

Quality Control of the Hindsight's Axis Stabilization Using the Instrumental Servo System

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Abstract: In up to date wars, gunfiring from the vehicle in motion has become the basic way of action for operational armored vehicles (conveyors and tanks). Because of the rolling of the vehicle's body (caused by moving on the ground) and the change in the target coordinates (because the target is in motion, as well), the shooting accuracy in comparison with shooting accuracy in the case of shooting passive targets from the fixed position is substantially decreased. The particular problem is to measure the quality, that is, to measure the error of achieved stabilization. This study describes the new, simple (and cheap) simulation method for the stabilization quality check, which enables the complete laboratory simulation of driving over the optional terrain in the real conditions, as well as the undisturbed examining in the extreme temperature conditions.

Keywords: Hindsight's axis, girostabilization, simulation, quality control, independent axis method.

1 The Idea of Gyrostabilization

In order to explain the concept of the stabilization of the cannon's tube, we have to establish the following definitions and reference frames (coordinate systems) of the armored vehicle, the relations of which are represented in the Figure 1.

1. x_0, y_0, z_0 absolute non-rotating frame tied to the horizon and to the North.

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2. x_p, y_p, z_p frame connected to the body of the vehicle (conveyor or tank).
3. x_{kp}, y_{kp}, z_{kp} frame connected to the moving turret, which gives the position of the virtual azimuth (direction) of the cannon's axis, with $z_p = z_{kp}$.
4. x_{ct}, y_{ct}, z_{ct} frame connected to the tube of the cannon in such a manner that the longitudinal axis of the cannon's tube coincide with the axis x_{ct} (that is peak of the tube $i_{x_{ct}}$ is ort of axis x_{ct}). The axis x_{ct} "watches" the target, and it is at the same time the axis that is to be stabilized in space. At the same time it is $y_{kp} = y_{ct}$.
5. x_g, y_g, z_g frame connected to the block of the gyroscope, which gives the angular velocity of the virtual azimuth of the turret and virtual elevation of the cannon's axis. The gyroscopes are built in the rear part of the cannon and $\varphi_g = \varphi_{ct}$, $\gamma_g = \gamma_{ct}$ and $\nu_g = \nu_{kp} = \nu_{ct}$, where φ , ν and γ represent angular disturbances, which could be represented by three angles: φ -revolving, ν -rearing and γ -milling. These orthographic frames are not independent, as a result of the fact that $z_p = z_{kp}$, $y_{kp} = y_{ct}$ and $x_g = x_{ct}$, $y_g = y_{ct}$ and $z_g = z_{kp} = z_{ct}$.

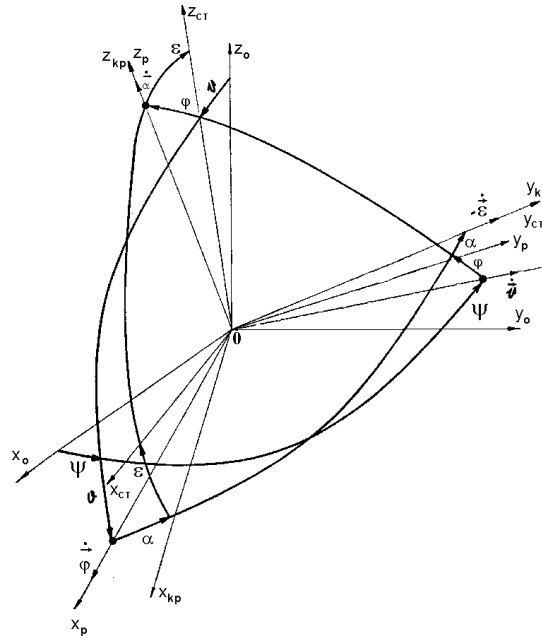


Fig. 1. Frames.

