Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 48 (2012) 650 – 655

Procedia Engineering

www.elsevier.com/locate/procedia

MMaMS 2012

Design of robot vehicle undercarriage with ability to operate in broken terrain

Róbert Surovec[a]*, Alexander Gmiterko[a], Martina Vacková[a], Ivan Virgala[a], Erik Prada[a], Tomáš Pipík[a]

[a]*Technical University of Košice, Faculty of Mechanical Engineering, Letná 9, 042 00 Košice, Slovak republic*

Abstract

This article deals with an undercarriage design of robot vehicle that will be able to work in broken terrain. It is a frequently solved problem in mechatronics. High requirements for its application in area of rescue assistance, fire fighting, in nuclear and space industry as well are taken into consideration. Within the frame of designing commercially available software, e.g., MATLAB/Simulink and SolidWorks have been used to analyze a one degree mathematical model and a six-wheeled spatial model. A series of computation have been performed to determine the appropriate stiffness and damping parameters.

Keywords: Mechatronics, robot vehicle, undercarriage, broken terrain, 3D model

Nomenclature

b	damping constant (Ns/m)
f	coefficient of friction
F_s	resistance force (N)
G	weight (N)
h	obstacle height (m)
k	spring constant (N/m)
K	amplification
l_{sf}	location of center of gravity coordinate (m)
m	the mass of 1/6-th robot body (kg)
M_p	overshoot (%)
T_s	settling time (s)
u	distance between robot body frontal surface and contact of wheel with obstacle edge (m)
Greek symbols	
α	angle of contact of wheel with obstacle edge (°)
μ_a	coefficient of adhesion
ξ	relative damping parameter
ω_0	natural angular frequency (rad/s)

* Corresponding author. Tel.: +421-055-602-2456.
E-mail address: robert.surovec@tuke.sk.

doi:10.1016/j.proeng.2012.09.566

1. Introduction

The designing of robot vehicle undercarriage is an actual problem in mechatronics. Mobile robots can be applied in area of rescue assistance, fire fighting, in nuclear and space industry and therefore they must meet some requirements because of assure high precision. The most important requirement is a relative low mass of vehicle, the next one is a large load capacity. There are other requirements like small dimensions, good maneuverability in operational space, ability of passing an obstacles and moving in broken terrain, simple steering and so on [1-6].

The inspiration of a vehicle undercarriage design was given after study of a current state of robots, that are able to operate in an unknown and broken terrain. The project was encouraged by BombTec-defender for deactivate bombs installed by terrorists, a six-wheeled Mars rover called Sojourner, Crusher that are usis for investigation and military purposes [2].

In this paper a mathematical model of the vehicle is analyzed and numerically solved in Sections 2 and 3. Then the motion of the robot vehicle is simulated by SolidWorks and the results are shown in Section 4.

2. 3D model in SolidWorks

The spatial model created in SolidWorks 2009 was designed as a six-wheeled vehicle, whereby the clearance height of the robot body is adapted to those obstacles which heights are a little bit lower than heights of wheels. The drives are set into wheels. Therefore the output shafts of the drives are clamped in guide ways between springs and dampers for make a robot body oscillation lower at passing an obstacle. This construction helps to protect the drives against damage, allows to increase a clearance height of the robot body and there is no need to employ gears. This variant provides us many advantages and it is depicted on Fig. 1 [3-7].

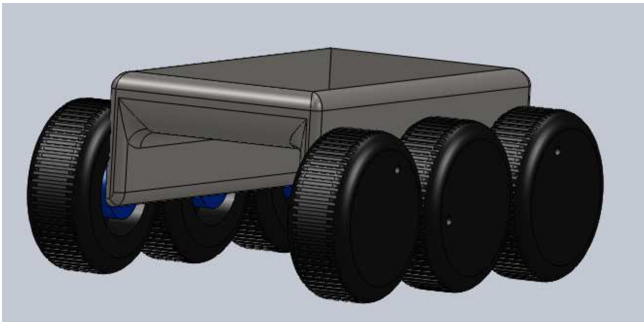

Fig. 1. 3D model of the robot vehicle in SolidWorks 2009

3. Mathematical analysis in MATLAB-Simulink

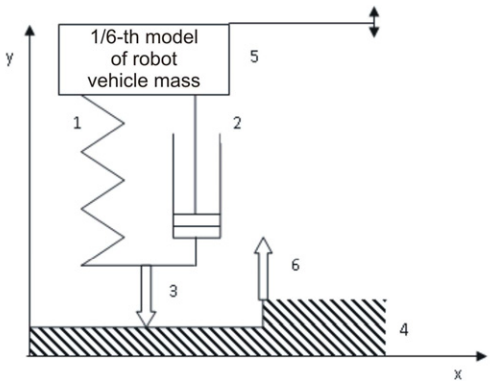

Fig. 2. 1/6-th mass-spring.damper model of robot vehicle. 1 – spring, 2 – damper, 3 – wheel-ground contact, 4 – obstacle, 5 – 1/6-th mass of the robot, 6 – a force from the obstacle

