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Analysis of the course of tangent reaction forces on the wheels of a motor vehicle performing a straightforward braking maneuver

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ABSTRACT

The article presents continuation of research carried out in [9]. However, its object are the changes in the tangential reaction forces occurring between the road surface and the wheels during the straightforward braking. Assumptions used in the analysis are the same as in [9], since they concern the same case study.

KEYWORDS: tangent reaction forces, road, wheel, braking of the motor vehicle

1. Introduction

One of the key elements of the analysis of vehicle dynamics seems to be the problem of cooperation between the wheels and the road surface. The most interesting, however seem to be such special cases, as eg. driving on icy [10], wet or dirty roads, motion of the vehicle with the disturbed mass – inertia parameters [5], impact of road conditions on the course of vehicles during collision ([3], [4]) as well as the issue of motor vehicle stability discussed, among others, in [2,5] and [10].

It also seems that the problems discussed in the presented analysis can be entered in the issues concerning transport telematics, mostly related to road safety (transport), as well as its monitoring.

In the selected papers a number of issues related to the problem of cooperation between the road and the wheels were discussed. Among others, in [1] and [7] the phenomenon of radial elasticity of the tire in different road conditions was considered. For example in [6], [8] and [9] impact of the selected factors on the normal reaction forces acting on the vehicle wheels were analysed, wherein [9] shows results of the studies related to uneven load distribution in a motor vehicle along with random road surface roughness. Generally in these works phenomena occurring in the wheel-road contact plane were analysed.

In this paper attention was paid to the changes of the reaction forces tangential to the road surface. The analysis was also prepared in terms of impact of both uneven vehicle load and random road roughness on the motion of a motor vehicle.

2. General assumptions

For studying the course of the normal reaction forces in [9] the results of previously conducted simulation were used. Because the tangential reactions were also examined for the same case, therefore the existing results were used again.

In [9] the assumptions were given, when adopted to examination of the normal reaction forces. In case of examining the reactions tangential to the road surface it must be added, that both longitudinal and lateral forces were engaged in the geometric center of the area of tire adhesion to the road surface (resultant forces). This approach was considered, among others in [6] and [8].

Of course, it should be noted that the geometric center of the wheel-road surface cooperation can displace during the motor vehicle braking process, for example in relation to the vertical axis passing through the center of mass of the wheel. This phenomenon can be explained by dislocation of the resultant normal reaction e.g. in relation to the vertical axis of symmetry of a specific wheel. However, it may be different for each wheel. It was therefore assumed, that changes the location of the center of cooperation area between each wheel and the road surface are negligible.

Other assumptions were adopted as in [9], ie. non-linear characteristics of the elastic – damping suspension elements, treating the vehicle body as quasi-rigid, the motion of the vehicle on a dry road surface with the adhesion coefficient μ=0.8, randomly occurring road irregularities, straightforward braking from the speed of 100km/h, fifth gear.

Simulation of the braking maneuver, carried out in [9], was prepared for the following configurations:

- vehicle unladen moving on a dry, flat road surface;
- vehicle unladen on a dry and uneven road surface;
- vehicle laden as in [9] also moving on a dry, flat road surface;
- vehicle laden (as in [9]) on a dry and uneven road surface.

3. The vehicle model and road irregularities

The vehicle model used in the simulation is described, among others, in [5] and [10]. The coordinates of the center of mass, indirectly representing the mass distribution in the vehicle, was determined in relation to the so-called point "origo" [10].

The total mass of the vehicle before loading, in accordance with the work [9] was 1528kg, and 1718kg after adding the load. If both the global and the local (originating at "origo") coordinate systems were adopted as in [10], then the absolute differences between the coordinates of the center of mass of the vehicle and after and before loading were:

$\Delta x_c = 0{,}06\,m,\ \Delta y_c = 0{,}0014m,\ \Delta z_c = 0.$

The absolute differences in the values of moments of inertia in the vehicle, relative to the axis passing through the point "origo" before and after loading were:

$\Delta I_x = 43\,kg \cdot m^2,\ \Delta I_y = 316\,kg \cdot m^2,\ \Delta I_z = 273\,kg \cdot m^2.$

In contrast, the absolute values of the differences between the moments of deviation in the vehicle, relative to the axis passing through the "origo" were:

$\Delta I_{xy} = 0,\ \Delta I_{zx} = 112\,kg \cdot m^2,\ \Delta I_{yz} = 0.$

Simulation of the vehicle braking from a speed of 100 km/h was carried out for the road with a flat or uneven, but in both cases the dry surface. It seems important to remind that the uneven road surface had randomly occurring irregularities. Generating of those irregularities as well as the tire model used in the simulation were both discussed in [9]. Also the reason for using a specific tire model was explained.

