# 904. Effects of friction in the system of vibration-isolation platform with gyroscopic stabilizer

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**Abstract.** In the previous works the mathematical models of vibration-isolation platform with gyroscopic stabilizer did not count with a friction in the joints of precession and stabilizer frames and especially the friction in the correction system drive. The works about gyroscopic systems for indication and measuring purposes presumed and required very low friction which could be neglected. However the friction occurs in the mentioned cases and could not be neglected in our gyroscopic stabilizer system. In the paper will be introduced, discussed and evaluated the effects of friction on the system behavior. The evaluation of impacts of the friction on the system behavior is necessary for adaptation of correction and compensation controllers to reduce the negative effects of the friction as well as for possible choice of more suitable correction system drive. Some effects will be compared with the experimental results.

**Keywords:** gyroscopic stabilizer, vibration-isolation, friction.

## Introduction

The vibration-isolation platform consists of the power gyroscope with vertical rotation axis, which is mounted in the precession frame (inner gimbal). It is also possible use the tandem of gyroscopes with opposite direction of rotation. Each gyroscope is mounted in own precession frame and precession frames are kinematic constrained by anti-parallelogram mechanism (see [1]). Precession frame (frames) with horizontal rotation is mounted on the stabilizer frame (outer gimbal) with also horizontal axis, but perpendicular on the precession frame rotation axis. Very important parts of the gyroscopic stabilizer are correction and compensation systems (described in [2]). Correction and compensation systems are represented by two feedbacks. Correction acts the torque, which is dependent on the deflection of the stabilizer frame from absolute or apparent (direction of resultant of accelerations) vertical post, on the precession frame axis. Compensation acts the torque, which is dependent on the angular deflection of the precession frame, on the stabilizer frame axis. The stabilizer frame (outer gimbal) of the vibration isolation platform with the gyroscopic stabilizer, unlike the classic gyroscopic stabilizer, is elastically mounted to the base. This is a big difference between classic gyroscopic stabilizer and described system of vibration-isolation platform.
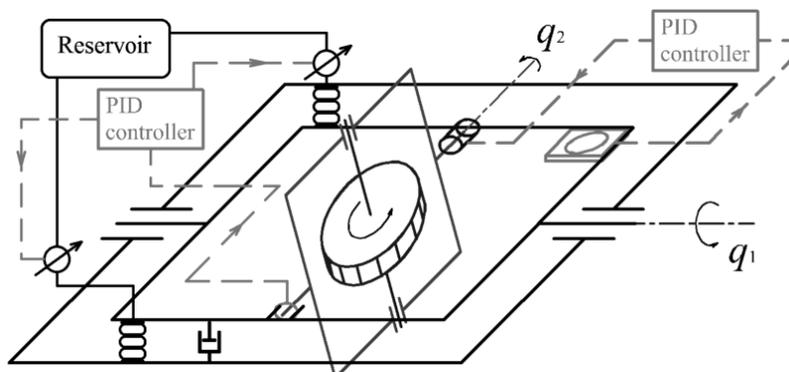


**Fig. 1.** Scheme of vibration-isolation platform with gyroscopic stabilizer

In the classic works [3, 4] we can find the requirements of very low passive resistances in the suspension of the gyroscope inner and outer gimbals. There can be seen various methods to minimizing of friction in precession frame bearings. On the other side the vibration-isolation platform frame must be elastically supported. The torque generated by the springs which support the stabilizer frame, similarly to the friction in the stabilizer frame joints, cause the increase of the deflection of gyroscope precession frame. The friction on the precession frame bearing should be minimized for the correct function of the gyroscopic stabilizer. The requirement of the very low passive resistances allows neglecting them in the mathematical model. However the passive resistances in the system of the testing device of vibration-isolation platform with gyroscopic stabilizer are not negligible. We used the swivel pneumatic motor as a correction system drive. This kind of motor contains a high friction between rotating vane and the wall of the cavity. This is the source of not negligible passive resistances in the precession frame suspension. However this is only a part of passive resistances in the precession frame suspension, there are also the friction in the bearings and also the forces generated by air supply of the gyroscope drive. All these passive resistances are not negligible and it is hard to minimize them to be considered as negligible. For that reason it is useful to analyze the effects of these passive resistances on the behavior of the whole system of vibration-isolation platform with gyroscopic stabilizer.