The first task of the mathematical analysis is to create a 1/6-th mass-spring.damper model of robot vehicle. One wheel rolling on broken terrain is fixed to the robot body by spring and damper. This model is shown on Fig. 2.

Using Newton´s second law of motion a second-order linear diferential equation have been obtained:

$$m\frac{d^2y}{dt^2} + b\frac{dy}{dt} + ky = -F_s u(t) \tag{1}$$

Then the Laplace transformation have been applied to create an image transmission of diferential equation:

$$\frac{Y(s)}{U(s)} = \frac{-F_S}{(ms'' + bs' + k)} \tag{2}$$

Dividing equation (1) by mass *m* the second standard form of differential equation is obtained

$$\frac{d^2y(t)}{dt^2} + \frac{b}{m}\frac{dy(t)}{dt} + \frac{k}{m}y(t) = -\frac{F_S}{m}u(t) \tag{3}$$

The coefficients of (3) are parameterized by relative damping parameter ξ and natural angular frequency ω_0.

$$\frac{b}{m} = 2\xi\omega_0, \qquad \frac{k}{m} = \omega_0^2, \qquad \frac{F_s}{m} = K\omega_0^2, \tag{4}$$

where *K* is a amplification.

It is necessary to calculate an overshoot denoted as M_p. In this case overshoot equals to 10% of stair height, which should be the 1/3-rd of clearance height of the robot body. The construction is designed with clearance height 84 mm.

The equation (5)

$$M_p = 100e^{-\frac{\xi\pi}{\sqrt{1-\xi^2}}} \tag{5}$$

have been used to calculate a relative damping parameter ξ:

$$\xi = \sqrt{\frac{1}{\left[\left(\frac{\pi}{\ln\frac{M_p}{100}}\right)^2 + 1\right]}} = 0.9176 \tag{6}$$

Let the settling time of robot body oscillation after passing an obstacle equals to 2 seconds meanwhile the amplitude is decreased to ±2% of the initial value. The time constant T_s is given by the following formula [4]:

$$T_s = \frac{4}{\xi\omega_0} \tag{7}$$

From (7) the natural angular frequency ω_0 have been obtained:

$$\omega_0 = \frac{4}{\xi T_s} = 2.179 \ rad \cdot s^{-1} \tag{8}$$

The mass of 1/6-th robot body m is 1,1 kg, substituting this numerical value with a relative damping parameter ξ and a natural angular frequency ω_0 the damping parameter b is calculated as:

$$b = 2\xi\omega_0 m = 5.05 N.s.m^{-1} \tag{9}$$

The same progress have been applied to calculate the spring coefficient k:

$$k = \omega_0^2 m = 6.91 N.m^{-1} \tag{10}$$

The last step is a calculation of resistance force F_s, which appears during passing an obstacle [5-8]:

$$F_s = \frac{G(l_{sf} + u)(\mu_\alpha - f)(f \sin\alpha + \cos\alpha)}{(\cos\alpha + f\sin\alpha - \mu_\alpha \sin\alpha)\cdot\left[h\left(-\mu_\alpha + f\right) + 2 l_{sf} + u\right]} = 45.5 N \tag{11}$$

On the base of differential equation (3) a simulation program has been written for MATLAB/Simulink program system. The block diagram of the code is shown on Fig. 3.