4. Simulation of the brake maneuver

Simulation of the brake maneuver, for the configuration shown in p. 2, was described in [9]. For each vehicle configuration a set of trajectories of tangential forces in the contact area between the road and the wheels was obtained. Four trajectories of longitudinal and transverse reaction forces in relation to the plane of wheel symmetry were obtained, for each case of the vehicle load and road surface.

The vehicle in all cases traveled 200m which, as mentioned in [9], resulted from the weak pressure on the brake pedal (soft braking). The aim of this analysis however, was not to assess the effectiveness of braking. Otherwise, such force acting on a brake pedal should be adopted, that the vehicle would stop after traveling the shortest distance possible. The problem focused on was the impact of load spread and road surface irregularities on the selected phenomena occurring in the area of contact between the wheels and the road. As mentioned in [9], while motion of the laden vehicle model on the road with random irregularities, distance traveled during the braking was shorter by about 10m due to an error of calculation algorithm for low vehicle speed in the final phase of the maneuver.

Fig. 1 shows the course of FX components of the tangential reaction forces acting on the wheels as a function of distance. The first graph presents the course for the unladen vehicle, while the second – the laden one, both on the flat road.

Fig. 2 shows the course of FX components of the tangential reactions for the uneven road surface, wherein the first graph shows the course for the unladen, whereas the second one – for the laden vehicle.

Fig. 3 and 4 show the pairs of charts presenting the courses of FY (transverse) components of the tangential reactions. The first set of curves in fig. 3 concerns the course of forces for the unladen and the second one for the laden vehicle, in both cases moving on the flat road. Fig. 4 shows the courses of transverse components of the analysed reactions for the vehicle moving on the uneven road, wherein the first graph presents results for the unladen and the second one – for the laden vehicle.

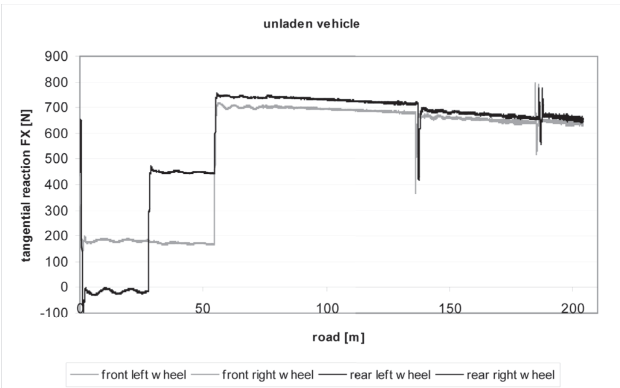

Fig. 1. a. Courses of the tangential reaction forces (FX components) on the flat and dry road [own study]

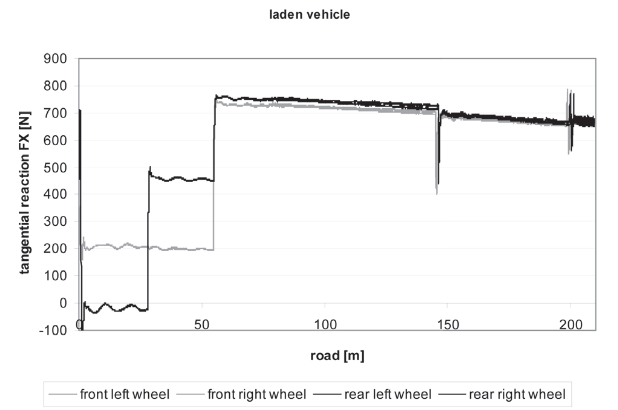

Fig. 1. b. Courses of the tangential reaction forces (FX components) on the flat and dry road [own study]

