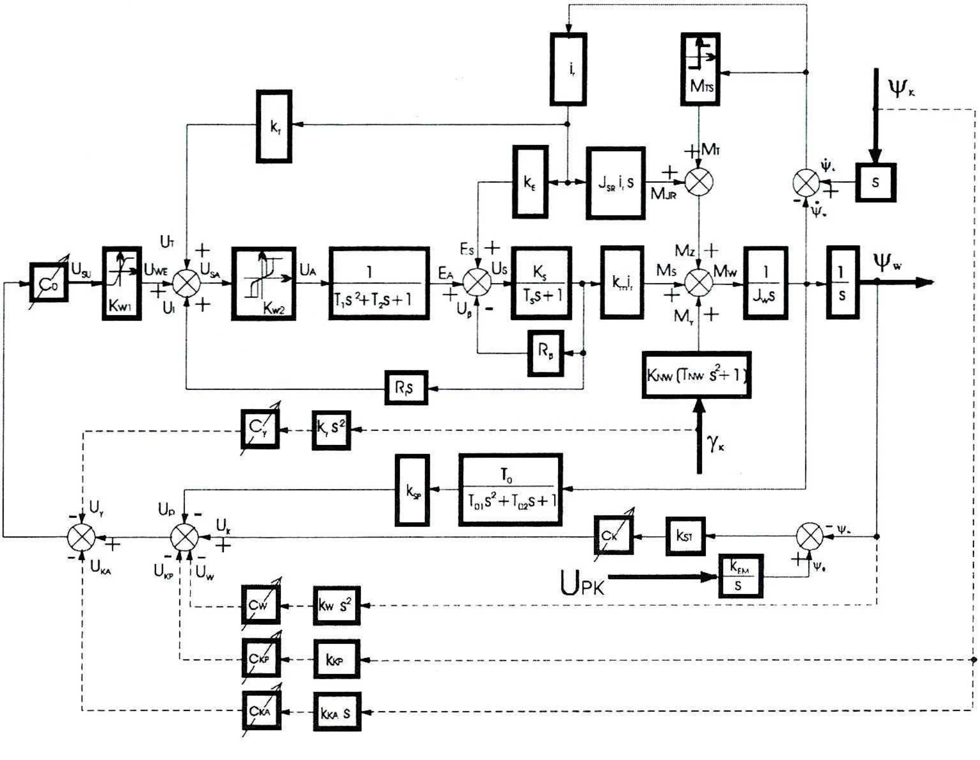

Fig. 6. Structural scheme of the system with additional feedbacks

The new proposed feedbacks are:

- feedback caused by the hull "snake-like" movements speed $\dot{\psi}_K$,
- feedback caused by the hull "snake-like" movements acceleration $\ddot{\psi}_K$,
- feedback caused by the gun turret "snake-like" movements acceleration $\ddot{\psi}_w$,
- feedback caused by the transversal angular displacements acceleration $\ddot{\gamma}_K$ of the hull around the longitudinal axis.

A system of new differential equations, formulated on the basis of the structural scheme with the modified feedbacks, has the form (of course real sensors are not proportional elements):

$$\dot{\psi}_K k_{KP} c_{KP} - U_{KP} = 0\,, \tag{32}$$

$$\ddot{\psi}_K k_{KA} c_{KA} - U_{KA} = 0\,, \tag{33}$$

$$\ddot{\gamma}_K k_\gamma c_\gamma - U_\gamma = 0\,, \tag{34}$$

$$\ddot{\psi}_W k_W c_W - U_W = 0\,. \tag{35}$$

In the above equations, the following notation is used:

$k_{KP}, k_{KA}, k_\gamma, k_W, c_{KP}, c_{KA}, c_\gamma, c_W$ – denote gain coefficients of synchro-control-transformers of angular-rate sensor and angular-acceleration sensors, and regulation potentiometers of these sensors, respectively;

$\ddot{\psi}_W, U_{KP}, U_{KA}, U_\gamma, U_W$ – model state co-ordinates;

$\ddot{\gamma}_K, \dot{\psi}_K, \ddot{\psi}_K$ – inputs.