The basic philosophy of the stabilization consists of the following facts: the longitudinal axis of the cannon should stay still (without angular moving). As $\vec{i}_{x_{ct}}$ is ort x_{ct} and if $\vec{\Omega}_{ct}$ denotes angular velocity of the cannon's tube, then the condition for stabilization can be expressed with the following vector equation

$$\frac{d\vec{i}_{x_{ct}}}{dt} = 0. \quad (1)$$

This frame rotates with respect to the fixed (absolute) frame with the angular velocity: $\vec{\Omega}_{ct} = \vec{\Omega}_{x_{ct}}\vec{i}_{x_{ct}} + \vec{\Omega}_{y_{ct}}\vec{j}_{y_{ct}} + \vec{\Omega}_{z_{ct}}\vec{k}_{z_{ct}}$. From the theoretical mechanics [1,2] it is known that differentiation the vector \vec{R} , which determinates the position of the point in the moving frame $0X_{ct}Y_{ct}Z_{ct}$ (with coordinates x, y, z), we get its absolute line velocity. Applied to the case of the peak of the cannon's tube moving, i.e. x_{ct} , we get

$$\frac{d\vec{i}_{x_{ct}}}{dx} = \frac{d\vec{i}_{x_{ct}}}{dt} + \vec{\Omega} \times \vec{i}_{x_{ct}}. \quad (2)$$

The first component on the right side of the equation represents the propriety rate of the point (peak of the tube) in the system $0X_{ct}Y_{ct}Z_{ct}$. The second component comprises the property that system rotates with respect to the fixed absolute frame $0X_0Y_0Z_0$. Since the axis X_{ct} is fixed related to the frame to which it belongs, that component of the equation equals zero. It is from the theoretical mechanics known that the axis of the cannon's tube will be stabilized in the space if

$$\Omega_{z_{ct}} = 0, \Omega_{y_{ct}} = 0, \text{ and } \Omega_{x_{ct}} \neq 0. \quad (3)$$

Since gyroscopes are firmly connected to the cannon, they measure absolute angular velocities of the turret and the cannon's tube, leading in: $\Omega_{z_g} = \Omega_{z_{ct}}$ and $\Omega_{y_g} = \Omega_{y_{ct}}$. Hence, the conditions for stabilization may be expressed with the following equations

$$\Omega_{z_g} = 0, \text{ and } \Omega_{y_g} = 0. \quad (4)$$

Namely, due to moving of the vehicle on the ground, the vacillation of the body of the vehicle appears, some angular disturbances appear, which could be represented by three angles: φ -revolving, ν -rearing and γ -milling. These disturbances are, by means of the drive system of the turret, transferred to the turret and further to the tube of the cannon, in the form of angles of disturbances φ' , ν' and γ' .

This speculation will not be less general if we suppose the following: $\varphi' = \varphi$, $\nu' = \nu$ and $\gamma' = \gamma$, but by doing so the mathematical description of the problem will be substantially simplified (because we can now completely omit the frame $0X_pY_pZ_p$ tied to the body of the vehicle). In further speculations we will use the fact that the angle of rolling is minor, i.e. $\gamma = \gamma' \simeq 0$ ($\gamma < 10^\circ$), hence $\cos(\gamma) \simeq 1$, since the elevation angles during the shooting at the earth targets are not large.

Because of these we need to define the angle of virtual azimuth α (the angle of rotation of the turret caused by the direction drive) and the virtual elevation ε (the rotating angle of the cannon's tube caused by elevation drive) instead of the angles of rotation and rearing $\dot{\alpha}$ and $\dot{\varepsilon}$ are appropriate angular velocities. What are gyroscopes measuring by the z and y axes, i.e. what are the values of Ω_{z_g} and Ω_{y_g} when the devices are active, that is during the stabilization mode activated (to fulfill the conditions of stabilization (4). We get

$$\begin{aligned} \Omega_{y_g} &= \dot{\varphi} \cos \theta \cos \gamma + \dot{\theta} \sin \gamma & \text{i.e.} & \quad \dot{\varphi} = \Omega_{y_g} \\ \Omega_{z_g} &= \dot{\theta} \cos \gamma - \dot{\varphi} \cos \theta \sin \gamma & & \quad \dot{\theta} = \Omega_{z_g} \end{aligned} \quad (5)$$

Expressions (5) represent rather correct approximation of the angular velocities of the turret in the horizontal plane and the cannon's tube in the vertical plane where all known stabilization systems are constructed (for land armored vehicles). In many systems the correction $1/\cos \nu$ is not taken into the consideration.

