ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1161733

INFLUENCE OF THE TIRE RELAXATION ON THE SIMULATION RESULTS OF THE VEHICLE LATERAL DYNAMICS IN ASPECT OF THE VEHICLE DRIVING SAFETY

Witold Luty

Warsaw University of Technology, Faculty of Transport
Koszykowa Street 75, 00-662 Warsaw, Poland
tel. +48 22 2348564
e-mail: wluty@wt.pw.edu.pl

Abstract

Selected experimental research results of truck tire in steady-state side cornering and transient cornering conditions are presented in this paper. Experimental research results of the tire have been used in simulation research of medium duty truck in nonlinear driving conditions. The paper presents the structure of the vehicle dynamics model and a description of applied tire-road interaction model. Simulation research of the vehicle lateral dynamics has been performed in two variants: without and with the model of tire relaxation. During research, the tire relaxation length has been also changed. The steering wheel angle changes were forced as continuous sinusoidal excitation signal with a constant amplitude and with continuously increasing frequency. There have been analysed basic physical quantities characterizing the vehicle lateral dynamics connected with the vehicle active safety, especially including body yaw velocity and lateral acceleration in the centre of the truck body mass. An analysis of research results have been performed in the time and frequency domain. Time courses of analysed physical quantities and their frequency spectrum, obtained for tire-road interaction model without and with the tire relaxation (with different values of relaxation length) have been compared. Based on the simulation research results there have been considered the influence of tire relaxation on the vehicle performance. There have been shown that the tire relaxation can significantly change courses of observed physical quantities connected with vehicle lateral dynamics connected with vehicle driving safety.

Keywords: *tire relaxation, vehicle safety and lateral dynamics, vehicle dynamics simulation, vehicle driving safety*

1. Introduction

The tire relaxation, as unsteady state process of tire-road interaction, occurs when the wheel is rolling with side cornering with fast changing the wheel working conditions. Tire relaxation process can be the easily observed in the laboratory conditions. There are many tire relaxation test methods in dynamic conditions [1, 2, 3]. The best method to observe and analyse the tire relaxation process is the quasi-static method [4, 5, 6]. An idea of tire relaxation process when rolling with side cornering in the quasi-static conditions has been presented at the figure 1a. That process can be described by the model function typical for the first order element of inertia. In case of the tire relaxation, such function called as the IPG-Tire relaxation model contains one important coefficient: the relaxation length L_n (Fig. 1b). When only the tire relaxation process achieved in the quasi-static conditions can be approximated by the IPG-Tire relaxation model, the value of the tire relaxation length L_n can be determined. Therefore, research results of tires tests in wide scope of the wheel working conditions, performed in quasi-static conditions allow determining the tire relaxation length L_n, as the parameter, which is often used when modelling a tire relaxation process [6, 7, 8]. The relaxation length value L_n significantly depends on the wheel side cornering angle and normal load, as well (Fig. 2) [4, 6, 8]. That is why when modelling the tire relaxation it is so important to introduce presented dependence of the relaxation length L_n in the tire-road interaction model.