**Model in MSC Adams**

Attempts to introduce the friction in the mathematical model which was created in Maple failed. Than system MSC Adams was chosen for the further work. We have developed the new model which respects the dimensions and inertia properties of the real testing device (see Fig. 2). Also there is considered the gyroscopic tandem with kinematic coupling between both gyroscopes using the gear train. Frames of stabilizer (basic frame and stabilizer frame) are modeled as elastic bodies using the flexible links with properties of the aluminum alloy profiles used to build the testing device. Gyroscopes are modeled as rotating masses with the same properties same as real gyroscopes. The elasticity of precession frames was neglected and these are modeled as rigid parts. Joints between the basic frame and stabilizer frame and also joints between the basic frame and ground are modeled as the spherical joints which correspond with real device.
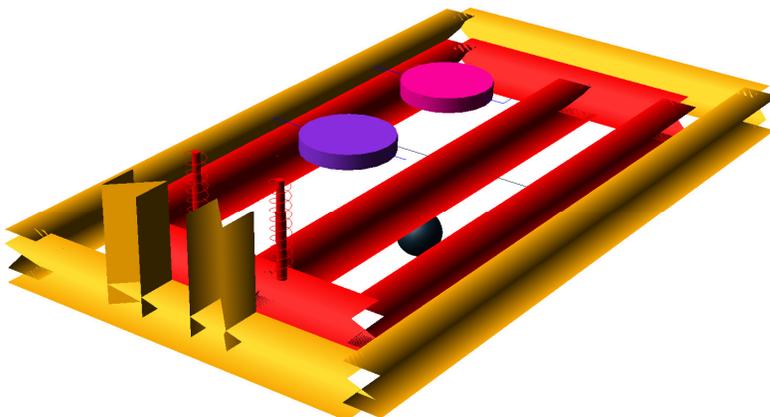


**Fig. 2.** Model in MSC Adams

There is added friction in the revolute joint of one of gyroscopes to simulate the friction in the correction system drive. We have performed a series of simulations to observe the influence

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of friction. In the simulations we used two types of friction allowed by MSC Adams – "sliding only" (Coulomb friction) and "stiction and sliding" (Coulomb friction with stiction) – see [5]. There was applied the kinematic excitation on the base frame. We used the semi-stochastic signal which had been measured during experiments on the real testing device.

**Simulations and results**

First we performed simulations to observe the effect of "sliding only" type of friction in the precession frame bearings – there is no increase of friction coefficient around zero velocity. See the comparison of influence of different values of the dynamic friction coefficient in the Fig. 3. Higher friction causes the increase of static deflection of the stabilizer frame and increase of the amplitude. Also we can observe a smoothing of the time response curve.
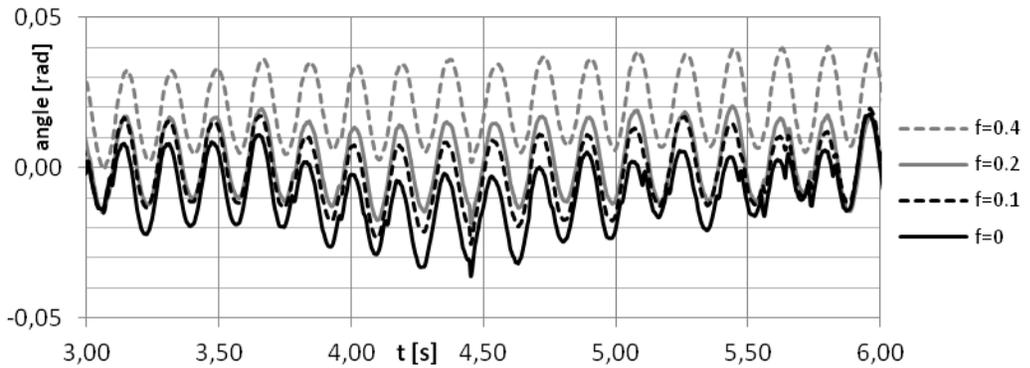