The simulation investigations of the influence of new feedbacks gain coefficients $k_{KP}, k_{KA}, k_\gamma, k_W$ on stabilisation exactness and transient processes quality was carried-out using the modified mathematical model of the system. For the investigation of optimum values of new feedback coefficients, one applied the systematic searching method of the range of decision variables $k_{KP}, k_{KA}, k_\gamma, k_W$. On the basis of general requirements for tank turret stabilisers, appropriate limiting conditions were formulated.

Tracked fighting vehicles move over rough ground whose irregularities are about 4–10 meters long and 0.05–0.4 meteers high. The vechicles are able to fire on the move (stabilisation system automatically maintains the position of the gun turret at a fixed bearing in space) only at speed of 5–20 km/h. In these circumstances, average frequency of the hull motion in roll (γ_K) is about 0.8 Hz and in yaw (ψ_K) it is about 0.6 Hz (vertical dashed line in Fig. 8 and Fig. 9). Then, the investigations were carried-out for such amplitude and frequency values of disturbing signals.

Detailed descriptions of requirements is presented in [4], [6], [8], [10], [11], [12], [18].

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

$$y(t)\begin{cases} 0 & \quad t < 1, \\ A_w\left[1-(\cos 2\pi f_w t)\right] \quad \text{for} & \quad 1 \le t \le t_i, \\ 0 & \quad t > t_i. \end{cases} \tag{36}$$

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 turret angular vibration, one gives the input function a form of a harmonic function.

One analysed the responses of the system for a main battle tank and a modernised tank (with heavier tank turret).

In the result of model investigations, optimum values of new feedback's coefficients and their influence on the stabiliser performance quality were determined.

1. Negative feedback controlled by the hull "snake-like" movements speed $\dot{\psi}_K$.

a) The following results were obtained for parameters of the main battle tank turret and for optimum value $k_{KP} = 1.5$:

– the amplitude of turret vibrations was reduced by about 45% for input harmonic functions caused by the hull "snake-like movements;

– for disturbing signals in the form of a fragment of a harmonic function, one obtain about 50% reduction of the first over-regulation and about 32% reduction of the second over-regulation as well as about 16% reduction of the settling time;

b) The following results were obtained for parameters of the heavier tank turret and for optimum value $k_{KP} = 1.3$:

– about 32% reduction of turret vibrations amplitude was obtained for input harmonic functions caused by the hull "snake-like movements;

– for disturbing input signals in the form of a fragment of a harmonic function, one obtained about 55% reduction of the first over-regulation and about 33% reduction of the second over-regulation as well as about 15% reduction of the settling time;

2. Negative feedback controlled by the hull "snake-like" movements acceleration $\ddot{\psi}_K$.

a) The following results were obtained for parameters of the main battle tank turret and for optimum value $k_{KA} = 0.3$:

– about 18% reduction of turret vibrations amplitude was obtained for input harmonic functions caused by the hull "snake-like movements;

– for disturbing input signals in the form of a fragment of a harmonic function, one obtained about 40% reduction of the second over-regulation and about 20% increase of the first over-regulation as well as about 2% reduction of the settling time.

b) For parameters of the heavier tank turret and for optimum value $k_{KA} = 0.3$, the responses of the system were just the same as for the parameters of the main battle tank turret.

3. Negative feedback controlled by the transversal angular displacement acceleration $\ddot{\gamma}_K$ of the hull around the longitudinal axis.

a) For parameters of the main battle tank turret and for optimum value $k_\gamma = 0.07$, one obtained about 63% reduction of characteristic parameters of the system responses (the first and the second over-regulation, settling time) with harmonic inputs caused by the acceleration of the hull around the longitudinal axis, and at the same inputs in the form of a fragment of a sinusoidal function.

b) The following results were obtained for parameters of the heavier tank turret and for optimum value $k_\gamma = 0.11$:

– about 62% reduction of the turret vibrations amplitude was obtained for input harmonic functions caused by the transversal angular displacements acceleration of the hull around the longitudinal axis;

– about 66% reduction of the first and second over-regulation and of the settling time was obtained for disturbing input signals in the form of a fragment of a harmonic function.