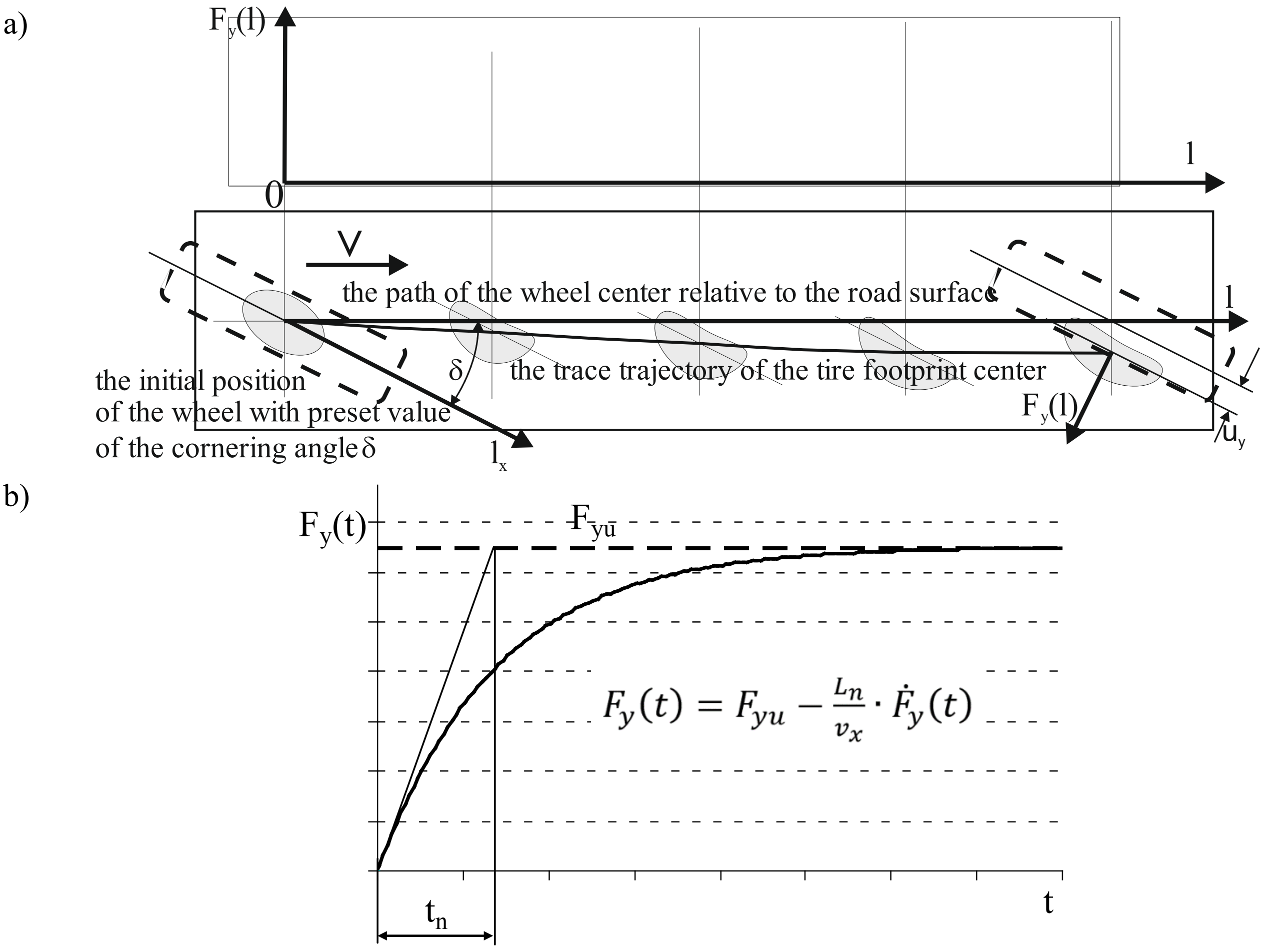


Fig. 1. Model course of the tire relaxation process because of a step-change in the wheel side cornering angle δ; a) Increase of the side reaction force F_y as a function of the distance travelled by the wheel in the quasi-static conditions; b) The IPG-Tire model - the course of the function and the model equation

where:

- v – *velocity of the wheel centre relative to the road surface;*
- l – *displacement of the wheel centre relative to the road surface;*
- u_y – *lateral deflection of the tire,*
- $F_y(t)$ – *temporary lateral reaction force, transmitted by the wheel,*
- F_{yu} – *the value of the side reaction force, transmitted by the wheel in the steady-state working conditions or by the tire model without relaxation,*
- L_n – *relaxation length, determined in the wheel longitudinal displacement,*
- v_x – *longitudinal velocity of the wheel centre relative to road surface,*
- t_n – *the relaxation time* $t_n = \frac{L_n}{v_x}$.

