23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

PLATFORM STABILIZED BY MEANS OF TWO GYROSCOPES AND DAMPED WITH MAGNETORHEOLOGICAL DAMPER

R. Votrubec*

Abstract: *The paper deals with stabilization of platform by means of gyroscopes. Whole platform consists of parallelogram, cardan frame and two contra rotating gyroscopes. Whole system is described with five generalized coordinates and with two cyclic coordinates. Pneumatic motors and pneumatic springs are used to actuating gyroscopes and cardan frame. Magnetorheological controlled damper was used to damping rotary frame. Control algorithm is based on frequency analysis.*

Keywords: Gyroscope, Active damping, LabView, Vibroisolation, Magnetogheological damper.

1. Introduction

In the past, our team dealt with the development of active ambulance stretcher (Votrubec, 2011 and Votrubec, 2009). This platform is similar and it consists of parallelogram and two rotating frames, Fig. 1. First prototype of stabilized platform is simplified and it consists of frame rotating around one axis only, Fig. 2. Upper frame is propelled by pneumatic springs. Pressures in both springs are controlled by electrical proportional valves. Two gyroscopes with vertical rotation axis are mounted to upper inner frame. Gyroscopes have the air bearing support in precession frames. Gyroscopic stabilizer mechanical system was described in (Skliba, 2007 and Sivcak, 2010). Gyroscopes are driven by air turbine. Its nominal speed is 30.000 rpm. Manufacturing of gyroscopes with aerostatic bearings is described in (Simek at al., 2011 and Simek, 2011). Speed of gyroscopes is measured with magnetic sensor which generates pulses. The torque motor of radial correction is mounted on precession frame axis between upper inner stabilizer and precession frame. This pneumatic torque motor is actuating device of correction and compensation system. It was described in (Votrubec, 2010). Pneumatic springs and motors are controlled using pneumatic valves.

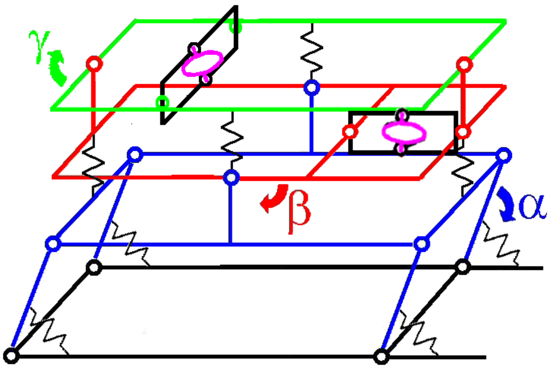

Fig. 1: Scheme of stabilized platform.

2. Description of Stabilized Plate

A photograph of prototype is in Fig. 3. The scheme of stabilized plate is in Fig. 2. Auxiliary ground frame is red. Base frame is green. Upper inner stabilized frame is blue. This frame is propelled by pneumatic springs. Precession frames of gyroscopes are mounted on blue frame. They are driven by pneumatic

* Ing. Radek Votrubec, PhD.: Technical University of Liberec, Studentska 2; 461 17, Liberec; CZ, radek.votrubec@seznam.cz

motors. Problems of using tandem of gyroscopes are solved in (Skliba, 2008). Blue frame is controlled to horizontal position.

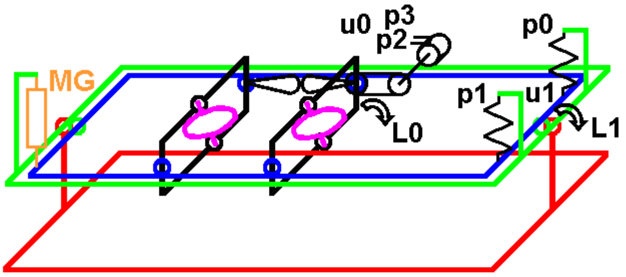

Fig. 2: Scheme of one-axis prototype.

Correction and compensation systems consist of two proportional feedbacks with PID controllers. Correction torque motor on precession frame axis is controlled by feedback from sensor of stabilized frame position. It indicates direction of an apparent vertical. Compensation system has feedback, which applies the torque on stabilized frame. It is driven with respect to magnitude of precession frame angular displacement.

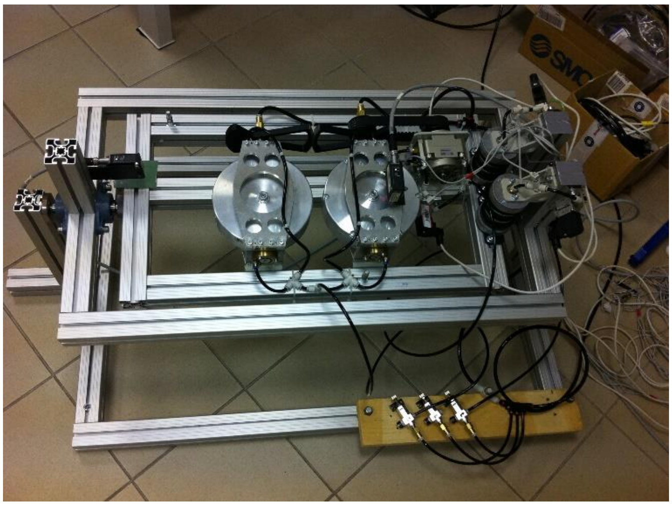

Fig. 3: Prototype of stabilized platform.