4. Negative feedback controlled by the gun turret "snake-like" movements acceleration $\ddot{\psi}_w$. For disturbing signals (a fragment of a harmonic function) and for the reference signals given by the operator, the feedback did not have any essential influence on the stabiliser performance quality.

For the disturbing signals (input harmonic functions caused by the hull movements), we did not yield any profit from this feedback.

The above results indicate that only two of the considered feedbacks may be taken into account for further investigations.

The indispensable feedbacks are:

- feedback controlled by the hull "snake-like" movements speed $\dot{\psi}_K$,
- feedback controlled by the transversal angular displacements acceleration $\ddot{\gamma}_K$ of the hull around the longitudinal axis.

Application of the mentioned above feedbacks improve parameters of the stabiliser.

Exemplary impulse responses of the tank gun stabiliser in modernised and non-modernised version of the stabiliser are shown in Fig. 7. One can notice the effect of reduction of the amplitude of the first and second over-regulations as well as reduction of the settling time.

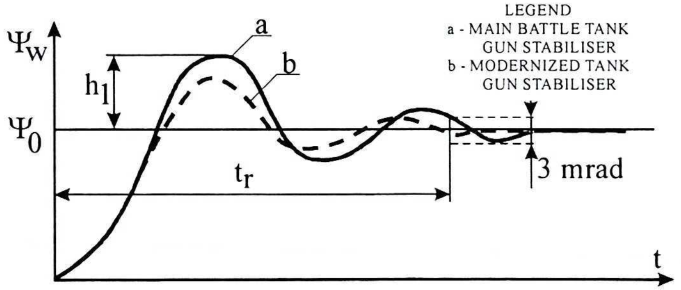

Fig. 7. Impulse responses of tank gun stabiliser in modernised and non-modernised version of stabiliser

Exemplary attenuation characteristics of the gun turret angular vibration (caused by the hull "snake-like" movements speed and those caused by the transversal angular displacements acceleration of the hull around the longitudinal axis) for the main battle tank gun stabiliser and for the modernised tank gun stabiliser are shown in Fig. 8 and Fig. 9, respectively. The amplitude of the turret and gun angular displacements was significantly reduced, mainly for average frequency of the hull motion in yaw (vertical dashed line in Fig. 8) and in roll.

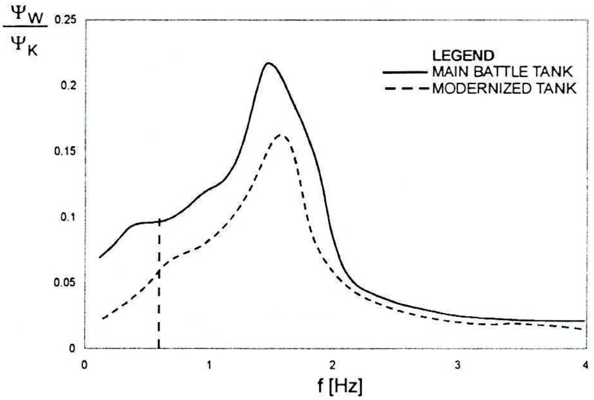

Fig. 8. Attenuation characteristics of the gun turret angular vibration caused by the hull "snake-like" movements speed in modernised and non-modernised version of stabiliser

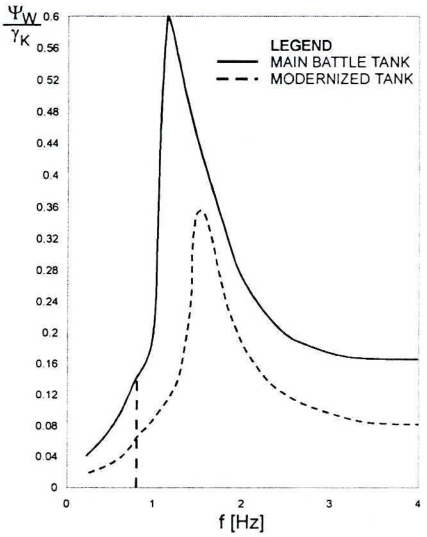

Fig. 9. Attenuation characteristics of the gun turret angular vibration caused by the transversal angular displacements of the hull around the longitudinal axis in modernised and non-modernised version of stabiliser