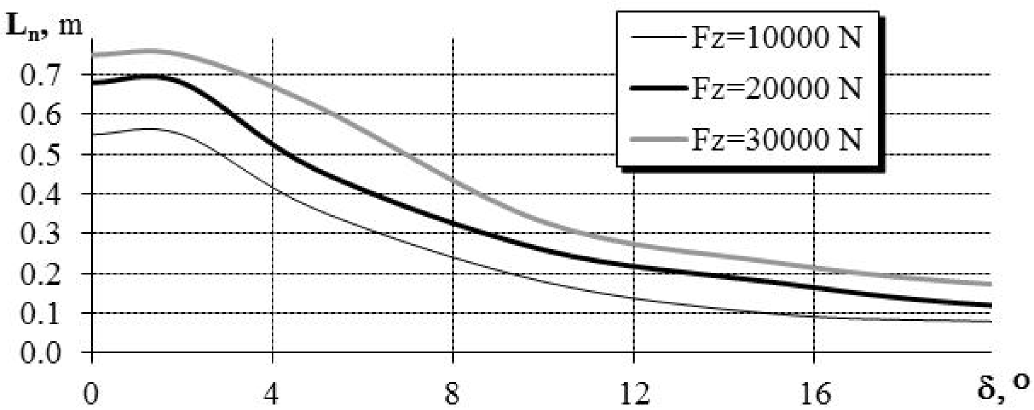


Fig. 2. Changes in the relaxation length L_n of typical truck tire due wheel normal F_z load and side cornering angle δ

The tire relaxation, when applied in the tire-road interaction model, as an unsteady state process of the side cornering can change results of vehicle dynamics simulation. Some papers present simulation research results of the vehicle model in typical open-loop tests where the vehicle model was forced by the steered wheels step or sinusoidal turning with constant frequency [9]. Now it is necessary to assess impact of the tire relaxation more general on the results of the vehicle lateral dynamics simulation. The aim of this work is to assess the impact of the tire relaxation on the vehicle lateral dynamics simulation results in a wide scope of the model forcing frequency as the steered wheels sinusoidal turning.

2. Research method, vehicle dynamics model, test conditions and observation scope of research results

Simulation research has been performed in the following conditions:

a) research method – simulation research using biaxial vehicle dynamics model (Fig. 3a, b, Fig. 4),
b) the vehicle dynamics model – multibody model with 10 degrees of freedom,
c) basic part of the tire-road interaction model – calculating tangential forces in the tire footprint F_x (longitudinal) and F_y (lateral), overturning torque M_w, stabilizing torque M_s (Fig. 3c, Fig. 4),
d) the tire relaxation model – additional and separate part of the tire-road interaction model using the IPG-Tire model (Fig. 4),
e) the speed of the vehicle model during research – *v=40 km/h*,
f) the vehicle model forcing method – sinusoidal changes of the vehicle steered wheels turning angle δ_z with fixed amplitude and continuously rising frequency from *0* to *14 Hz*,
g) the tire-road interaction model variants – two variants, without relaxation or with the relaxation during side cornering, with different value of relaxation length: typical *Ln1*, twice *Ln2* and quadruple *Ln4*,
h) relaxation length *Ln1* depended on the wheel cornering angle δ and its normal load F_z (as presented at the Fig. 2),
i) scope of simulation research results observation - basic physical quantities characterizing vehicle steerability and turning dynamics (connected with vehicle driving safety):
   - $\dot{\gamma}_1$ – yaw angular velocity of the vehicle body,
   - a_{1y} – lateral acceleration in the centre of the vehicle body mass.

