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THE INFLUENCES OF MOTORCYCLE VIBRATIONAL PROCESSES ON DRIVER SAFETY

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Abstract. *The current problems and demands regarding the safe driving of single-track vehicles are presented in this paper. The influence of motorcycle vibration processes on driver safety is emphasized, both in on road and off-road conditions. In order to investigate vibration processes from the point of view both comfort and safety, a simulation model was created. The presented research results indicate a complex interaction of motorcycles and riders in terms of achieving the stable motion of the system and thus obtaining the appropriate safety level in traffic conditions. The presented results indicate the need for seeking a compromise solution in the phases of design, construction and motorcycles use i.e. adjusting its constructive and exploitation characteristics (load mass distribution, tire selection, the maintenance of required technical conditions).*

Key words: *motorcycle, vibration, driver safety*

1. INTRODUCTION

In road traffic one can meet vehicles with various design concepts and various characteristics. According to the number of tracks and wheels, all cars can be classified into the single-track and two-wheeled vehicles and into double-track vehicles with four or more than four wheels. More information on the classification and categorization of vehicles is given in the *Regulations on the division of motor vehicles and trailers, and technical requirements for vehicles operating on the roads*, as an appendix to the norms of traffic safety.

Bicycles and motorcycles are two representative categories of single-track vehicles with two wheels, which are freely found in traffic and whose dynamic characteristics in interaction with the driver's behavior significantly affect safety.

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Studies of the dynamics of single-track vehicles have been carried out for more than 200 years, and significant results in this area have been achieved over the past four decades. Thereby, it could be said that the motion of bicycles and motorcycles share a lot of common features, but that they are very different from the motion of double-track vehicles [1], [2], [3].

In some papers, published in this field, various problems were included depending on the actual events in the given period of time. Theoretical analyses involved the investigation of the rectilinear and curvilinear motion of the vehicle. Mathematical models were established for rigid or flexible mounting systems, including the of the influence of the driver, when the driver is passive, as added mass and modified structure and configuration of the entire system, on the one hand, and when the driver is active, as a steering action using the vehicle's commands and changing the position of the body related to the vehicle, on the other [4], [5], [6], [7], [8].

Unlike double-track vehicles, which do not have the stability to keep the direction of movement without the help of the driver, single-track vehicles have neither stability of direction of movement, nor the stability of the position in relation to the road [9], [10], [11].

For these reasons, the role of the driver of single-track vehicles is very complicated and difficult. While driving, the driver gets tired, and frequently causes the traffic accidents with serious injuries or deaths [12], [13], [14].

In this sense, theoretical-experimental studies of motorcycle dynamics still remain a current issue. In the aforementioned works, mathematical and simulation models with varying complexity were used, depending on the assumed elasticity characteristics of the supporting system, depending on the adopted number of degrees of freedom, the driver's behavior and environmental conditions. However, a few recent papers dealing with this issue investigated the impact of the motorcycle transient oscillatory process that is caused by typical motions and regimes of movement, which refer to steering and safety characteristics [15], [16], [17].

Taking into consideration the highlighted problems, this paper considered some of the characteristics of single-track vehicle vibrational processes.

2. THE KEY ISSUES

The research carried out in this study should, above all, emphasize the complex interaction between motorcycles and the riders in terms of achieving a stable motion of the system and thus obtaining the appropriate safety level in traffic conditions. These aspects include important optimal design, construction, vehicle maintenance, and the adequate training of drivers.

Bearing in mind the different performances and driving characteristics of the vehicle on the one hand, and the possible regimes of motion and scenarios in traffic on the other, but also considering the differences in age, temperament and strategy of the drivers, the selection of appropriate simulation models is of particular importance for this study, along with the conditions of motion and dominant factors, in order to analyze their impact on each other.

Starting from the complex dynamics of the motorcycle as a 3D system, i.e. including three oriented planes, it was necessary to create an adequate model for the motorcycle dynamics analysis with the passive role of the driver. This was needed to create a basis for the investigation of vibration effects on a motorcycle (a) the ability to follow the road profile, on road and off-road conditions without transferring (or significantly dampening) vibrations on the driver and passenger, and therefore, the aspect of driving comfort (b), the conditions necessary for achieving reactive forces in tire-road contact, drive force, brake force, lateral force, the economical aspect, dynamics, brake efficiency, the lateral stability (c), the stability of the motorcycle's position, required for various regimes of motion operation under variable speed, along the path of a variable curvature.