2 The Block Scheme of the System in the Stabilization Mode

In order to remain the cannon's tube fixed in space it is necessary that the servo system of the turret (by the direction) and the cannon (by the elevation) moves the turret and the cannon in the opposite directions from the direction of the disturbance action, but for the same angle and with angular velocity that is equal to the angular velocity of the disturbance. In the stabilization mode there are two more types of the motion: moving of the turret in relation to the body of the conveyor with the angular velocity $\dot{\alpha}$ and moving of the cannon's tube with respect to the turret with the angular velocity $\dot{\varepsilon}$. The angular velocities measured by the gyroscope are

$$\begin{aligned} \Omega_{y_g} &= (\dot{\varphi} + \dot{\alpha}) \cos \theta \cos \gamma + \dot{\theta} \sin \gamma & \text{i.e.} & \quad \Omega_{y_g} = \dot{\varphi} + \dot{\alpha} \\ \Omega_{z_g} &= (\dot{\theta} + \dot{\varepsilon}) \cos \gamma - (\dot{\varphi} + \dot{\alpha}) \cos \theta \sin \gamma & & \quad \Omega_{z_g} = \dot{\theta} + \dot{\varepsilon} \end{aligned} \quad (6)$$

Hence, the gyroscopes (sensors) in the stabilization mode actually measure the error of stabilization, that is the signals achieved from the gyroscope equal the difference between the angular velocity of the body of the conveyor related to the ground (disturbance) and the angular velocity of the turret related to the body of the conveyor by the direction ($\Omega_{yg} = \dot{\varphi} + \dot{\alpha}$) and the difference between the angular velocity of the body of the conveyor (and the turret) related to the ground and the angular velocity of the cannon's tube related to the turret by elevation ($\Omega_{zg} = \dot{\theta} + \dot{\varepsilon}$). Since our goal is to prevent the moving of the cannon's tube in space, it means that the errors must be as small as possible, i.e. the ideal case: $\Delta\varphi = 0$ and $\Delta\theta = 0$. To calculate the error of stabilization we must integrate the signals from the rate gyroscopes, so the first block in the servo controller for the cannon's stabilization would be the ideal integrator [3,4] (block 2 on Figure 2.). The output signal from the integrator would be the measure of the quality of the achieved stabilization, and at the same time the input to the servo regulator.

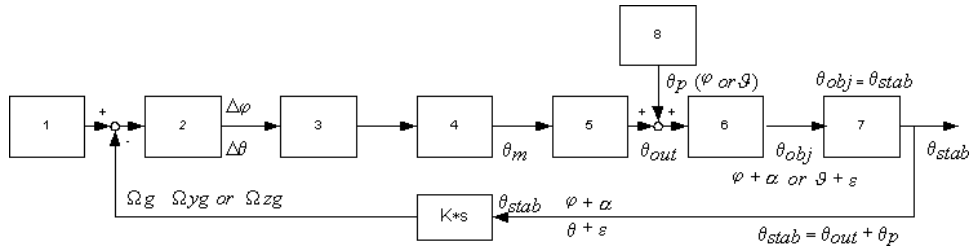


Fig. 2. The block scheme of the system in the stabilization mode. 1. Target tracking error correction made by the pointer. 2. Integrator (calculates the stabilization error). 3. Servo regulator, generates the control signal for the drive system. 4. Drive system with local feedbacks for the angular velocity control. 5. Low-range gear lever. 6. Control object (steering mechanism: the turret or cannon) 7. Sensor, rate gyroscope. 8. Disturbance caused by the moving of the vehicle.

3 The Stabilization System Quality Check

The particular problem is the quantitative test of the stabilization system, which is obligatory for the warfare resources; not only in as real as possible conditions regarding the terrain, but also in the extreme temperature conditions (between -30°C and $+50^{\circ}\text{C}$). So far the following methods have been used:

1. The ride on the terrain or on the special made sinusoidal path.
2. The ride simulation using the platform with three degrees of freedom.

The procedure for the stabilization check for the first mentioned method is:

1. The vehicle is brought into the starting position and the tube of the cannon (the hindsight's axis) is pointed in the direction of the target.
2. The vehicle starts moving along the special made waving path (of sinusoidal shape); the vehicle's speed must be constant (10 km/h).
3. The vehicle moves along the full circle and returns to the starting position. The tube of the cannon must be pointed to the target, and during the ride the pointer must not lose the target from the sight.
4. During the ride, the recording of the signal, which represents the integral of the signal from the appropriate rate gyroscope, is being performed, that is the angular error of stabilization is being recorded.