The model consists of motion equations, which are derived from Lagrange equations. External torques are on right side.

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{q}_i} - \frac{\partial T}{\partial q_i} + \frac{\partial U}{\partial q_i} = M_{s_i} + M_{d_i} + M_{pas_i} + M_{cor_i} \qquad i = 1..3 \tag{1}$$

Stabilized frame has index i = 1 with angle displacement q_1. Precession frame has index i = 2 with angle displacement q_2. Sensor of apparent vertical has index i = 3. q_3 is angle between apparent vertical and z-axis of stabilized frame. M_{Si} are torques of air springs. M_{di} are torques of dampers, M_{pasi} are torques of passive resistances and M_{cor2} is torque of correction motor. It is only on the precession frame axis. The whole model contains air spring models and models of electric valves.

3. Magnetorheological Damper

Magnetorheological damper is a controlled damper, which characteristic is changed by the modification of the properties of the working liquid using controlled magnetic field. Mathematical model of the damper was created. Damper was described multidimensional static characteristic. It is two dimensional function of damping force that depends on velocity and actuating current. This function is nonlinear. Entire range is divided into several sections. Identification consists in finding polynomial functions at borders of each interval

$$A(\dot{x}) = a_r \dot{x}^r + \cdots + a_2 \dot{x}^2 + a_1 \dot{x} + a_0 \tag{2}$$

where x’ means velocity and a_i mean found coefficients.

Next translation of coordinates was used

$$b_n = \sum_{i=0}^{N-n} a_{n+i} \binom{n+i}{i} (-1)^i {x_0}^i \tag{3}$$

where b_i mean new coefficients and ai mean original coefficients in Eq. (2).

Next it is necessary to find two-dimensional function passing through these border conditions.

$$F = c_{2n+1} \dot{x}^n I + c_{2n} \dot{x}^n + \ldots + c_5 \dot{x}^2 I + c_4 \dot{x}^2 + c_3 \dot{x} I + c_2 \dot{x} + c_1 I + c_0 \tag{4}$$

where x’ is velocity and I is actuating current.

Identified function is in Fig. 4.

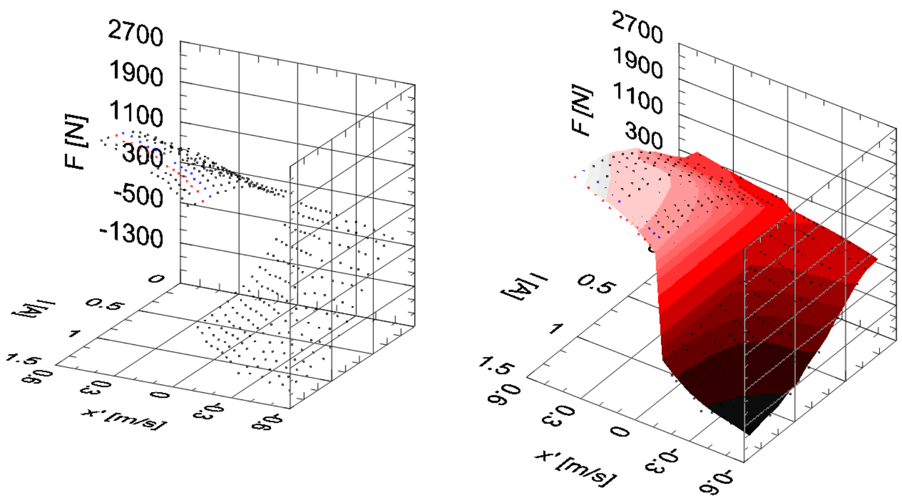

Fig. 4: Static characteristic of magnetorheological damper.

Next it was necessary to identify dynamical properties of damper. That means its transfer function of velocity and transfer function of actuating current. Complex model of damper is in Fig. 5.

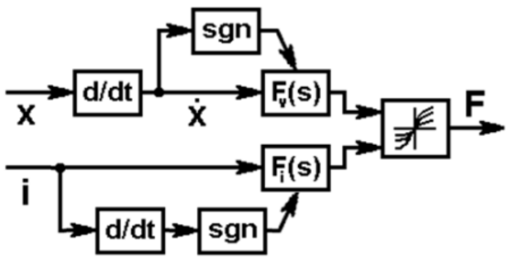

Fig. 5: Model of magnetorheological damper.

Control circuit of magnetorheological damper is in Fig. 6. It is a quasistationary control of actuating current. Frequency analysis of the excitation signal is performed every 5 s, Fig. 7.

