MATHEMATICAL MODEL OF THE MAIN BATTLE TANK WITCH STABILIZED TURRET AND GUN

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Abstract

The subject of discussion is the T-72 main battle tank. The tank is treated as three distinct bodies, representing the hull, the turret and the gun. The rigid bodies are subject to a set of kinematics constraint relationships, which provide the physical interface of the system. The gun and turret are assumed to bend in the elevation and azimuth direction.

Angular and axial displacements of vehicle are the input signals acting on the turret and the gun. The tank gun stabiliser, minimise the effects of vehicle motion on the main armament of tank and compensates the velocities of the vehicle. Stabilisation system, automatically maintain the position of the gun at a fixed bearing in space, in spate of any motion of the vehicle in roll, in pitch or in yaw.

Mathematical model of the tank, the turret and the gun functioned as one system with the model of tank gun stabiliser (verified on the base of experimental investigations) were build. The equations of motion associated with a military tank are derived using Lagrange equations.

In the next stage of the work the mathematical model could be used for versatile numerical tests of existing, modernized and new types of combat vehicles.

Keywords: *main battle tank, tank gun stabiliser, mathematical model*

1. Introduction

The most of combat vehicles have traditional main design. Large turret is located on the hull and can rotate in yaw round axis **z** (see Fig. 1). Inside the turret are stored ammunition and are located the seat of the commander and gunner. The azimuth movement of the turret is realized through a mobile link between turret and hull, consisting of a ball race roller bearing with the fixed part connected to the hull and mobile part connected to the turret. The turret is rotated in yaw relative to the hull by an azimuth drive system. A motor, fixed to the turret or to the hull, drives a gear box which contains an output pinion that drives a ring fixed in the hull or in the turret, respectively.

The main gun is fitted inside the turret in front part and rotated in pitch round axis $\mathbf{x_G}$ parallel to axis **x**. The elevating mass consists mainly of the cradle of the main gun and of the cradle of the coaxial machine gun and performs elevation and depression movements. The connection between the elevating gun and the turret is obtained by the elevation bearings. The gun is rotated in pitch relative to the turret by an elevation drive system. A hydraulic servo-motor, fixed to the gun and turret drives the gun [2, 7, 15, 16].

Angular and axial displacement of vehicle is the input signals acting on the turret and the gun. Two-axis stabilisation system compensates the velocities of the vehicle. Stabilisation system, automatically maintains the position of the gun at a fixed bearing in space in spite of any motion of the vehicle in roll (γ_H), in pitch (ϕ_H) or in yaw (ψ_H). The tank gun stabiliser minimises the effects of vehicle motion on the main armament of tank, under typical conditions of tank operation over rough ground.

The mathematical models of turret and gun stabilisers were presented in earlier publications. Mathematical models of interactions between the hull and the stabilised turret as well as the turret and the stabilised gun, also equations of motion associated with suspended vehicle are presented below.

2. Moments and forces acting on the stabilised armament

The military tank consists of three separate bodies: the hull, the turret and the main gun (see Fig.1). The tank is subject to two constraints [6, 9, 11, 13, 14]:

- the main gun must elevate relative to the turret,
- the turret must rotate relative to the hull.