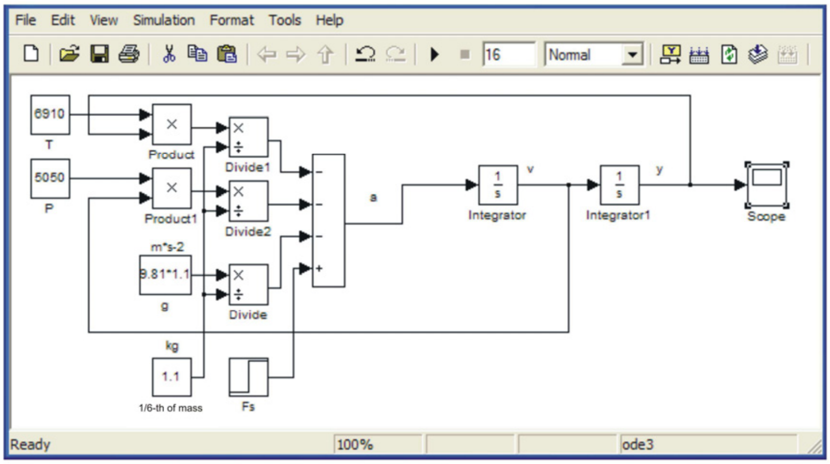

Fig. 3. The block diagram in MATLAB/Simulink

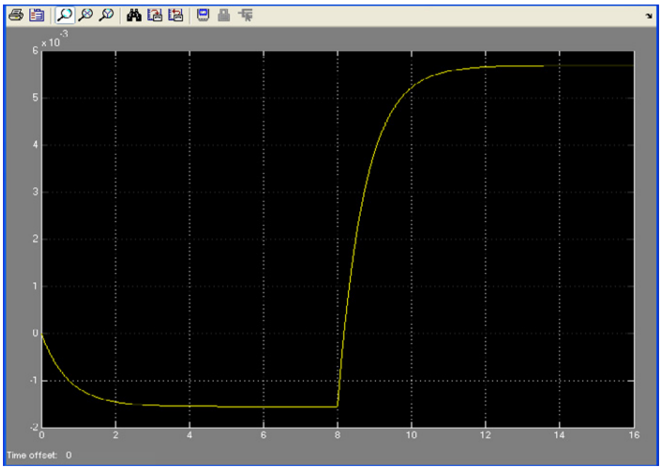

Fig. 4. A graph of the robot oscillation after passing a one stair-step obstacle

The code can simulate the vertical displacement of the vehicle during obstacle passing process. The displacement versus time is shown on Fig. 4. Due to the initial value of displacement and the self-weight and the payload capacity vertical displacements are experienced at the beginning of the simulation until study state motion without obstacle. The obstacle passing starts at time 8 seconds and finished at 14 seconds.

4. Simulation of passing an obstacle

The simulation is carried out in SolidWorks assuming self-weight and payload capacity of 50N. In order to make a simulation easier, only a one stair-step obstacle problem have been investigated. The phases of simulation process are shown on Fig. 5. One can see that there are phases when not all of the wheels are in contact with the ground or the surface with the stair-step. For example at time interval from 0.5 to 2.0 seconds the middle wheels are not in contact.