**Fig. 3.** Effect of "sliding only" friction – absolute displacement of stabilizer frame
(gyroscopes speed 15 000 RPM)

In the next step we were simulated the behavior of the system where was applied the "stiction and sliding" type of friction. We were interested in the influence of the both variables of this type of friction – static friction coefficient ($f_{stat}$) and transition speed. The static friction coefficient influence is smaller than the influence of the transition speed – see Fig. 4. Increasing the transition speed causes the time delay in the compensation system function. This causes the increase of the static deflection and also increases the amplitude of the stabilizer frame movement.
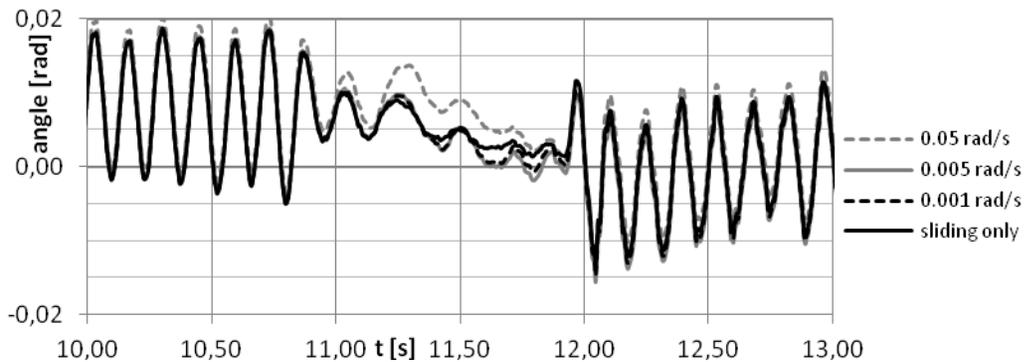


**Fig. 4.** Effect of transition speed (gyroscopes speed 15 000 RPM, $f_{dyn} = 0.2$, $f_{stat} = 0.4$)

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Comparison of the basic frame time responses, when was applied different rotation speeds of gyroscopes, showed us that the influences of the same value of the static friction coefficient are the same for all rotation speeds of gyroscopes. We also compared how the "stiction and sliding" type of friction affect the system behavior when is applied the different gyroscope rotation speed. Comparison of the time responses showed that the system with higher impulse-moment (higher RPM) of the gyroscopes is more affected by the stiction effect; it causes the higher static deflection of the stabilizer frame.

We have also compared the simulated behavior of the system with the measured time responses of the real testing devices. Comparison showed us that the system is affected also by another effects than the friction. We have registered the chaotic motion of the gyroscopes; it can be explained by the clearance between gears of the gyroscopic tandem coupling.

## Conclusions

Analyzing the simulated time responses we discovered how the friction in the correction system or in the precession frame bearings can affect the system. It generally causes the increase of the static deflection of the stabilizer frame and increase of amplitude of its motion. There we also observed some kind of smoothing of the stabilizer time responses when friction was increased, which cause the higher transfer function for higher frequencies. We have discovered that the system is more sensitive to the change of the transition velocity of "stiction and sliding" type of friction and it is less sensitive on the value of stiction friction coefficient ($f_{stat}$). There is also important the discovery of the higher influence of the stiction effect when there is applied the higher impulse moment (higher rotation speed) of gyroscopes.

As a result we have to have on mind the recommendation of reducing the friction, especially the stiction effect. Anyway this research showed that the influence of friction on described vibration-isolation platform with gyroscopic stabilizer is not as bad as we expected. However the reducing of the friction is helpful for better function of stabilizer with higher impulse-moment of gyroscopes, which is also required for better stabilization.

## Acknowledgements

## References

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