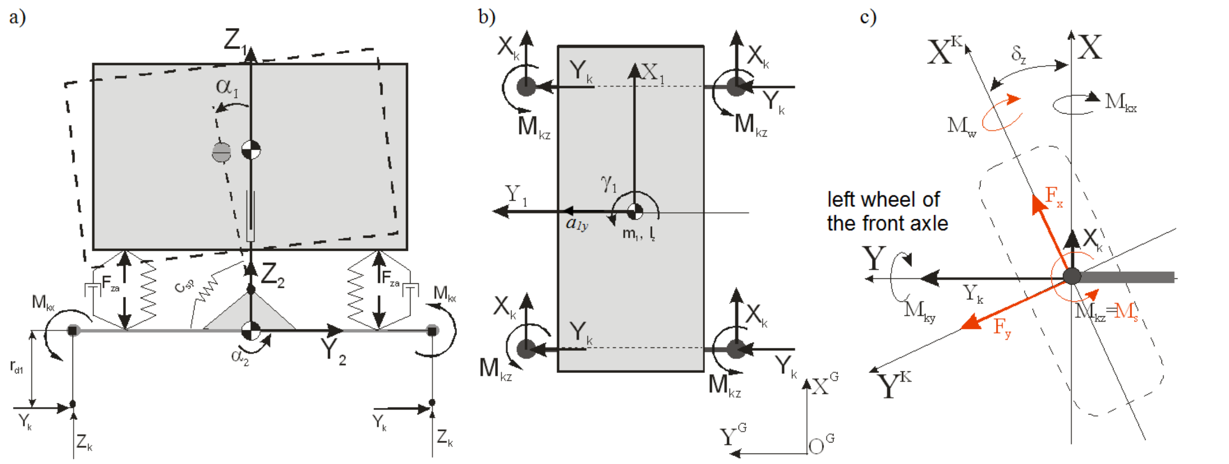


Fig. 4. The scheme of the vehicle physical model; a) front view; b) top view; c) system of forces and torques transmitted by the wheel from the road surface to the vehicle chassis, shown as the example of the left front vehicle wheel

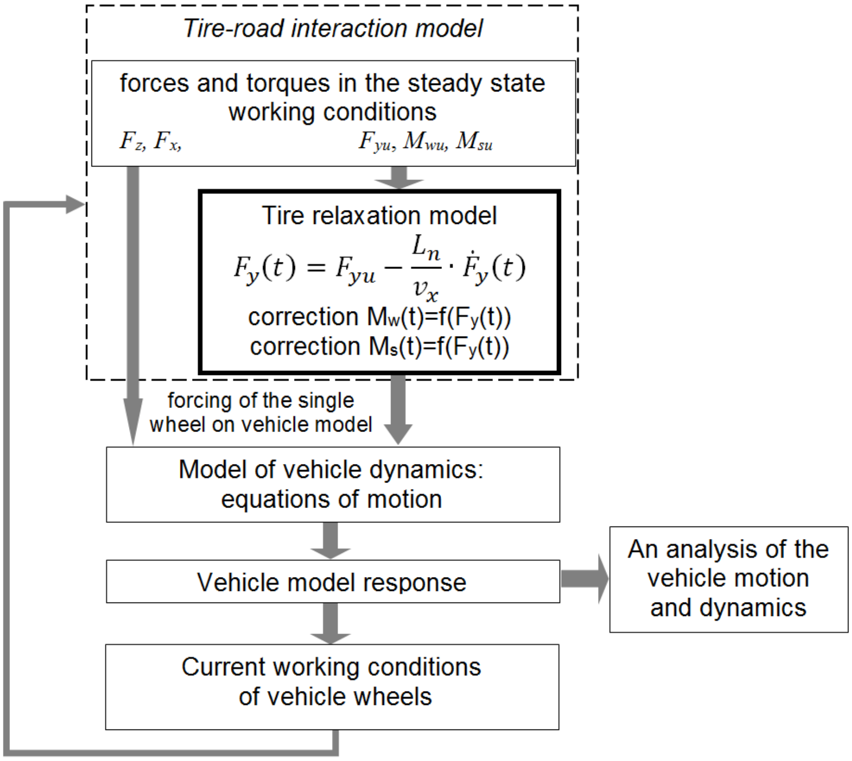


Fig. 5. Calculations scheme of vehicle dynamics model – connections between the tire-road interaction model with the tire relaxation model and vehicle dynamics model