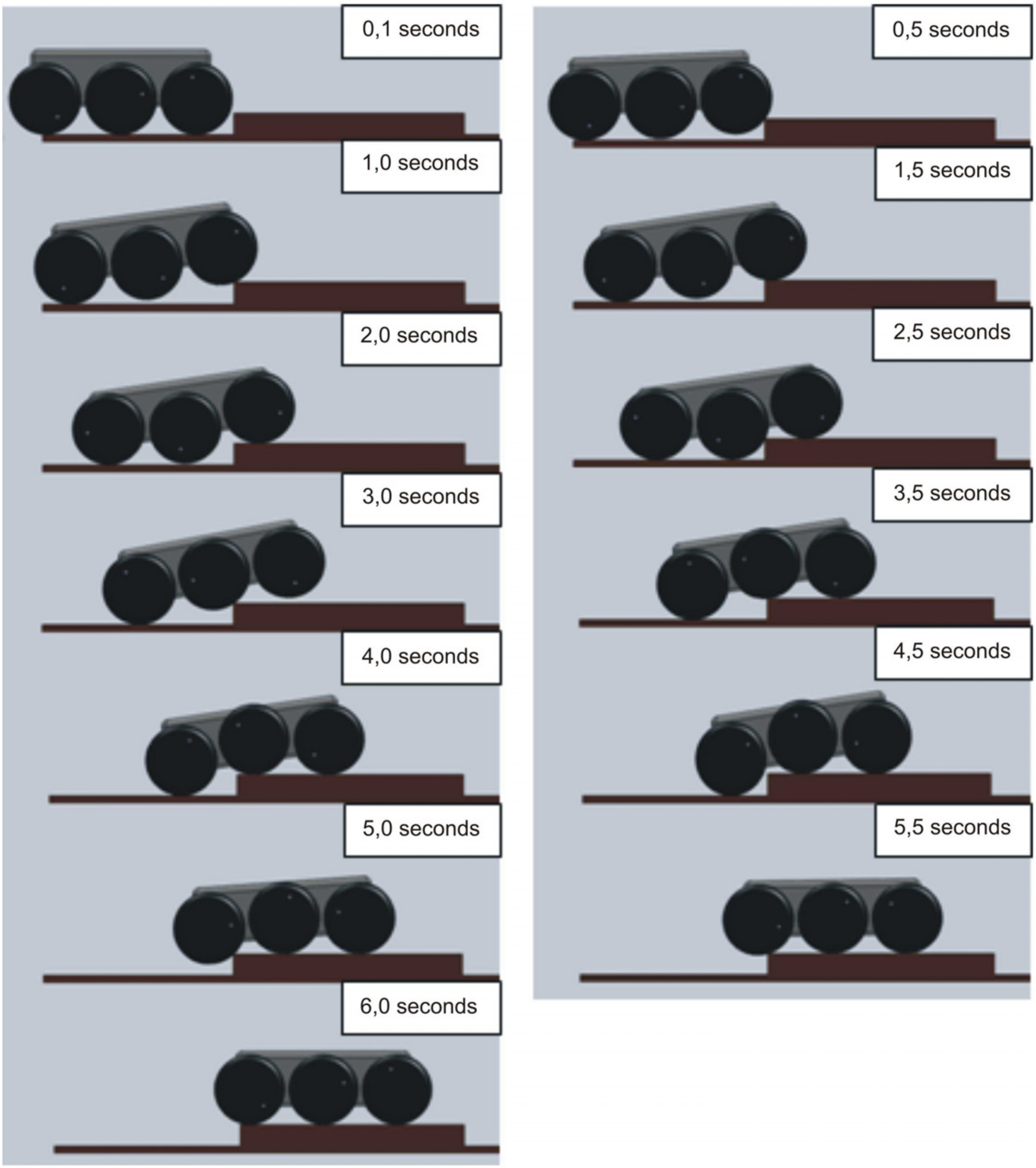

Fig. 5. Simulation of passing one stair-step

A series of computation have been performed for different spring *k* and damper *b* coefficients. Usually the robot is passing through the obstacle without large oscillation when *k* is greater than 6.91 N/m and *b* is greater than 5.05 Ns/m.

5. Conclusion

In this paper a robot vehicle have been investigated. The simplified differential equation of the model was analyzed by MATLAB/Simuling program. The six-wheeled spatial model were created with SolidWorks 2009. A one stair-step obstacle problem was analyzed to determine the appropriate stiffness and damping parameter of the suspension.

Acknowledgements

The authors would like to thank to Slovak Grant Agency – project VEGA 1/1205/12 „Numerical modelling of mechatronic systems". This contribution is also the result of the project implementation (2011et017) „LOCOSNAKE – locomotion of robotic mechanisms with control software supporting" supported by the grant program E-talent funded with Foundation of Tatra Banka.

References

[1] Smrček, J., Kárník, L., 2008. Robotika - Servisné roboty. Navrhovanie - Konštrukcia – Riešenia. Edícia vedeckej a odbornej literatúry - SjF TU v Košiciach, Tlačiareň Kušnír Prešov, Košice. ISBN 978-80-7165-713-2.
[2] Pipík, T., 2012. Návrh modelu robota so schopnosťou adaptability po členitom teréne. Bakalárska práca KAMaM, SjF TUKE, Košice.
[3] Kelemen, M., 2004. Komponenty a moduly mechatronických systémov. Dočasná vysokoškolská učebnica. TU-SjF, Košice. ISBN 80-8073-212-4.
[4] Gmiterko, A., Šarga, P., Hroncová, D., 2010. Teória dynamických systémov. Edícia študijnej literatúry - SjF TU v Košiciach, Košice. ISBN 978-80-553-0603-2. s. 227-237.
[5] Surovec, R., 2010. Návrh rekonfigurovatelného mobilného robota. Diplomová práca KAMaM, SjF TUKE, Košice.
[6] Surovec, R., Kelemen, M., Fabian, M., 2010. Transformer rekonfigurovatelný mobilní robot Wheeking 1. In: IT CAD, vol. 20, no. 4, p. 68-70. ISSN 1802-0011.
[7] Surovec, R., Kelemen, M., Fabian, M., 2010. Žiadna hračka, ale rekonfigurovateľný mobilný robot. In: Ai Magazine : automotive industry magazine, vol. 3, no. 4, p. 48-49. ISSN 1337-7612.
[8] Surovec, R., Kelemen, M., Vacková, M., Virgala, I., 2011. A conceptual design of the self-reconfigurable mobile robot Wheeking 1. In: ATP Journal plus, no. 1, p. 57-60. ISSN 1336-5010.