The disadvantages of this method:

1. The whole vehicle is first being assembled and driven on the appropriate terrain. This is rather expensive and on the other hand the interventions on the stabilization system cannot be done on the polygon in most cases.
2. It is difficult to maintain the constant speed of the vehicle on the terrain because of the type of the path.
3. It is not possible to examine the system on the extreme temperature conditions.
4. Expensive and complicated manufacturing of the path under very strict conditions.

The procedure for the stabilization check for the second mentioned method is:

1. The stabilization system is built onto the turret (with the turret for the simulation or the real turret is assembled).
2. The turret is placed on the simulation platform with three axes, which simulates the movement of the vehicle on the terrain (Figure 3.). It is possible to simulate the turning of the vehicle along one of the axes itself or along the two or three axes simultaneously. Because of the presence of the displacement (turning of the platform), the servo drive turns the tube of the cannon (the turret) in the opposite direction. Since the tube of the cannon turns in the opposite direction of the direction of the turning of the platform, the gun is being stabilized in the space.

3. The further procedure may be the same as mentioned in the first method, or it is possible to detect the stabilization error with special free gyroscope, but the processing of the accomplished signal of the angular stabilization error of the cannon's tube is the same.

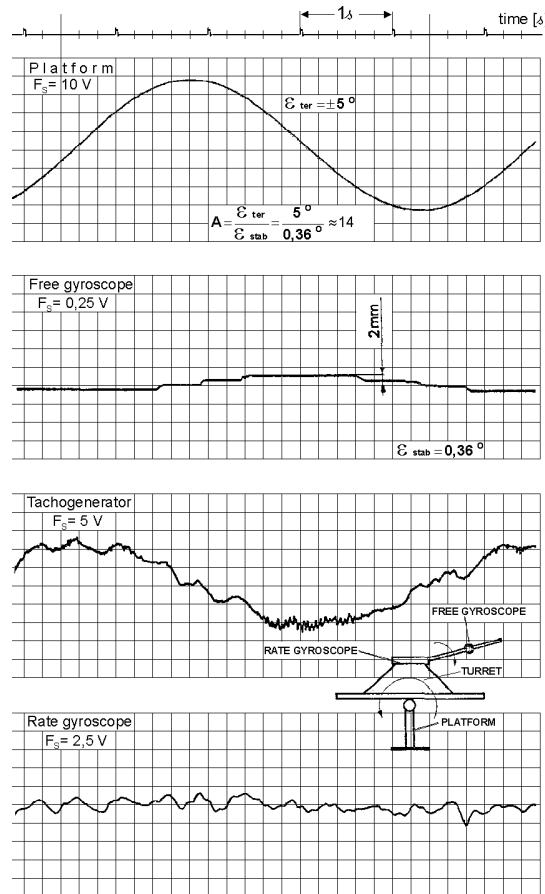


Fig. 3. The ride simulation using the platform.

The advantages of this method compared to the first are:

1. In the case of insufficient stabilization quality it is easier to perform the inter- vention because the mistake is detected in the phase of the integration of the turret or even earlier at the check of the servo system for stabilization.
2. Instead of the clear stochastic signal, the platform can be moved according to some of the basic waveforms (periodical or square pulse

signals). It is also possible to simulate the real conditions on the optional terrain and with the optional speed.

The disadvantages of this method:

1. To move the platform it is necessary to make high quality and high power (and expensive) servo systems.
2. At least two independent servo systems are necessary - for moving by the azimuth and by the elevation.
3. It can practically be used only for the turrets of the conveyors (about 2 t), while for the turrets of the tank (more than 15 t) it is not worthwhile to make such systems.