In accordance with the above listed requirements, for the purpose of this study a model of the system for analysis of the basic motion along the straight direction was created, in a general case, involving interaction of the vertical and longitudinal dynamics of a motorcycle.

3. Motorcycle Dynamics Modelling

To create a physical-mathematical model in order to investigate the vibrational process, from the starting point was the concept and design characteristics of the motorcycle shown in Figure 1.

Fig. 1 The motorcycle

The initial data, expressed in general designations are the following: total mass, m, the distance between the wheels, l, the center of mass position, T with, the longitudinal coordinates a, b and height, h. An adequate model of this system of analysis in the plane of vertical-longitudinal dynamics is shown in Figure 2.

In addition to the above given marks, Figure 2 shows: I – the moment of inertia of sprung mass around the transverse axis, c_i, k_i, i=1,2, the stiffness and damping of the elastic suspension system of the front and the rear wheel respectively; c_{ip}, k_{ip}, i=1,2, the stiffness and damping of tires of the front and the rear wheel respectively, m_1– unsprung mass of the front wheel, m_2 – unsprung mass of the rear wheel, z_{01}, z_{02} – excitation signals of the front and rear wheel respectively, v – the speed of the motorcycle's longitudinal movement.

In a general case, the model possess five degrees of freedom, 5 DOF: two degrees of freedom for sprung mass m, transmission z, rotation α; one degree of freedom per each unsprung mass m_1, z_1, and m_2, z_2 and one degree of freedom for basic, longitudinal motion, velocity v.

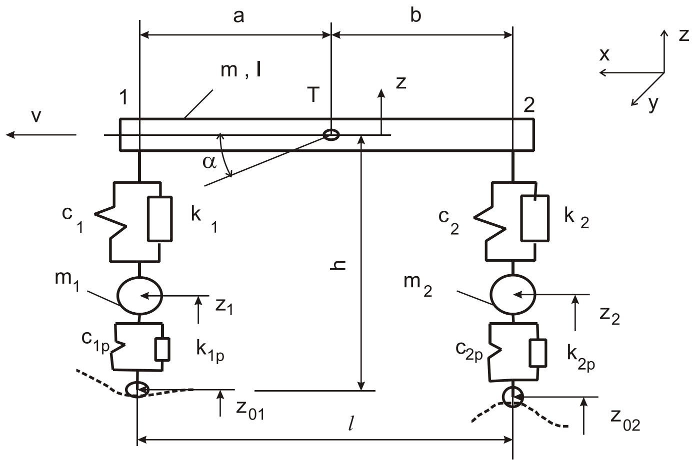


Fig. 2 Vibrational model of a motorcycle

Differential equations of motion are obtained from dynamic conditions of equilibrium for the acting forces and moments with respect to the position of static equilibrium, written in a general form (1), (2), for sprung mass (3), (4) for each unsprung mass, separately.

$$m \cdot \ddot{z} + F_{ck1} + F_{ck2} = 0 \tag{1}$$

$$-I \cdot \ddot{\alpha} + F_{ck1} \cdot a + F_{ck2} \cdot b = 0 \tag{2}$$

$$m_1 \cdot \ddot{z}_1 - F_{ck1} + F_{pck1} = 0 \tag{3}$$

$$m_2 \cdot \ddot{z}_2 - F_{ck2} + F_{pck2} = 0 \tag{4}$$

where, besides the marks, already shown in Figure 2, the following marks were also introduced (1) ÷ (4): F_{cki} (i = 1,2...) – the sum of the restoring and damping force of the front wheel suspension, and the rear wheel, respectively, F_{pcki} (i = 1,2,...) – the sum of the restoring and damping force of the front and the rear wheel tires, respectively.

Extended expressions of those forces include the influence of stiffness and damping, c_i, k_i, c_{ip}, k_{ip}, according to Figure 2, and they are the functions of relative displacements and the relative velocities of sprung and unsprung masses of the motorcycle.