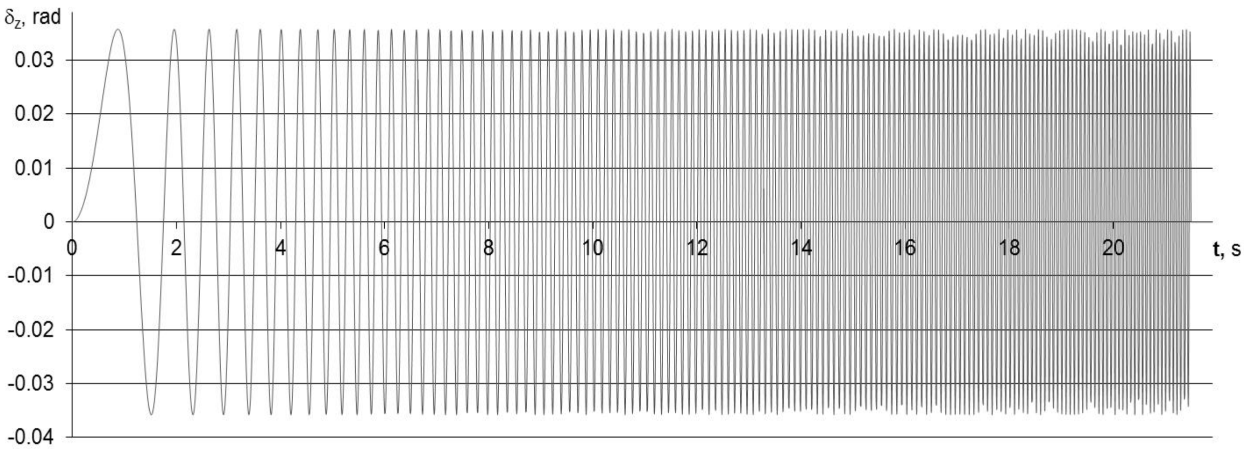
It should be noticed that the vehicle steered wheels turning angle δ_z is the vehicle model-forcing signal but it is not their side cornering angle δ. Steered wheels side cornering angle δ depends on the front axle moving conditions, which are a part of physical quantities describing the vehicle model response to its forcing.

3. Simulation research results

3.1. Impact of the tire relaxation on time courses of observed physical quantities

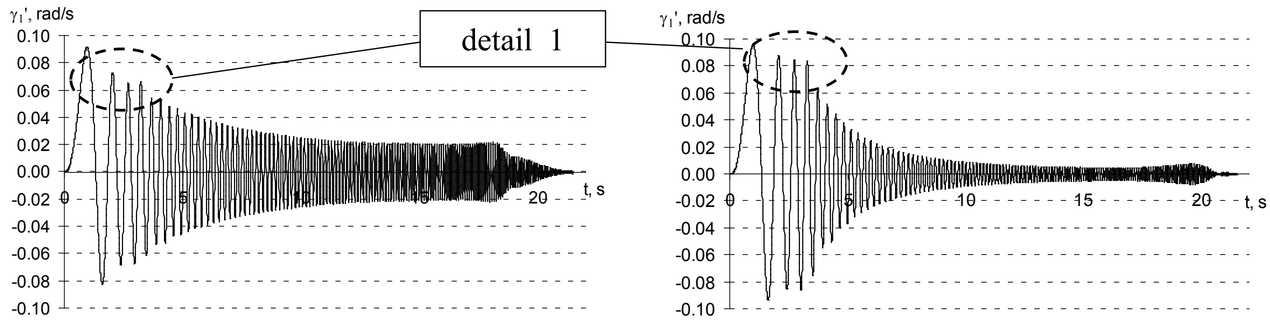
– been presented in the in the time on the figure (Fig. 6).

a) the course of the steered wheels turning angle during simulated test – signal forcing the vehicle dynamics model



Model without the tire relaxation – L_{n0} Model with the tire relaxation – L_{n1}