4 The Proposition of the New Method: the Independent Axis Method

Discussing the stabilization of the cannon's tube or the hindsight's axis, we are actually discussing the stabilization of the axis of the sensor sensitivity, i.e. rate gyroscopes! Hence the essential idea of the stabilization and the relations that must be fulfilled are expressed not with the equations (3), but with the equations (4). Common for both known methods is that the measurement gyroscopes are placed on the rear part of the cannon and that the axes of the gyroscopes are connected to the axes tied to the tube of the cannon, $x_g = x_{ct}$, $y_g = y_{ct}$ and $z_g = z_{ct}$. Hence, $\Omega_{z_g} = \Omega_{z_{ct}}$ and $\Omega_{y_g} = \Omega_{y_{ct}}$. The essential of the proposed method is to untie the axis of the gyroscope from the frame connected to the tube of the cannon. The gyroscope block is connected to the tube by the device simulating servo system, so it can be independently moved related to the tube (and the turret). In this case it would be $\Omega_{z_g} \neq \Omega_{z_{ct}}$ and $\Omega_{y_g} \neq \Omega_{y_{ct}}$, but the conditions for the stabilization of the sensor axes would still be the same, (4), i.e. $\Omega_{z_g} = 0$ and $\Omega_{y_g} = 0$.

The fundamental idea is the following [5]: instead of bringing the information about the displacement (caused by the movement of the vehicle or the simulation platform) to sensors by means of the drive plants of the turret and the cannon's tube, displacement is brought to the sensors directly using the simulating servo systems for moving the gyroscope block related to the cannon's tube. That means that gyroscopes can move (turn) related to the cannon's tube, and they are not firmly connected to them (Figure 4).

The servo system for moving the cannon (and the turret by the direction), now by means of the sensors, get the stabilization error signal and their

turning in the opposite direction begins (because of the negative reverse connection), so the axes of the sensitivity stay stable in the space so it is $\Omega_{z_g} \neq \Omega_{z_{ct}}$ and $\Omega_{y_g} \neq \Omega_{y_{ct}}$ but the conditions for the stabilization of the sensor axes are fulfilled, i.e. it would be $\Omega_{z_g} = 0$ and $\Omega_{y_g} = 0$ and not necessarily $\Omega_{z_{ct}} = 0$ and $\Omega_{y_{ct}} = 0$ or $\Omega_{z_{ct}} \neq 0$ and $\Omega_{y_{ct}} \neq 0$. So, the gyroscopes are, related to the tube, moving with some angular velocities $\dot{\varphi}$ and $\dot{\theta}$, which cause the error signals $\Omega_{z_g} \neq 0$ and $\Omega_{y_g} \neq 0$. These signals are now being processed using the controller in the servo system of the drive plant of the cannon, and under the action of the control signal, the servo of the cannon moves the cannon in the opposite direction with the angular velocities $\dot{\alpha}$ and $\dot{\varepsilon}$. Since the servo system of the cannon gets the same signals from the same sensors and the same values as in the case of the ride over the terrain, then the servo of the cannon would move in the same way as in the real conditions, so the angular velocities $\dot{\alpha}$ and $\dot{\varepsilon}$ would be $\dot{\alpha} \simeq -\dot{\varphi}$ and $\dot{\varepsilon} \simeq -\dot{\theta}$ such that the axis of the gyroscopes would stay fixed in the space $\Omega_{z_g} = 0$ and $\Omega_{y_g} = 0$. In this case frame connected to the gyroscopes can, by the two axes, freely turn related to the tube of the cannon, while the third axis x_g is firmly connected to the axis of the cannon's tube, i.e. $x_g = x_{ct}$. Hence, the gyroscopes can freely turn related to the cannon's tube in the vertical and horizontal plane with some angular velocities $\dot{\varphi}$ and $\dot{\theta}$. The angular velocity measured by the rate gyroscopes is now obtained based on the equations identical to equations (6).

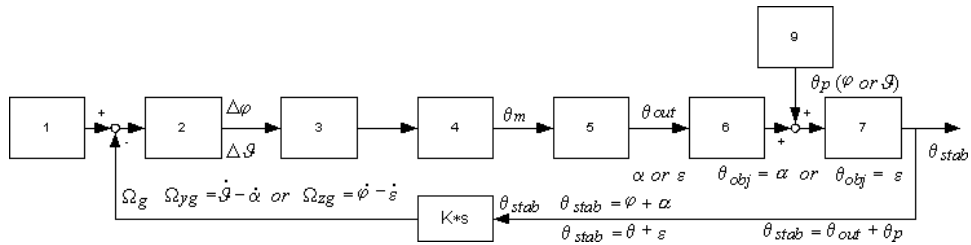


Fig. 4. Simulation the moving of the vehicle using instrumental servo. 9. Instrumental servo for the simulation of the moving of the vehicle (for the disturbance generating).