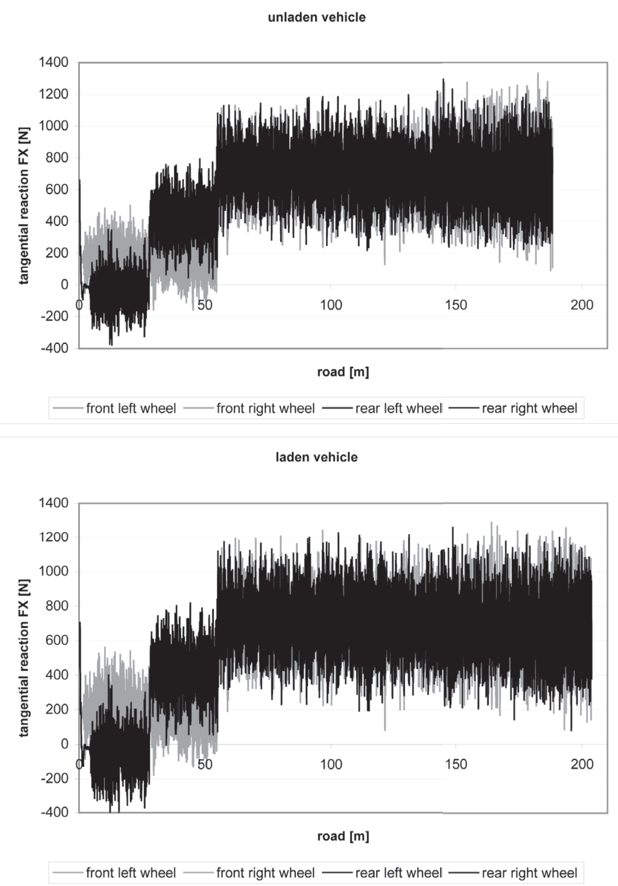

Fig. 2. Courses of the tangential reaction forces (FX components) on the uneven and dry road [own study]

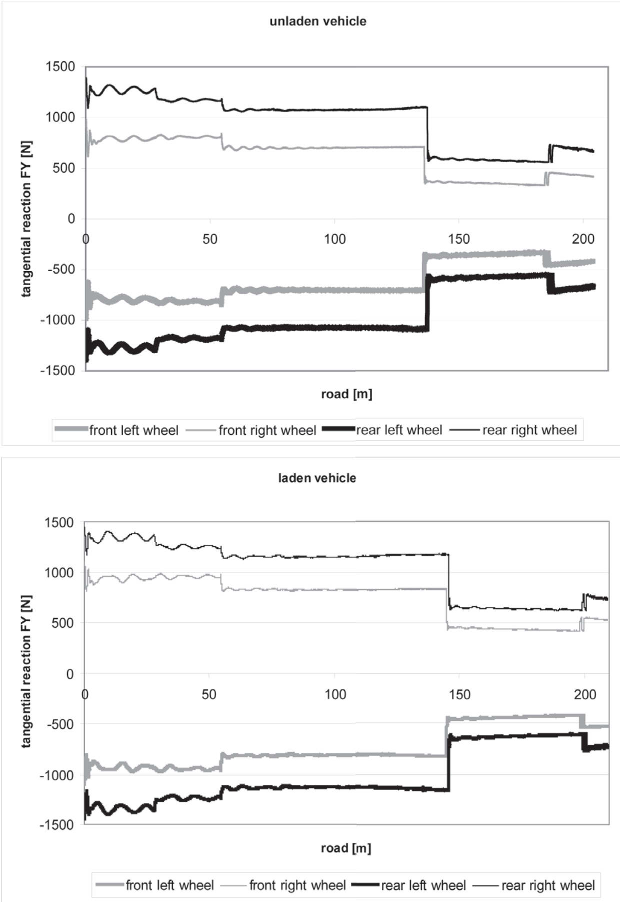

Fig. 3. Courses of the tangential reaction forces (FY components) on the flat and dry road [own study]

Fig. 4. a. Courses of the tangential reaction forces (FY components) on the uneven and dry road [own study]

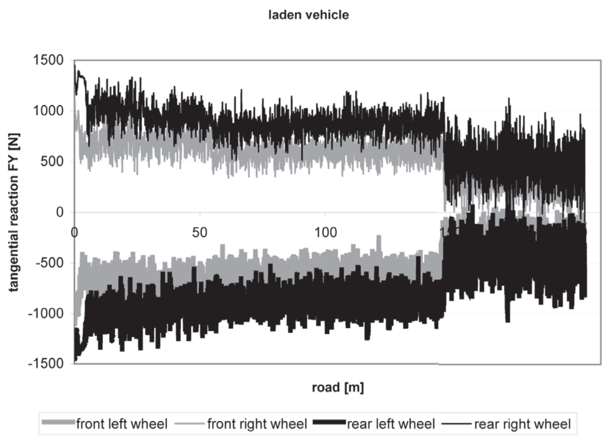

Fig. 4. b. Courses of the tangential reaction forces (FY components) on the uneven and dry road [own study]

5. Analysis of the simulation results

Attempt towards qualitative and quantitative evaluation of the resulting trajectories was prepared, for both longitudinal and transverse components of tangential reactions.