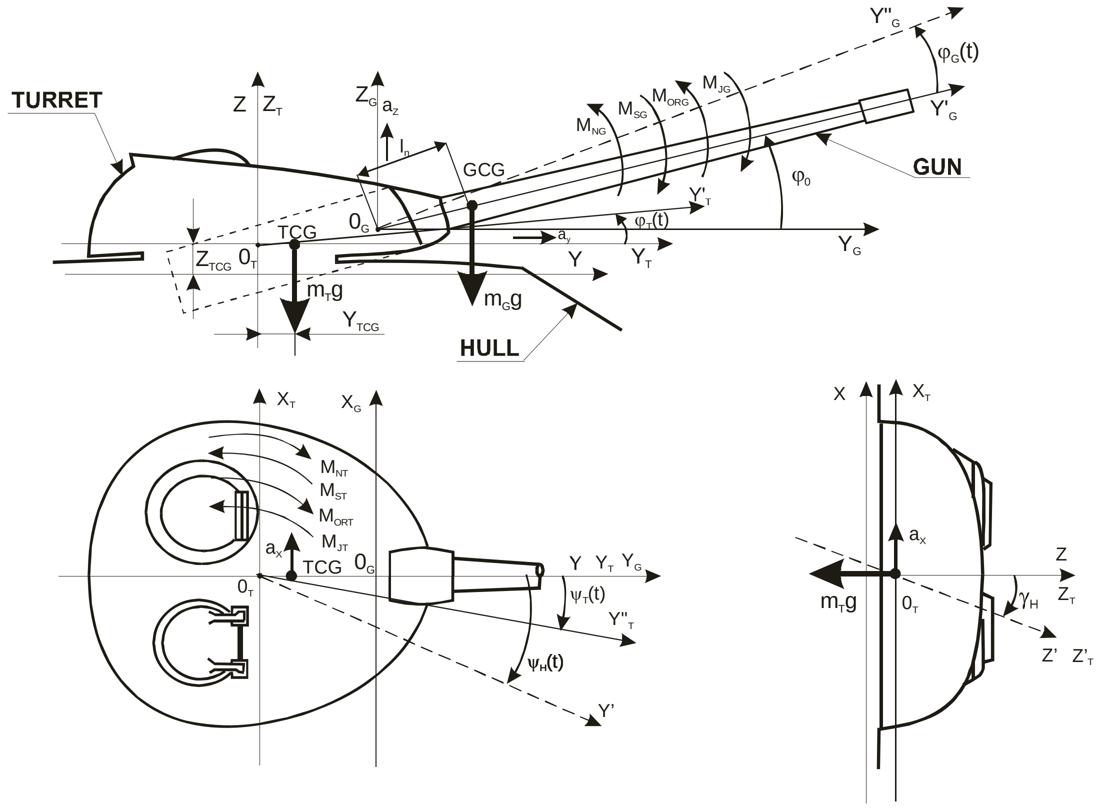

Fig. 1. Main moments and forces acting on the turret and the gun of the tank

Moments and forces acting on the rigid body of tank's turret and gun are illustrated in Fig. 1.

The tank's turret and gun are treated as a rigid body with mass m_T and m_G, respectively. The turret moment of inertia with respect to vertical axis of rotation Z_T was fixed as J_T and the gun moment of inertia with respect to horizontal axis of rotation, through the gun trunnion, X_G was fixed as J_G.

Angular displacement of turret and gun (while stabilising the position of the gun) are in fact very small (about 3 mrad), so Cartesian coordinates are used to describe the bending of the main armament.

3. Structural scheme of the system

On the basis of the obtained system of differential and algebraic equations as well as of the knowledge about the system feed-backs, the overall structural scheme of the system has been found (see Fig. 2).

The input signals are:

- reference signal (for turret and gun stabiliser) given by the operator (gunner),
- disturbing signal caused by the hull "snake-like" angular vibration ψ_H (motion of the vehicle in yaw),
- disturbing signal caused by the hull transversal angular vibration $\gamma_H = \gamma_T$ (motion of the vehicle in roll),
- accelerations of the GCG in Y_G and Z_G direction as well as accelerations of the TCG in X_T direction ($a_{y,} a_z, a_x$), respectively;
- disturbing signal caused by the hull longitudinal angular vibration φ_H (motion of the vehicle in pitch),
- static moment due to non-balance of the gun M_{St}.

In many cases when gun is balanced accelerations $a_{y,} a_z$ and, as less important, accelerations a_x as well as static moment M_{St} (drawn at scheme by dashed line) can be omitted.

The gun angular displacement of the turret and the gun represent the output signals:

- the turret angular vibration in yaw ψ_T;
- the gun angular vibration in pitch φ_G.