Since the gyroscopes always measure the angular velocities in the absolute frame, the origin of the displacement is irrelevant; only the angular velocities (and the angles of inclination eventually) are relevant. When the servo system is in the stabilization mode, the signals from the gyroscopes (proportional to the value of the angular velocity) are led to the input of the controller and according to them, control signals for the drive plant of the turret by the direction and for the cannon by the elevation are generated. The drive plants move the turret and the cannon's tube in the directions

opposite to the direction of the disturbance (because of the negative feedback), with the rates $\dot{\alpha}$ and $\dot{\varepsilon}$ for the angles α and ε . Since the block scheme of the servo system hasn't been changed, the response of the system to the signal from the gyroscope will be the same; hence the turret and the cannon's tube stay so that the gyroscope block stays changeless in the space. So, the angular velocities of the turning of the turret and the cannon's tube will be: $\Omega_{y_g} = \dot{\varphi} + \dot{\alpha}$ and $\Omega_{z_g} = \dot{\theta} + \dot{\varepsilon}$.

That means that now, in the stabilization mode, the rate gyroscopes (sensors) actually measure the stabilization error, that is the signals obtained from the gyroscopes are equal to the difference between the angular velocity of turning of the gyroscope block related to the ground (the disturbance) and the angular velocity of turning of the turret related to the ground by the direction ($\Omega_{y_g} = \dot{\varphi} + \dot{\alpha}$) and the difference between the angular velocity of the gyroscope block related to the ground and the angular velocity of the cannon's tube related to the turret by the elevation ($\Omega_{z_g} = \dot{\theta} + \dot{\varepsilon}$). Integrator is now also calculating the stabilization error. In order that the gyroscope block stays fixed in the space the errors should be as small as possible. The ideal case would be with $\Delta\varphi = 0$ and $\Delta\theta = 0$, that leads in: $\Omega_{z_g} = 0$ and $\Omega_{y_g} = 0$ i.e. $\dot{\alpha} = -\dot{\varphi}$ and $\dot{\varepsilon} = -\dot{\theta}$.

So, the essential of the stabilization with the independent axes method is the stabilization of the sensors, which are detecting the movement, i.e. the angular velocity. The gyroscope block is being stabilized, and not the cannon's tube. However, the servo system and the control are the same in the case of the stabilization test riding over the terrain, so the results of the stabilization of the gyroscope with this method and the cannon's tube are the same. As the consequence of the gyroscope stabilization, the object on which it is situated is stabilized as well, and that does not change the essential idea of the stabilization.

5 The Measurement Method Description

For this measurement method it is necessary to construct a mini platform with the three instrumental servos, dedicated to enable the movement of the gyroscope block itself (with its weight about a few kilos). The advantage of this method is that it is not necessary to construct the platform, but instead to build just one instrumental servo, with just one degree of freedom. The point is that the complex movement over the surface can be transformed to three independent movements over each of the axes. So, for each axis it is

possible to build the separate servo plant for moving the gyroscope block, meaning two independent servos for the direction and the elevation.

Since these disturbances are independent, the stabilization for these movements can be examined independently, during the two different periods. That means that it is enough to build just one high quality instrumental servo plant for moving of the gyroscope in one plane. During the stabilization quality check in the vertical plane the servo plant is fixed to the tube so the output shaft belongs to the horizontal plane and it is normal on the axis of the cannon's tube. The gyroscope block must have the same position as it is built in the hindmost part of the cannon. The transition to the turning in the other plane is performed simply by turning of the plant related to the tube for 90° ($\pi/2$), and after that the gyroscope block declines in the opposite direction by the 90° . In this way we accomplish that the position of the gyroscope block related to the tube stays fixed in space.

For measuring the stabilization quality, free gyroscope with the three degrees of freedom, which is built in so its two axes of sensitivity coincide with the axis of the sensitivity of the rate gyroscopes, has been used (first channel on the Figure 5). This gyroscope is not necessary for this measurement method, but it has been used as the additional sensor, which directly measures the angular error of the stabilization. As the measure of the stabilization error the output signals from the integrator can also be used. The angle of turning of the gyroscope block related to the holder (and the tube) is measured using the potentiometer (second channel on the Figure 5). When the drive system of the cannon is not activated, or it is not in the stabilization mode, then the angle of the gyroscope block related to the cannon's tube is at the same time equal to the angle of turning of the gyroscope block in the absolute frame, that is, it is equal to the absolute disturbance. Hence, if the signal of the disturbance on the cannon's tube during the movement of the vehicle with the certain speed and over the certain terrain is recorded using the free gyroscope, then that signal can be brought as the input signal to the instrumental servo system for the move of the gyroscope block. This servo will turn the gyroscope block for the same angle, as the vehicle is moving. In this way we can accomplish very genuine simulation of the angles of the disturbances, which would be present with the actual movement over the terrain.