The simulation investigations of the influence of the regulation potentiometers settlings (c_K, c_0) on the stabilisation exactness and transient processes quality was carried-out using the mathematical model of modernised stabiliser. These investigations show that appropriate settlings have essential meaning for obtaining right performance characteristics of the stabiliser. The settling range of regulation potentiometers is shown in Fig. 10.

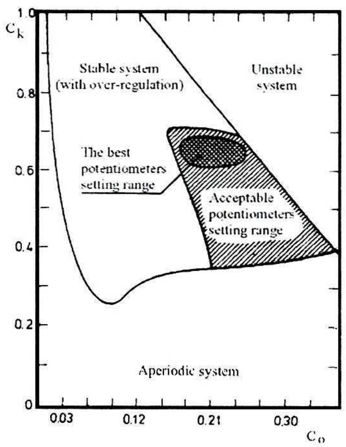

Fig. 10. Setting range of regulation potentiometers in main battle tank with modernised stabiliser

In comparison to non-modernised version of the stabiliser, the best and acceptable potentiometer settling range was widened.

5. Conclusion

The proposed feedbacks improve performance parameters of the investigated stabiliser by about thirty to fifty percent. One of them, controlled by the hull "snake-like" movement speed $\dot{\psi}_K$, is used in “the second generation” of stabilisers.

These second-generation systems are equipped with an additional gyroscope in closed loop feed-back which responds to angular velocities of the vehicle and provides anticipatory commands to the elevation and traverse drives, thereby approximately stabilises the gun. Thus, one additional gyroscope is mounted in the hull to sense the angular velocity of the hull in the plane of rotation of the turret, and to generate feed-back commands to the traverse drive. The second of additional gyroscopes is mounted in the turret to sense the angular velocity of the turret in the elevation plane of the gun, and to generate feed-back commands to the elevation drive.

The use of this kind of feed-backs was pioniered by the United States for M-60 tank, and consequently was adopted by the German and Belgian Armies for their Leopard 1 tanks.

Feedback caused by the transversal angular displacement acceleration $\ddot{\gamma}_K$ of the hull around the longitudinal axis was first used by the Soviet Abmy in T-72 tanks.

The simulation investigations proved that introducing the proposed feedbacks would be a good solution for the investigated stabiliser.
The considered mathematical model may be generalised in a simple way for the case of random disturbing signals.

Introducing of the proposed additional feed-backs in the real object should be the next stage of the presented work.

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Badania modelowe stabilizatora uzbrojenia czołgu

Streszczenie

Przedmiotem rozważań jest rzeczywisty układ stabilizacji i naprowadzania, a mianowicie czołgowy stabilizator położenia kątowego armaty w płaszczyźnie poziomej (horyzontalnej).

Wykorzystując zweryfikowany model matematyczny układu przeprowadzono badania symulacyjne wpływu nastaw potencjometrów regulacyjnych na dokładność stabilizacji i procesów przejściowych.

Przeanalizowano możliwości poprawy charakterystyk działania stabilizatora poprzez zmiany współczynników sprzężeń zwrotnych jak również wpływu wartości amplitudy i częstotliwości sygnałów zakłócających (oddziałujących od kadłuba na wieżę i armatę) na dokładność stabilizacji zadanego położenia.

W wyniku badań modelowych stwierdzono, że nie jest możliwa znaczna poprawa osiągów stabilizatora w jego obecnej strukturze. Z tego powodu zbadano możliwości wprowadzenia nowych sprzężeń zwrotnych w układzie i ich wpływ na jakość stabilizacji. Wprowadzone sprzężenia zwrotne poprawiły charakterystyki działania stabilizatora około trzydziestu do pięćdziesięciu procent.