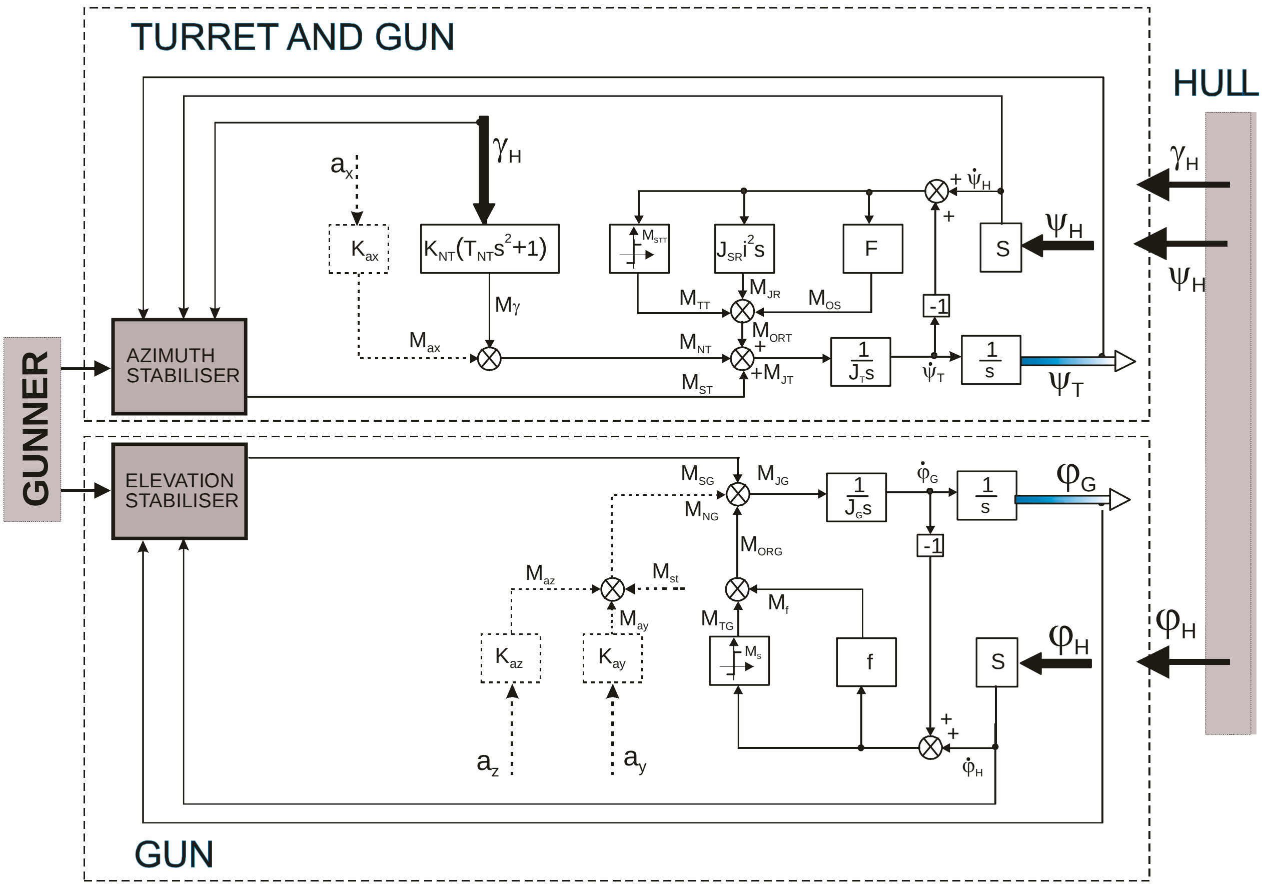

Fig. 2. Structural scheme of stabilised main armament

The symbols used in Figure 1 and 2 were:

M_{JT} - the total moment acting on the turret due to moment of inertia,

M_{ORT} - the total damping moment between the hull and the turret,

M_{NT} - the total moment acting on the turret due to non-balance,

M_{ST} - the moment produced by an azimuth drive motor,

J_T - the turret moment of inertia with respect to vertical axis of rotation Z_T,

$\ddot{\psi}_T$ - The turret angular acceleration in yaw (plane $X_T O_T Y_T$),

M_{TT} - moment acting on the turret due to coulomb damping between the turret and the hull (mainly in the turret ball bearing),