6 The Measurements and the Results

The Figure 5. presents the typical diagrams achieved by recording the stabilization using this method, when we bring the periodical signal from the signal generator as the input of the simulating servo. On the Figure we have the diagrams recorded using the four-channel writer with the time base during the check of the stabilization by the azimuth. To the input of the instrumental servo (from the signal generator) the sinusoidal waveform (with the frequency $f = 0.1$ Hz and whose amplitude is actually the disturbance of $\varphi_p = 21^\circ$) is brought. The first, pulse signal represents the record of the time base so that one second represents one centimeter.

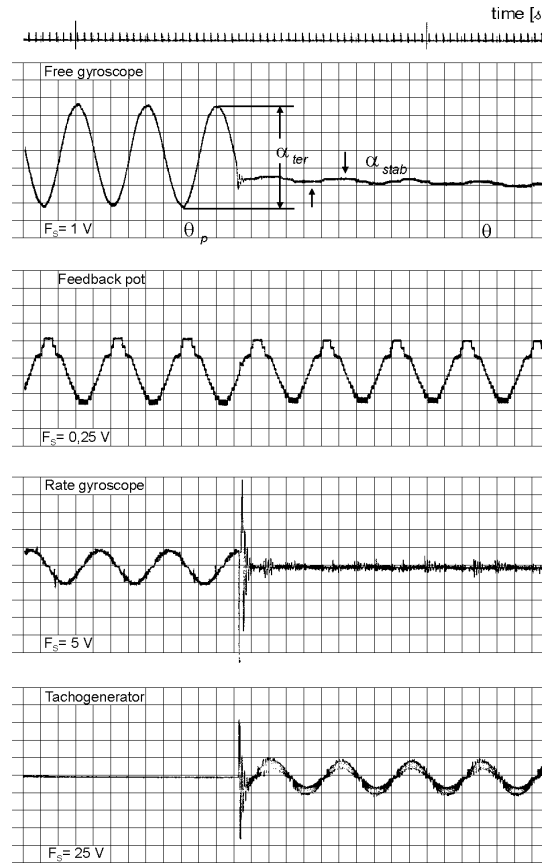


Fig. 5. Simulation of the moving of the vehicle using instrumental servo, for the disturbance generating.

The signal obtained from the free gyroscope is recorded on the first chan-

nel. This signal contains the record of the absolute angle (φ) of the gyroscope block that is the angle of the disturbance in the absolute frame.

In the beginning of the measurement the drive of the turret by the direction is off, and the cupola is still related to the ground. Hence, the angle of the gyroscope block related to the cannon's tube is at the same time the absolute angle related to the ground ($\varphi = \varphi_p$). That means that the signals from the free gyroscope and from the potentiometer of the reverse connection should be opposite phase which is correct and the slight deviation (1.5 mm) is the consequence of the static error made by building the writer in. When the drive by the direction is off, then it is $\dot{\alpha} = 0$, so the rate gyroscopes also turn related to the ground, and the angular of the gyroscope in the absolute system ($\dot{\varphi}$) is equal to the angular velocity of the disturbance ($\dot{\varphi}_p$), that is the turning of the gyroscope related to the tube ($\dot{\varphi} = \dot{\varphi}_p$). The signal from the rate gyroscope which measures the angular velocity in the horizontal plane (by the azimuth) is recorded on the third channel. This diagram also represents one parameter in the absolute frame, and it corresponds to the angular velocity of the disturbance, that is the absolute angular velocity of turning the gyroscope block related to the ground. We can see that these two signals are moved in the phase for about 90° , which is natural, because the angular velocity is the first differential of the angle.

The fourth channel represents the signal from the tachogenerator. This diagram actually represents the angular velocity of the cannon (or the turret) related to the body of the vehicle, and since it is still, that is actually the angular velocity related to the ground. This angular velocity corresponds to the angle α , which is the angle of turning related to the ground.