It should be emphasized that those are reduced features of the elastic suspension system obtained by reducing the real system in the plane of the vertical dynamics. For the above defined mathematical model, the constant velocity of the longitudinal motion was assumed for a single simulation realization. And the same may be varied from one realization to another in terms of the analysis of the effects of its changes on the parameters of vibrational processes. Depending on the relationship between structural parameters and, above all, depending on the mass, moment of inertia, mass distribution, the coordinates of the center of mass, stiffness and damping relations of the front and rear suspension and the properties of tires, it is possible to establish different coupling degrees between the fundamental oscillation modes of the system - so in the same way it could be simplified for some specific tasks and research conditions.

On the basis of the presented oscillation model in Figure 2, a number of simulation studies has been performed, using software developed in the interactive environment of modular blocks and varying parameters.

This paper presents, analyses and illustrates the examples of the research on vibrational motorcycle processes, shown in the time domain, generated by the specific excitation of the step and impulse form, in accordance with the structure of identification model with two inputs and four outputs as shown in Figure 3.

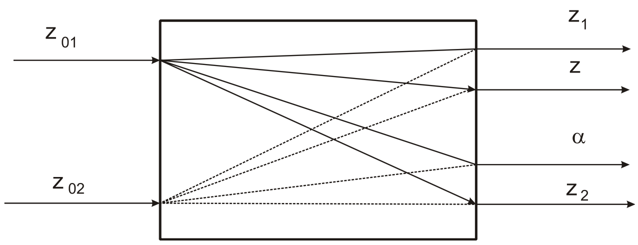


Fig. 3 Identification model of the motorcycle

Thereby, three typical cases were observed:

1. excitation of the front wheel only,
2. excitation of the rear wheel only,
3. excitation of both wheels, with time delay, in accordance with the values of the longitudinal motion velocity and the distance between the wheels.

The numerical values of the simulation model parameters, speed and excitation signals are shown in the 3rd section of this paper, for some specific simulation cases which are presented as illustrative examples. Doing so, within the framework of the developed software for the numeric integration, some modular blocks were used, which have implemented mode 45 function. This function implements the Runge-Kutta method with variable time steps for efficient computation.

4. Research Results

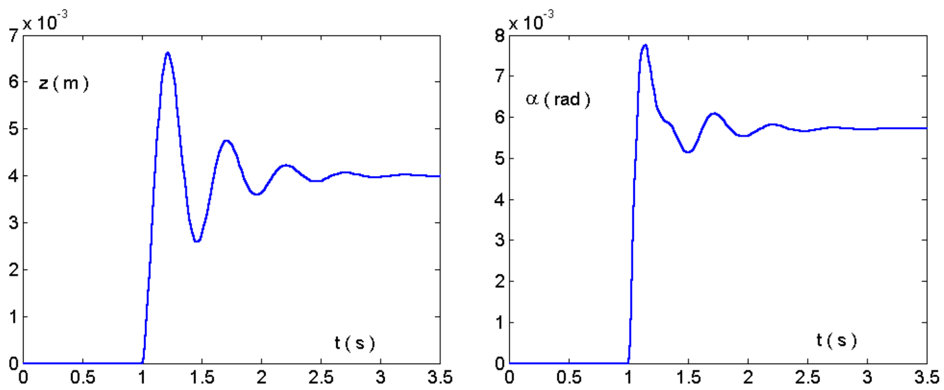
For the motorcycle shown in Figure 1, in accordance with the model marks shown in Figure 2, the following various parameters values for the simulation and investigation were used, m=174 kg, I=35 kgm^2, l=1430 mm, a=b=l/2, c_1= 16 kN/m, c_2= 25 kN/m, k_1=0,6 kNs/m, k_2=0,8 kN/m, c_{1p}=c_{2p}=190kN/m, k_{1p}=k_{2p}=0; m_1=17kg, m_2=20 kg. The speed of movement varies in a range of 5-50 km/h, bearing in mind the values of natural frequencies of two dominant modes of sprung mass oscillation. The focus of this paper is to investigate the low-frequency oscillation processes, i.e., the domain of the lower speeds at which it is difficult to stabilize the position of the motorcycle. Step and pulse height, as excitation characteristic of the road, varied in the range of 1 to 10 mm. Pulse duration which is in relation with the geometry of the characteristic of the bumps and the speed v in simulation programs varied from 0.1 to 1 second.