M_{JR} - moment acting on the turret due to moment of inertia of azimuth drive system (motor's rotor and gear box's inter-mating gears),

M_{OS} - moment acting on the turret due to azimuth drive system (depends on the type of drive),

M_{STT} - static moment of friction,

$\dot{\phi}_{\mathrm{H}}, \dot{\phi}_{\mathrm{T}}$ - the hull and the turret angular velocity in yaw,

$\dot{\phi}_{\mathrm{TH}}$ - the velocity of the turret relative to the hull,

J_{SR} - the azimuth drive motor's rotor and gear box's moment of inertia with respect to the axis of rotation,

i - azimuth drive transmission ratio,

F - damping coefficient of azimuth drive,

M_{ax} - moment due to non-balance of the turret caused by a_x (acceleration of the TCG in X_T direction),

M_{γ} - moment due to non-balance of the turret caused by angular displacement γ_{H} of the TCG in roll (plane $Z_T O_T X_T$),

a_{x} - accelerations of the TCG in X_T direction,

m_T - total mass of turret,

g - accelerations of gravity,

y_{TCG} - the distance of the TCG from Z_T (turret axle of rotation),

z_{TCG} - the distance of the TCG from Y (hull axle of rotation),

γ_H - angular displacement in roll,

M_{JG} - the total moment acting on gun due to moment of inertia,

M_{ORG} - the total damping moment between the turret and the gun),

M_{NG} - the total moment acting on the gun due to non-balance,

M_{SG} - the moment produced by an elevation hydraulic servo-motor,

J_G - the gun moment of inertia with respect to gun axle of rotation X_G,

$\ddot{\varphi}_G$ - the gun angular acceleration in pitch (plane $Z_G O_G Y_G$),

M_{f} - moment acting on the gun due to viscous damping between the turret and the gun (mainly in the elevation hydraulic servo-motor),

M_{TG} - moment acting on the gun due to coulomb damping between the turret and the gun (mainly in the gun trunnion),

f - damping coefficient of hydraulic servo-motor,

$\dot{\phi}_{\mathrm{G}}, \dot{\phi}_{\mathrm{T}}$ - the gun and the turret angular velocity in pitch,

$\dot{\phi}_{\mathrm{GT}}$ - the velocity of the gun relative to the turret,

M_{S} - static moment of friction,

M_{ay} - moment due to non-balance of the gun caused by a_y (acceleration of the GCG in Y_G direction),

M_{az} - moment due to non-balance of the gun caused by a_z (acceleration of the GCG in Z_G direction),

M_{St} - static moment due to non-balance of the gun,

$a_{y,}a_z$ - accelerations of the GCG in Y_G and Z_G direction,

m_G - total mass of the gun,

l_n - the distance of the GCG from gun trunnion,

ϕ_o - angle of gun bending.

To simplify the structural scheme of the stabilised main armament the symbols were applied in the form as follows:

$$K_{ax} = m_T y_{TCG} , \tag{1}$$

$$K_{NW} = m_T g y_{TCG} , \tag{2}$$

$$T_{NW} = \frac{z_{TCG}}{g} , \tag{3}$$

$$K_{ay} = m_G l_n \sin\varphi_o , \tag{4}$$

$$K_{az} = m_G l_n \cos\varphi_o , \tag{5}$$

4. Mathematical description of the tank

A tank suspension has two sort of task to perform. The static task is to distribute the weight of the vehicle. The dynamic task – when the vehicle is moving – is to minimise vibration and shocks. The suspension allows the road wheels to follows the vertical motion of the tracks without transferring too much of that motion to the hull. It also guarantees that tracks and roads wheels stay in contact with each other and thus helps stop the vehicle from throwing a track. It reduces vertical hull motion when moving across country and maintains a constant ground clearance as far as possible.

The suspension consists of damping elements to compensate for the irregularities in terrain and shocks absorbers that not only carry out the above function, but also compensate for roller movement so that a track is not thrown.

The idealization of suspension system is shown in Figure 3. It consists of twelve linear rod springs and six shock absorbers [1,4]. The earth plate motion is a prescribed function depending upon the terrain data.