b) $\dot{\gamma}_1$ – yaw angular velocity of the vehicle model body



c) a_{1y} – lateral acceleration in the centre of the vehicle body mass

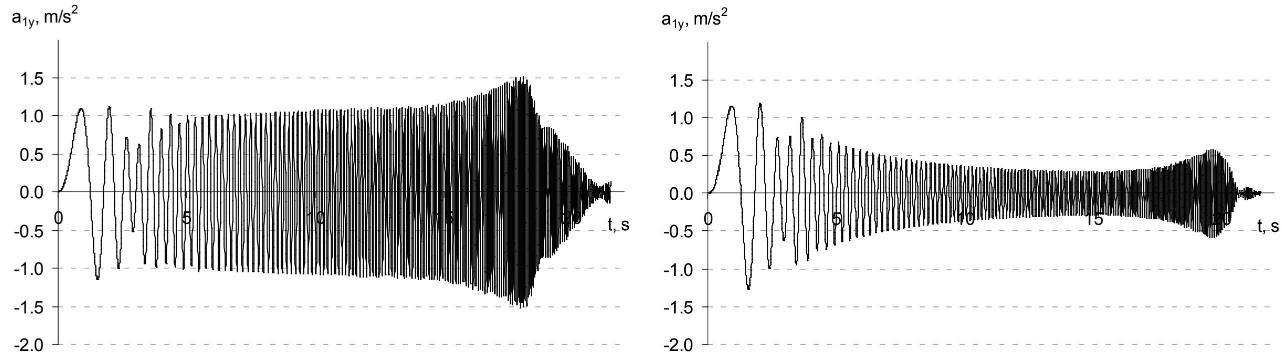


Fig. 6. Preliminary simulation results - time courses; a) steered wheels turning angle - signal forcing the vehicle dynamics model; b) vehicle response - yaw angular velocity $\dot{\gamma}_1$ of the vehicle body; c) vehicle response - lateral acceleration a_{1y} in the centre of the vehicle body mass

Basing on presented research results it is already possible to put some preliminary conclusions:

- putting simple tire relaxation model into the tire-road interaction model causes significant changes in the time courses of observed physical quantities characterizing the vehicle lateral vehicle dynamics connected with its steerability,
- generally with putting tire relaxation in the tire-road interaction model, a reduction in amplitude over a wide scope of forcing signal frequency is visible but in the low-frequency range also the increase of the yaw angular velocity $\dot{\gamma}_1$ amplitude is clearly noticeable (Fig. 6b, detail 1),
- assessment of the tire relaxation impact on the simulation results of vehicle lateral dynamics requires the preparation of the complete dynamic characteristics, including also different values of the tire relaxation length L_n.

3.2. Impact of the tire relaxation on the vehicle dynamic characteristics prepared based on the simulation research results

Dynamic characteristics of the vehicle determined for the observed physical quantities have been presented on the figures 7 and 8. Basing on these characteristics, to formulate the following conclusions is possible:

- putting the tire relaxation into the tire-road interaction model results makes a significant change of the vehicle dynamic characteristics courses, both for the amplitude and phase shift,
- generally, the tire relaxation reduces the amplitude of observed physical quantities in a wide range of the forcing frequency over the value of about 2.5 Hz.