Illustrative examples of the results of simulation studies are shown in Figure 4 to Figure 11. The results shown in Figure 4 are related to the simulation of a motorcycle's vibrational process exposed to step excitation only of the front wheel.

At the same time, the step, as the excitation of the road, is described with the following parameters: step by 1s, initial valve 0 mm, final valve 8mm, sample time 0s. The value of the constant speed for this case is 5.148 km/h. In accordance with these images, the following characteristics of the process are indicated. Vertically, z and angularly α, the motion of supported mass, m, according to Figure 4a and 4b, as the transient vibration damping processes are different during the flow, and also according to the values of their natural frequencies, which could be concluded on the basis of their mutual coupling graphics, shown in Figure 5a. On the basis of these results, the coordinates of the sprung mass rotation center could be determined along with its position relative to the center of the total mass in relation to the positions of the driver's seat and rear passenger, as an important indicator of the impact of a motorcycle's characteristics on the vibrational loads of human factors.

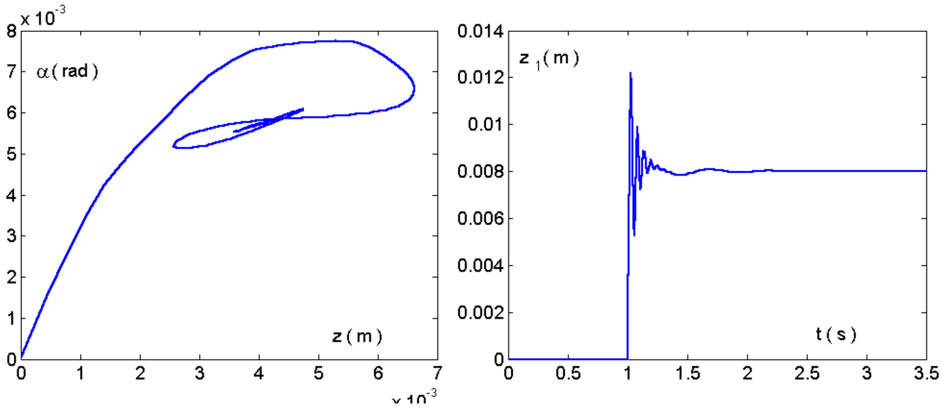
Figure 5b shows a characteristic superposition of low-frequency vibrations of the sprung mass and the high frequency of unsprung mass as a result of front wheel vibration conditioned by significant difference in the stiffness of elastic suspension and tires.

Comparing the vibrational processes from Figure 5b and 6a, a significant difference was emphasized in their flows, regarding the share of low-frequency and high-frequency components. The reasons for this are different directions and contours for excitation transfer in one case and in another case. Insight of high-frequency vibrations in the second case is more complete based on the vibration speed flow, shown in Figure 6b. In this sense, a higher time derivate of the studied processes provides more information about their influence.



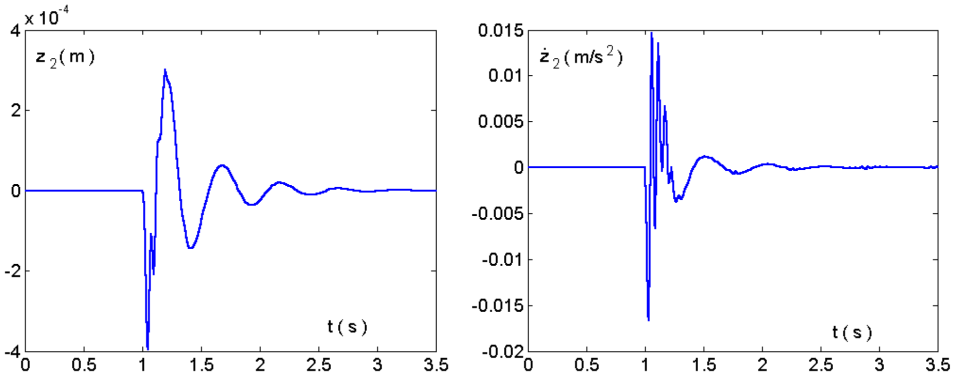
a) b)

Fig. 4 a) Vertical, b) Angular motion of a motorcycle's sprung mass under step excitation along the front wheel



a) b)

Fig. 5 a) Mutual coupling of vibrational process in Fig. 4, b) Vertical displacement of the center of unsprung mass of the front wheel for the aforementioned type of excitation.