The equations of motion associated with a military tank were derived using Lagrange equations [2,3].

$$\frac{d}{dt}\left(\frac{\partial E_K}{\partial \dot{q}_i}\right) - \frac{\partial E_K}{\partial q_i} + \frac{\partial E_R}{\partial \dot{q}_i} + \frac{\partial E_P}{\partial q_i} = F_i \qquad \text{i = 1,2,n,} \tag{6}$$

$$E_K = \frac{1}{2}[m\dot{z}^2 + I_{X_K}\dot{\varphi}_H{}^2 + I_{Y_K}\dot{\gamma}_H{}^2 - 2I_{Y_K X_K}\dot{\varphi}_H\dot{\gamma}_H] , \tag{7}$$

$$E_P = \frac{1}{2}\sum_{i=1}^{n} k_i (z - y_i\varphi_H + x_i\gamma_H - z_i)^2 , \tag{8}$$

$$E_R = \frac{1}{2}\sum_{i=1}^{n} c_i(\dot{z} - y_i\dot{\varphi}_H + x_i\dot{\gamma}_H - \dot{z}_i)^2, \tag{9}$$

where:

i – degrees of freedom quantity, i = 3,
E_K – kinetic energy,
E_P – potential energy,
E_R – dissipation energy,
F_i – generalized forces,
q_i – generalized coordinates: $q_1 = z$ – displacement, $q_2 = \varphi_H$ - rotation round axis **x**,
$q_3 = \gamma_H$ – rotation round axis **y**,
m – mass of vehicle,
$\dot{z}$ – speed of gravity centre,
$\dot{\varphi}_H, \dot{\gamma}_H$ – rotational speeds of the hull,
I_{X_K}, I_{Y_K} – moments of inertia,
$I_{Y_K X_K}$ – moment of deviation,
n – quantity of road wheels,
k_i – spring rate coefficient,
z_i – displacements of road wheels (motion depending upon the terrain data),
x_i, y_i – coordinates of road wheels,
c_i – damping coefficient,
$\dot{z}_i$ – speed of road wheels.