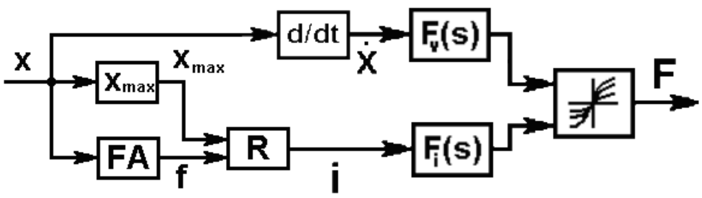

Fig. 6: Model of magnetorheological damper.

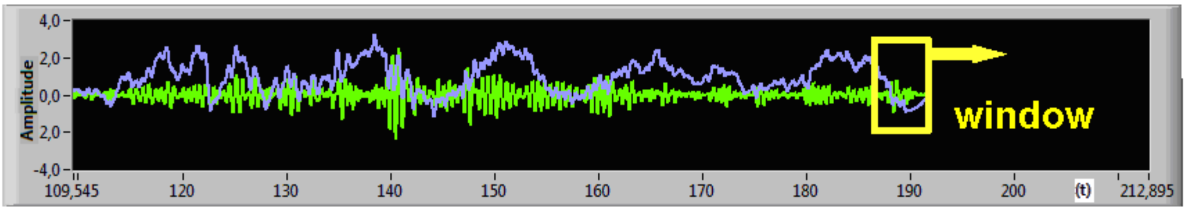

Fig. 7: Frequency analysis of excitation signal using Hanning window.

Controller R sets actuating current of magnetorheological damper every 5 s according to maximum amplitude and dominant frequency of excitation signal.

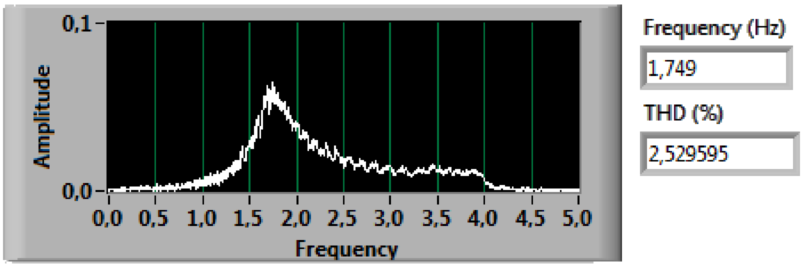

Fig. 8: Frequency analysis.

4. Conclusions

The prototype with control system of stabilized platform with gyroscopes was designed and realized. Its mathematical model was created and used for optimization of controller parameters. Simulation results were verified on real prototype. For technical reasons it was not possible to achieve the required speed gyroscopes 30000 rpm, but only 12000 rpm. Increasing speed of gyroscopes will cause their stabilizing effect even higher. System was improved with active damping system with magnetorheological damper. Damping force was controlled with frequency analysis algorithm.

Acknowledgement

The research has been supported by project SGS 21130 "Research and development in the field of 3D technology, manufacturing systems and automation".

References

Votrubec, R. (2011) Control of Active Sanitary Coach, Annals of DAAAM for 2011 & Proc. of the 22nd Int. DAAAM Symposium, Vienna, Austria, Vol. 22, No. 1, ISBN 978-3-901509-83-4, ISSN 1726-9679, (ed. Katalinic, B.), pp. 617-618, Published by DAAAM International Vienna.

Votrubec, R. (2009) Identification of Magnetorheological Damper, Annals of DAAAM for 2009 & Proc. of the 20th International DAAAM Symposium, Vienna, Austria, ISBN 978-3-901509-70-4, ISSN 1726-9679, (ed. Katalinic, B.), pp. 1791-1792, Published by DAAAM International Vienna.

Skliba, J. (2007) About a possibility of a gyroscopic stabilisation of the vibroisolation system. National Conference with International Participation Engineering Mechanics 2007, in Proc. of Int. Conf. Engineering Mechanics 2007. Svratka, pp.275-276.

Sivcák, M. and Skoda, J. (2010) Radial correction controllers of gyroscopic stabilizer. Journal of Vibroengineering Vol. 12, Iss. 3, pp. 300-304.

Simek, J., Skliba, J., Sivcak, M. and Skoda, J. (2011) Power gyroscopes of stabilizing system. Engineering Mechanics, Vol. 18, No. 3/4, pp. 259-267.

Simek, J. (2011) Application of a new type of aerodynamic tilting pad journal bearing in power gyroscope, Colloquium Dynamics of Machines 2012, Praque, pp. 130-136.

Votrubec, R. and Sivcak, M. (2010) The Correction and Compensation Motors for the Gyroscopic Stabilizer, Mechatronic Systems and Materials, Diffusion and Defect Data - Solid State Phenomena, Vol. 164.

Sklíba, J. and Sivcak, M. (2008) Some Problems of the Application of Tandem of Opposite Running Gyroscopes. X. International Conference on the Theory of Machines and Mechanisms Proceedings, pp. 601-606.