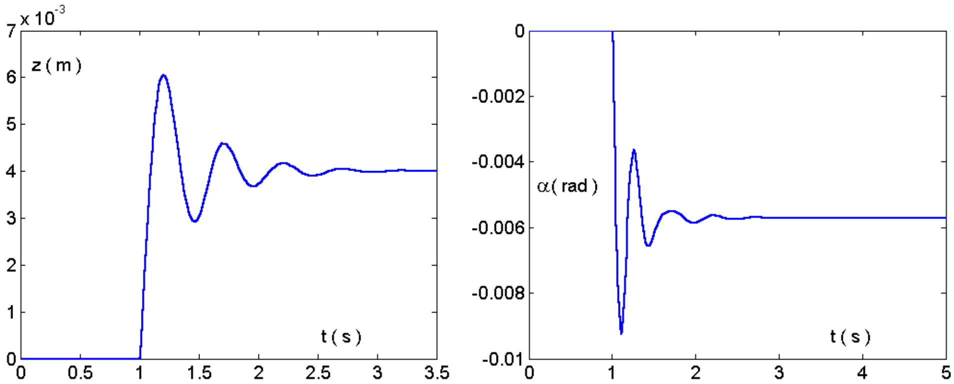
a) b)

Fig. 6 a) Vertical displacement and b) the corresponding velocity of the center of unsprung mass of the rear wheel respectively, for the given type of excitation.

Typical examples of the vibrational processes with the introduction of step excitation over the rear motorcycle's wheel are given in Figure 7a and 7b, for the vertical and angular motion of the sprung motorcycle mass. Compared to Figure 4a and 4b, higher levels of both transient processes are noticeable just like the change in the direction of angular movement, Figure 7b.

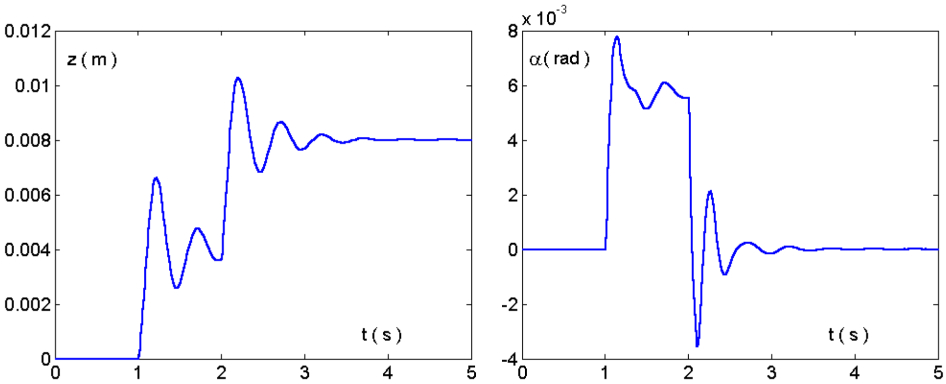
Figures 8 and 9 show typical examples of motorcycle vibrational processes with the introduction of incentives to both wheels with an adequate time delay depending on the values of the longitudinal velocity of movement and the distances among the wheels, for the above given parameters of excitation, speed, distance between the wheels and a pulse duration of 0.2 seconds. In the first case for step excitation, and in the second, for impulse excitation. In accordance to the diagram shown in Figure 9, an overview of the vertical displacements of the front and rear unsprung mass is also provided in Figure 10.

In order to analyze the impact of motorcycle speed on the parameters of transient oscillatory processes in Figure 11a and 11b, the vertical and angular movement of motorcycle sprung mass is shown during the impulsive excitation of both wheels at a speed of 50 km/h. Compared to adequate curves given in Figure 9a and 9b, an increase in the speed for the above mentioned unchanged parameters, according to 11a and 11b, the damping and filtering of motorcycle properties as the oscillatory system is indicated.