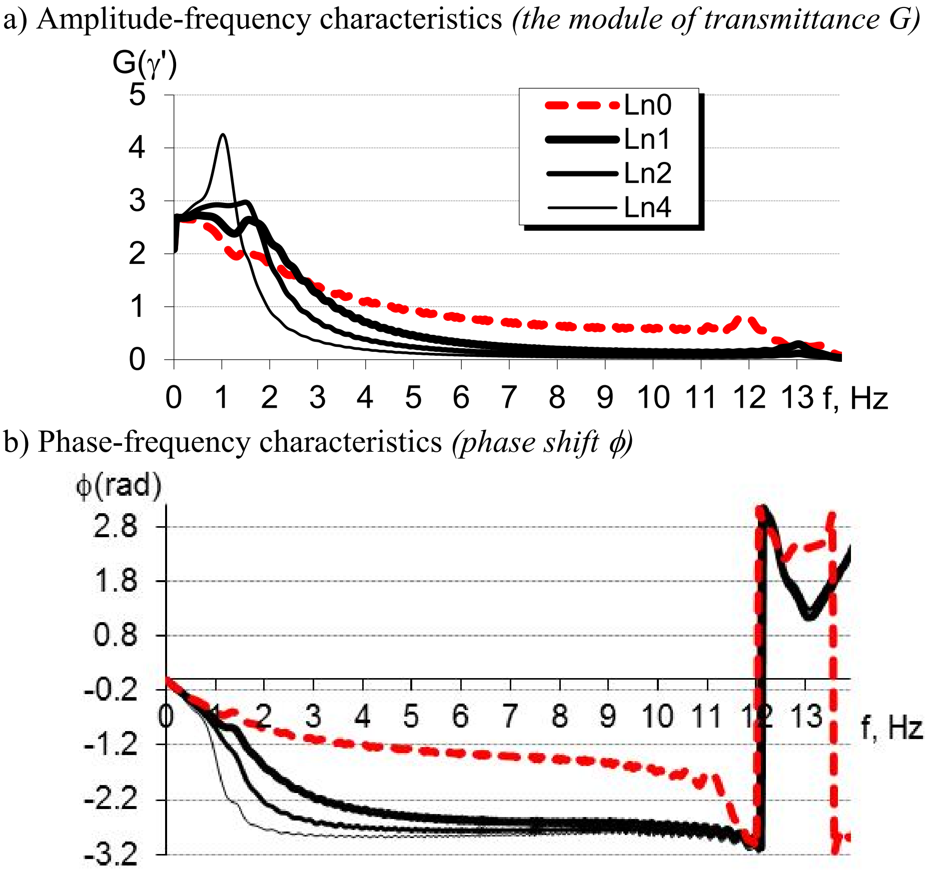


Fig. 7. Dynamic characteristics of the vehicle model determined for the yaw angular velocity $\dot{\gamma}_1$ of the vehicle body

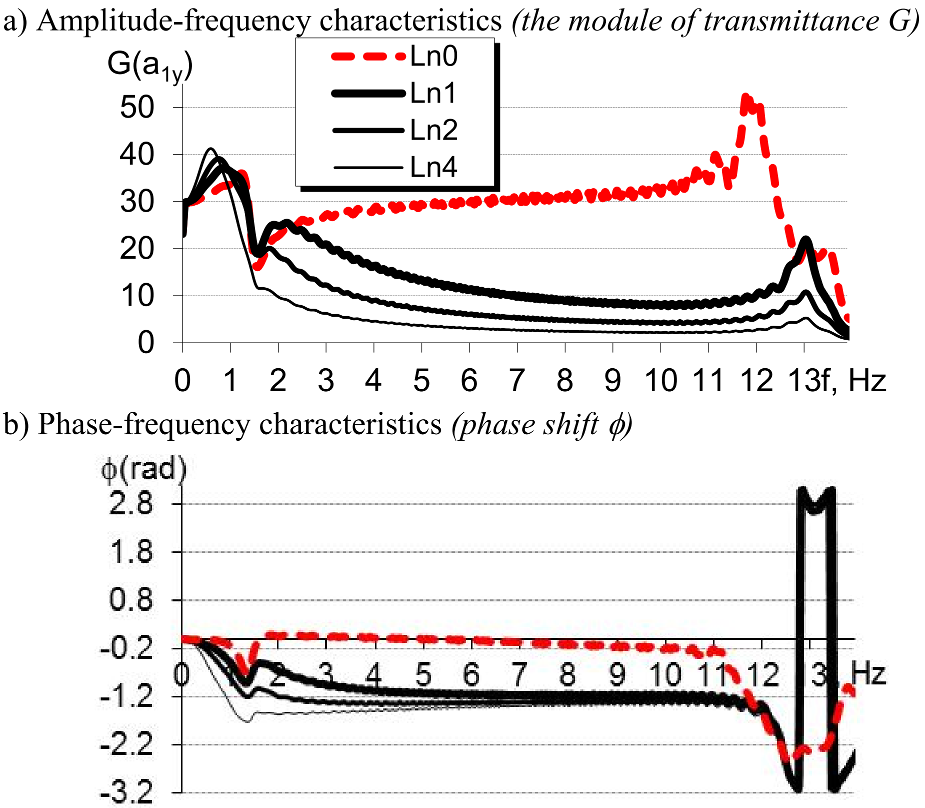


Fig. 8. Dynamic characteristics of the vehicle model determined fort the lateral acceleration a_{1y} in the centre of the vehicle body mass