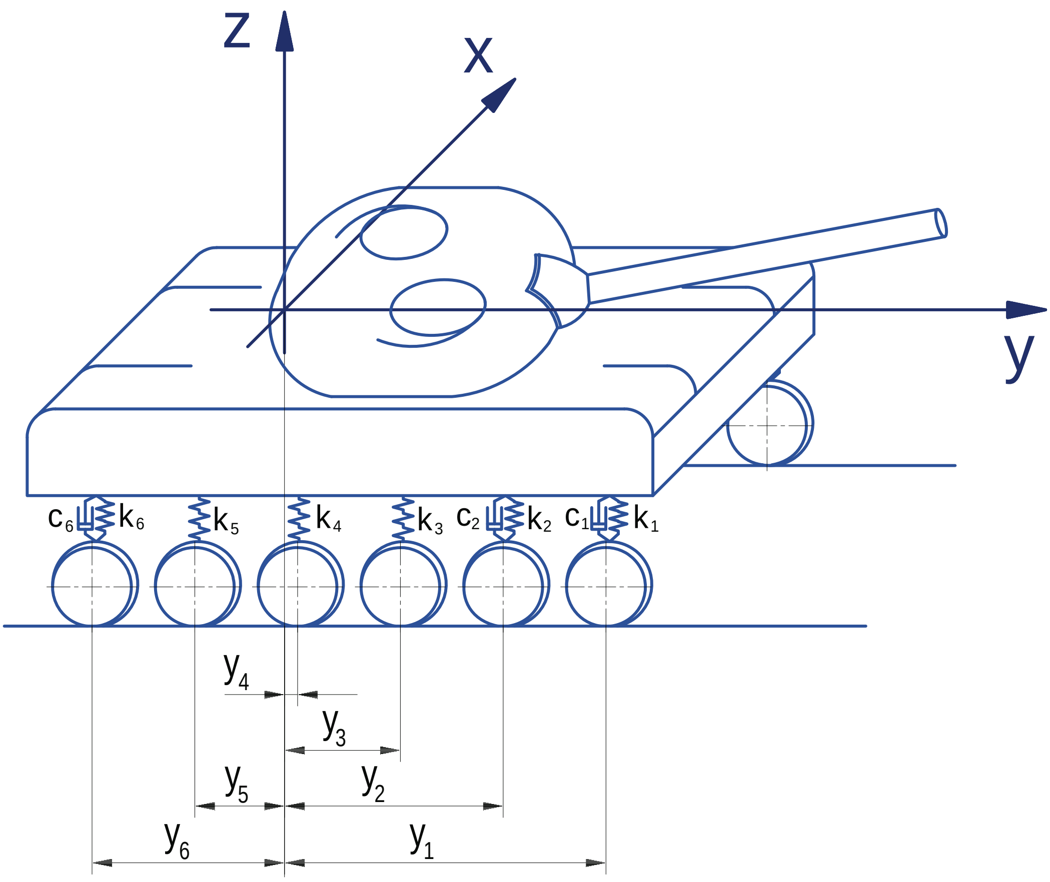

Fig. 3. Schematic diagram of the tank suspension

After transformations we obtained matrix equation:

$$\mathbf{M}\underline{\ddot{q}} + \mathbf{C}\underline{\dot{q}} + \mathbf{K}\underline{q} = \mathbf{F}\underline{w}, \tag{10}$$

where:
M – inertia matrix,
C – damping matrix,
K – stiffness matrix,
F – forces matrix:

$\underline{\ddot{q}}$ - vector of generalized accelerations,

$\underline{\dot{q}}$ - vector of generalized speeds,

$\underline{q}$ - vector of generalized displacements.

Above vectors have the forms:

$$\underline{\ddot{q}} = \begin{bmatrix} \ddot{z} \\ \ddot{\varphi}_H \\ \ddot{\gamma}_H \end{bmatrix} \quad \underline{\dot{q}} = \begin{bmatrix} \dot{z} \\ \dot{\varphi}_H \\ \dot{\gamma}_H \end{bmatrix} \quad \underline{q} = \begin{bmatrix} z \\ \varphi_H \\ \gamma_H \end{bmatrix} \quad \underline{w} = \begin{bmatrix} \ddot{z}_i \\ \dot{z}_i \\ z_i \end{bmatrix}, \tag{11}$$

Above matrixes have the forms:

M – inertia matrix

$$\begin{bmatrix} m & 0 & 0 \\ 0 & I_{X_K} & -I_{Y_K X_K} \\ 0 & -I_{Y_K X_K} & I_{Y_K} \end{bmatrix}$$

C – damping matrix

$$\begin{bmatrix} \sum_{i=1}^{n} c_i & -\sum_{i=1}^{n} c_i y_i & \sum_{i=1}^{n} c_i x_i \\ -\sum_{i=1}^{n} c_i y_i & \sum_{i=1}^{n} c_i y_i^2 & -\sum_{i=1}^{n} c_i y_i x_i \\ \sum_{i=1}^{n} c_i x_i & -\sum_{i=1}^{n} c_i y_i x_i & \sum_{i=1}^{n} c_i x_i^2 \end{bmatrix}$$

F – forces matrix

$$\begin{bmatrix} 0 & \sum_{i=1}^{n} c_i & \sum_{i=1}^{n} k_i \\ 0 & -\sum_{i=1}^{n} c_i y_i & -\sum_{i=1}^{n} k_i y_i \\ 0 & \sum_{i=1}^{n} c_i x_i & \sum_{i=1}^{n} k_i x_i \end{bmatrix}$$

K – stiffness matrix

$$\begin{bmatrix} \sum_{i=1}^{n} k_i & -\sum_{i=1}^{n} k_i y_i & \sum_{i=1}^{n} k_i x_i \\ -\sum_{i=1}^{n} k_i y_i & \sum_{i=1}^{n} k_i y_i^2 & -\sum_{i=1}^{n} k_i y_i x_i \\ \sum_{i=1}^{n} k_i x_i & -\sum_{i=1}^{n} k_i y_i x_i & \sum_{i=1}^{n} k_i x_i^2 \end{bmatrix}$$