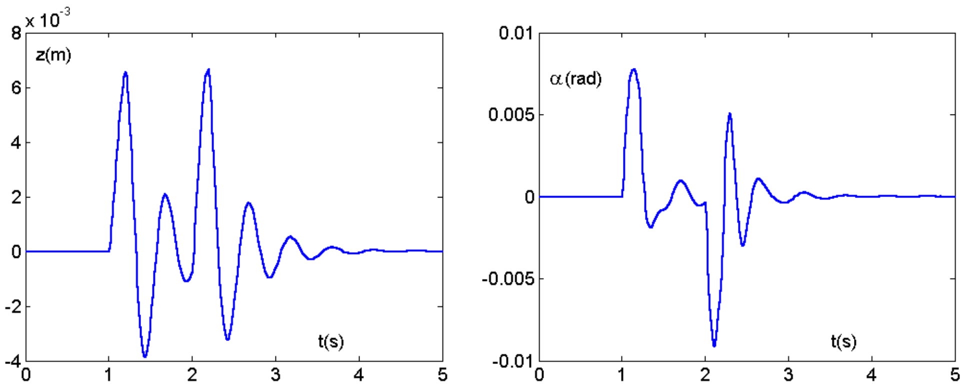
a) b)

Fig. 7 a) Vertical, b) Angular motion of sprung motorcycle mass with step excitation along the rear wheel.



a) b)

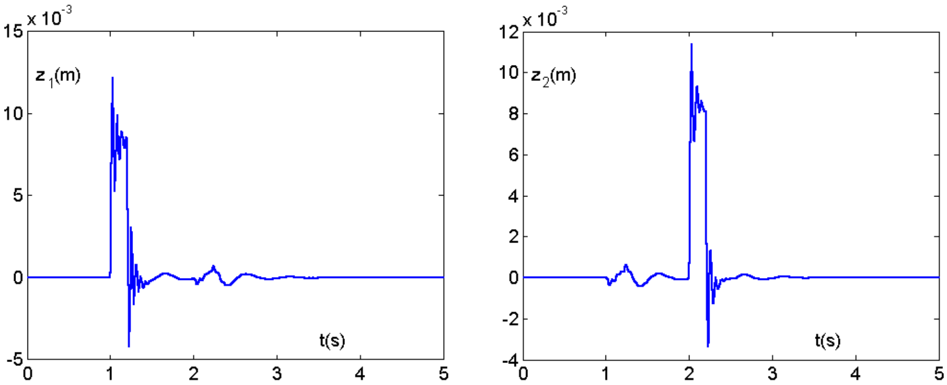
Fig. 8 a) Vertical, b) Angular motion of sprung motorcycle mass with step excitation along both wheels.



a) b)

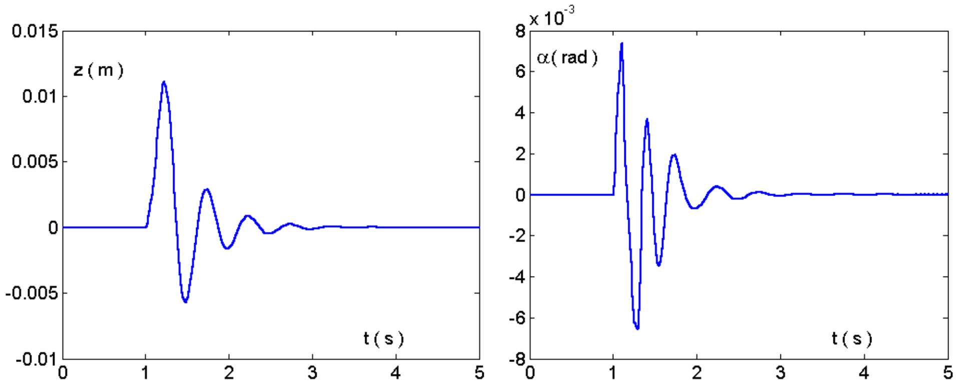
Fig. 9 a) Vertical, b) Angular motion of sprung motorcycle mass with impulse excitation along both wheels.