At the beginning ($\simeq 32$ s) the drive plant of the turret is not in the stabilization mode, so the cannon is not moving related to the ground ($\alpha = 0$ and $\dot{\alpha} = 0$). This fact is recorded on the fourth channel in the form of the flat line about zero, that is the angular velocity of the cannon related to the ground (which is measured by the tachogenerator) equals zero. The consequence of this is that the relative turning of the gyroscope block related to the tube (φ) equals their absolute turning related to the ground ($\varphi = \varphi_p$). This fact is represented on the record of the signal from the free gyroscope, which is in the beginning of the diagram sinusoidal with the amplitude of about 21° . Hence, the stabilization error is equal to the simulated disturbance. The fact that the gyroscope block is turning related to the ground is also represented on the third channel, which records the angular velocity of the gyroscope block $\dot{\varphi}$ in the absolute space (and it is $\dot{\varphi} = \dot{\varphi}_p$).

After about thirty seconds this drive is activated in the stabilization mode. This is done for the security of the people and the equipment. From the diagram on the fourth channel we can see that then the cupola begins to move by the direction ($\alpha \neq 0$) and in the opposite direction from the direction of the turning of the gyro- scope block related to the tube ($\dot{\alpha} \simeq -\dot{\varphi}_p$) so the gyroscope block stands still related to the ground ($\dot{\varphi} \simeq 0$). This can be seen from the diagram on the third channel where the signal from the rate gyroscope practically has the character of the high frequency noise about zero. The fact that the gyroscope block is still related to the absolute, inertial, frame is seen from the diagram on the first channel, because the signal from the free gyroscope after activating the stabilization is practically the same ($\varphi = \text{const}$). More precisely, the gyroscope block is not completely stabilized, but there is some stabilization error $\Delta\varphi \simeq 0$ which is actually measured by the free gyroscope. The fact that the gyroscope block is still related to the ground is obvious from the signal from the free gyroscope, because the diagram on the first channel has practically became the straight line, and that means that the gyroscope block is not moving in the absolute space. Its position is now the consequence of the two movements:

1. The gyroscope block is turning related to the tube (using the instrumental servo) for some angle φ_p ,
2. At the same time, it is together with the turret, turning related to the ground for some angle α . Hence, $\varphi = \alpha + \varphi_p$ since these two turnings are contra phase ($\alpha \simeq -\varphi_p$), the gyroscope block is practically still. It does not change its position related to the ground ($\varphi = \text{const}$).

The stabilization error signal can be further processed in the same way as described for the case when the vehicle is moving over the special made path, that is the average error and its standard deviation can be calculated. For the quick analysis of the stabilization quality, it is possible; instead of complex statistic methods; in the simple way give the stabilization factor A on the certain frequency. The stabilization factor can be defined as the rate of the maximum value of the disturbance angle φ_p and the stabilization error $\Delta\varphi$: $A\varphi_p[0.1\text{Hz}] = \varphi_p/\Delta\varphi$.

Hence, we can say that the stabilization system has the satisfactory quality if the stabilization factor on the certain frequency is inside in advance determined boundaries.

Keeping in mind that today the powerful computers can very quickly perform very complex analysis of the signal as well as the statistical processing, there is no reason that for the quality checks we don't use even more

complex methods. Also, everything is done in the laboratory conditions so there are neither big problems nor big investments for the experiments. The only investments are actually buying a PC with the D/A converter and the production of one axis instrumental servo, while the sensors are rate gyroscopes and the signals (the output from the integrator) from the servo as well as its drive plants.

7 Conclusion

The simulation method of the independent axes enables the test and measurement of the stabilization error using the instrumental servo system, which simulates the moving of the vehicle on the terrain. It is possible to perform measurements with the one axis instrumental servo, while the change of the axis is obtained with the simple turning of the holder for 90° and the gyroscope block for 90° in the opposite direction. The obtained results are completely comparable with the results obtained using other methods, driving over the terrain or simulating the movement using the simulating platform. The advantages of this method are low price, low power and the possibility for testing and measuring the stabilization error in the early phase of the production of the servo system for the stabilization (by the manufacturer of the drive plant). This method is also suitable for testing and examining even in the extreme temperature conditions.

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