- there is a range of forcing frequency values which are close to the natural frequency of vehicle body motion (yaw and roll) (from 0 to 2.5 Hz) where the amplitude of observed physical quantities clearly increase after putting the tire relaxation into tire-road interaction model,
- the tire relaxation significantly changes the phase shift of the observed physical quantities, thus delaying the model response due to forcing signal,
- the increase of the relaxation length L_n of tire relaxation model consistently strengthens identified changes of the amplitude and shift phase of observed physical quantities, but the greatest changes in the vehicle dynamic characteristics involves putting tire relaxation into tire-road interaction model with a typical value of the relaxation length L_{n1}.

4. The final conclusions

It has been demonstrated quantitative and qualitative changes in the vehicle dynamic characteristics because of putting the tire relaxation into the model of tire-road interaction. The tire relaxation causes quite significant changes in the amplitude and the phase shift in the physical quantities characterizing the vehicle lateral dynamics connected with the vehicle driving safety: angular yaw velocity and lateral acceleration in the centre of vehicle body mass. However, it should be noted that also the impact of tire relaxation on other physical quantities characterizing the vehicle lateral dynamics is quite interesting. These are physical quantities, which characterize for example the level of lateral dynamic loads of the vehicle structure, or quantities, which can be felt by the driver while driving real vehicle or high-class driving simulator.

References

[1] Lee, S., Heydinger, G. J., Guenther, D. A., *The application of pulse input techniques to the study of tire lateral force and self-aligning moment dynamics in the frequency domain,* SAE Paper 950317, 1995.

[2] Schmid, I. Tomaske, W., *Tire testing facility for simulation of transient operating conditions,* ATZ 1/ 1984.

[3] Zanten, R., Erhardt, Lutz, A., *Measurement and simulation of transients in longitundial and lateral tire forces,* SAE Paper 900210, 1990.

[4] Luty, W., *Analiza właściwości ogumienia samochodu ciężarowego w nieustalonym stanie znoszenia bocznego,* Zeszyty Naukowe Politechniki Warszawskiej 3/38, 2000.

[5] Luty, W., Prochowski, L., Szurkowski, Z., *Stanowisko do badań ogumienia dużego rozmiaru.* VII Międzynarodowe Sympozjum IPM, Warszawa-Rynia, 8-10.12.1999.

[6] Luty, W., *Analiza nabiegania ogumienia nowych konstrukcji podczas toczenia ze znoszeniem bocznym w quasi-statycznych warunkach ruchu,* Praca zbiorowa pt. Analiza wpływu ogumienia nowych konstrukcji na bezpieczeństwo samochodu w ruchu krzywoliniowym, Wojskowa Akademia Techniczna, ISBN978-83-61486-21-3, Warszawa 2009.

[7] Luty W., A*n analysis of tire relaxation process during dynamic changes of cornering angle,* Journal of Kones Powertrain and Transport, Vol. 16 No. 1, 2009.

[8] Georg, Rill, *First order tire dynamics,* III European Conference on Computational Mechanics, Solids, Structures and Coupled Problems in Engineering C.A. Mota Soares et.al. (eds., Lisbon, Portugal, 5–8 June 2006.

[9] Walczak, S., *Wpływ właściwości dynamicznych modelu ogumienia na dynamikę poprzeczną samochodu.* Czasopismo techniczne Mechanika. Politechnika Krakowska, 3-M, Zeszyt 8, 2012.

[10] Lozia, Z., *Ocena roli stanów nieustalonych ogumienia w badaniach dynamiki poprzecznej samochodu.* VII Międzynarodowe Sympozjum Instytutu Pojazdów Mechanicznych. WAT Warszawa, 1999.

[11] Luty, W., *Nieustalone stany znoszenia bocznego ogumienia kół jezdnych w symulacji ruchu krzywoliniowego pojazdu*. Prace Naukowe Politechniki Warszawskiej. Transport, Oficyna Wydawnicza Politechniki Warszawskiej, nr 96, 2013.