On the basis of the previously illustrated overviews of simulated motorcycle vibrational processes, with short time excitation, one can outline the relevant parameters for their evaluation in terms of the required performances. In general, they are the parameters of evaluation of the development process: the levels, relations of superimposed components, harmonics, their frequency, nature and attenuation intensity. The final result of this set of estimation parameters is a continuation of the parameters of their frequency content, expressed through the power of the process itself, depending on time and depending on frequency in terms of comfort, stable and safe motion. In this sense, the compromise solutions are being sought in the phases of design, construction, motorcycle usage, i.e. the adjustment of its relevant characteristics, such as, load mass distribution, tire selection, and the maintenance of the required technical conditions.



a) b)

Fig. 10. Motorcycle vertical displacement of unsprung mass
a) the front and b) rear respectively with impulse excitation along both wheels



a) b)

Fig. 11. a) Vertical, b) Angluar motion of sprung motorcycles mass with impulse excitation along both wheels, at 50 km/h.

5. Conclusion

Single-track vehicles are popular in both off-road and road traffic and represent a major risk for safety motion.

Compared to double-track vehicles, these vehicles are difficult to control due to the complex interactions with the environment and the driver, in order to maintain the stability of motion direction and position.

The developed simulation model of the motorcycle dynamics in both the vertical and longitudinal plane in this paper has enabled the analysis of influencing factors on the oscillatory processes which are caused by the excitation characteristic of the road, in the form of steps and pulses. The results show that the vertical and angular oscillations of sprung mass in a single step or pulsed excitations (excitation of only 1 wheel) are significantly different and they are in relation with its natural frequency. On the basis of their values, the center position of sprung mass oscillation is determined in relation to the position of the driver's seat and position of the passenger, as one of the significant indicators of motorcycl3 comfort. The simulation results also indicate, the effects of coupling among the oscillations in the front and rear parts of sprung mass, as well as the coupling of sprung and unsprung mass. Superimposed low-frequency oscillations of sprung mass and high-frequency oscillations of unsprung mass are the result of significant differences in the rigidity of the motorcycle support system, and the stiffness of motorcycle tires. There is also a significant difference in the oscillatory processes of sprung mass at the excitation of only one wheel, only the front or the rear wheel. Particularly important results, for further research, were obtained by the excitation of both wheels, with phased delay, that is, in relation to the speed and the distance between the wheels. These relations, along with the geometrical parameters of characteristic roughness, steps, impulse and their flow (period) define the character and intensity of the excitation time of the simulation model. It is also important to emphasize the impact of increasing speed on the parameters of transient oscillatory process, while the other conditions are unchanged. The obtained results show that at higher speeds, the motorcycle oscillatory system shows certain damping and filtering properties. Namely, transient processes are more uniform and as a result of significantly shorter time delay, therefore they are associated to oscillatory processes with a single excitation. In other words, the oscillatory transient processes at lower speeds are more complex in terms of comfort and handling, which in the given conditions create difficulties in stabilizing the position and direction of movement.

In terms of planning further research, it may be noted that the formed oscillatory model in this paper can be used to explore the regime of movement of variable speeds, such as typical regimes of a motorcycle's start and acceleration, involving the combination of regimes with intensive braking, both on flat and uneven roads.

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UTICAJ VIBRACIONIH PROCESA MOTOCIKLA NA BEZBEDNOST VOZAČA

U ovom radu predstavljeni su aktuelni problemi i zahtevi koji se odnose na sigurnu vožnju vozila dvotočkaša. Istaknut je uticaj vibracionih procesa motocikla na bezbednsot vozača, kako u uslovima na putu, tako i van puta. Kako bi se proces vibracija ispitao i sa aspekta udobnosti kao i sa aspekta bezbednosti formiran je simulacioni model. Prikazani rezultati ispitivanja ističu kompleksnu interakciju između motocikla i vozača, u smislu postizanja stabilnog kretanja ovog sistema, a samim tim i postizanje odgovarajućeg nivoa bezbednosti u saobraćaju. Prikazani rezultati ukazuju na potrebu za traženjem kompromisnog rešenja u fazama projektovanja, izrade i upotrebe motocikala, odnosno podešavanjem njegovih konstruktivnih i eksploatacionih karakteristika (raspodela opterećenja masa, izbor pneumatika, održavanje potrebnih tehničkih uslova).

Ključne reči: *motocikl, vibracije, bebednost vozača*