After transformations we obtained equations of motion:

$$m\ddot{z} = -\sum_{i=1}^{n} c_i \cdot \dot{z} + \sum_{i=1}^{n} c_i y_i \cdot \dot{\varphi}_H - \sum_{i=1}^{n} c_i x_i \cdot \dot{\gamma}_H - \sum_{i=1}^{n} k_i \cdot z + \sum_{i=1}^{n} k_i y_i \cdot \varphi_H - \sum_{i=1}^{n} k_i x_i \cdot \gamma_H + \sum_{i=1}^{n} c_i \cdot \dot{z}_i + \sum_{i=1}^{n} k_i \cdot z_i, \tag{12}$$

$$I_{X_K}\ddot{\varphi}_H=\sum_{i=1}^{n}c_i y_i\cdot\dot{z}-\sum_{i=1}^{n}c_i y_i^2\cdot\dot{\varphi}_H+\sum_{i=1}^{n}c_i y_i x_i\cdot\dot{\gamma}_H+\sum_{i=1}^{n}k_i y_i\cdot z-\sum_{i=1}^{n}k_i y_i^2\cdot\varphi_H+\sum_{i=1}^{n}k_i y_i x_i\cdot\gamma_H-\sum_{i=1}^{n}c_i y_i\cdot\dot{z}_i-\sum_{i=1}^{n}k_i y_i\cdot z_i\,, \tag{13}$$

$$I_{Y_K}\ddot{\gamma}_H=-\sum_{i=1}^{n}c_i x_i\cdot\dot{z}+\sum_{i=1}^{n}c_i y_i x_i\cdot\dot{\varphi}_H-\sum_{i=1}^{n}c_i x_i^2\cdot\dot{\gamma}_H-\sum_{i=1}^{n}k_i x_i\cdot z+\sum_{i=1}^{n}k_i y_i x_i\cdot\varphi_H-\sum_{i=1}^{n}k_i x_i^2\cdot\gamma_H+\sum_{i=1}^{n}c_i x_i\cdot\dot{z}+\sum_{i=1}^{n}k_i x_i\cdot z_i\,. \tag{14}$$

Equations were the basis of the final mathematical model. The model has three degrees of freedom: z - displacement; φ_H - rotation round axis **x**; γ_H - rotation round axis **y.**
Those angular and axial displacements of vehicle are the input signals acting on the turret and the gun.

5. Concluding remarks

Presented above mathematical models make possible numerical investigations of influence of determined and random input signals, generated by ground while moving across country, acting on stabilised armament of various types of combat vehicles. Will be possible numerical investigations of weapon stabilisation systems accuracy while:

- changes of amplitude and frequency of input signals, generated by ground, acting on individual road wheels,
- changes of suspension characteristics of individual road wheels of combat vehicle (damping, stiffness),
- changes of wheelbase and road wheels quantity,
- changes of the vehicle turret and gun mass as well as localization of the hull and the turret centre of gravity,
- changes of kinematics links between the hull and the turret as well as the turret and the gun resulted from stabilisation system properties,
- changes of the turret and the gun parameters,
- changes of the turret and the gun drives parameters,
- changes of the turret and the gun stabilisation systems as controlled systems,
- changes of existing feed-backs with stabilisation systems and implementing additional feed-backs.

Motion of the vehicle in roll (γ_H), in pitch (ϕ_H) and displacement (z) are generated by rough ground but motion in yaw (ψ_H) are generated independently and could have a form of determined or random signals that are proportional to motion of the vehicle in roll and in pitch. Correlation between motions ψ_H and γ_H as well as motions ψ_H and ϕ_H were determined while experimental tests [5,8,10,12,15,16,17,18] when the tank overcome various terrain obstacles with various speed.

In the next stage of the work the mathematical model could be used for versatile numerical tests of existing, modernized and new types of Polish Army combat vehicles. Mainly for checking the turret and the gun stabiliser in various ground condition (very often difficult to obtain using real vehicle in real terrain) and for improving stabilisation exactness.

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