As is [9] it has been noticed, that during braking the longitudinal components of reaction values stabilize after driving a certain road length. However, at certain points of the covered distance there was a sharp, temporary spike in their amplitudes. In case of motion on the road with random irregularities such changes were not observed, because for the course of the longitudinal components (FX) the amplitude variations occurred for the entire trajectory.

As for the transverse reaction components (FY), for both laden and unladen vehicle, their courses are similar, in that for the laden vehicle the response value is larger by about 50N. The course of these curves is characterized by a sudden decrease in magnitude after about 145m of the covered distance, by about 400N. The same can be seen for the motion of the vehicle on uneven road (fig. 4), wherein it seems more difficult to even approximate decrease of the reaction values.

Quantitative evaluation of the wheels tangential reaction values was also attempted. In table 1 the mean values of the longitudinal reaction components (FX) are shown, as well as their maximum amplitude, in the conditions of motion for both laden and unladen vehicle. The same set, but for the transverse components (FY), is shown in table. 2.

From the values presented in both tables it can be seen, that when the unladen is braking, with the engine located at the rear, on both types of surface, then the rear axle is loaded down, which confirms the considerations fron the work [9]. In terms of the amplitudes shown in both tables, the cocnlusions do not appear to be so obvious, particularly in case of motion on the uneven road surface. Studying the phenomenon of cooperation between the wheels and the road, especially on uneven surface, momentary loading down or unloading of individual wheels should be taken into account. In addition, unevenly spread mass in the vehicle should be considered [9].

The average values of longitudinal reaction components for the unladen vehicle indicate an even pressure of the wheels on the flat road surface, with the rear wheels loaded down at the same time. For the laden vehicle these forces are not as even, although the differences are not large (about 5 – 7N). On the uneven road differences between the values of these reactions are lower – about 1 to 2N.

The resulting average transverse components have opposite values, which may indicate different vector senses. In this case, the differences are also greater than in longitudinal reaction components.

Table 1. Average values of the FX reaction components and their amplitudes, during the brake maneuver [own study]

	unladen			
	flat road		uneven road	
wheel	average FX reaction force [N]	amplitude [N]	average FX reaction force [N]	amplitude [N]
front left	665	785	658	1273
front right	665	790	657	1323
rear left	686	764	677	1217
rear right	686	761	675	1274

	laden			
	flat road		uneven road	
wheel	average FX reaction force [N]	amplitude [N]	average FX reaction force [N]	amplitude [N]
front left	690	773	682	1212
front right	695	787	682	1292
rear left	703	766	693	1266
rear right	711	771	692	1238

Table 2. Average values of the FY reaction components and their amplitudes, during the brake maneuver [own study]

	unladen			
	flat road		uneven road	
wheel	average FY reaction force [N]	amplitude [N]	average FY reaction force [N]	amplitude [N]
front left	-523	-328	-377	106
front right	524	725	390	753
rear left	-820	-549	-631	94
rear right	826	1110	653	1160

	laden			
	flat road		uneven road	
wheel	average FY reaction force [N]	amplitude [N]	average FY reaction force [N]	amplitude [N]
front left	-613	-412	-463	109
front right	637	842	469	877
rear left	-891	-601	-682	57
rear right	905	1181	691	1210

6. Conclusion

Results obtained after the simulation primarily show the impact of vehicle mass – inertia disturbances on both the tangential reaction courses along the travelled distance, and their average values. As it was noticed, the resulting curves are similar in shape, however vary in magnitude between the laden and unladen vehicle.

An important aspect seem to be the average values of tangential reactions shown in tables 1 and 2. The problem concerns both FX and FY components. Significant differences seem to occur for the unladen vehicle on the uneven road, and for the FY component of both unladen and laden vehicle moving on both types of road surface.

When it comes to transverse reaction components (FY), it can be noticed that their amplitudes, for the left front and left rear wheels, for both load cases (laden and unladen), indicate the change in the sense of the reaction vectors. This phenomenon could suggest occurrence of the lateral drift. If such conditions occurred for all wheels, then the result could be a loss of stability of the vehicle during braking. It should be recalled that the featured maneuver was conducted for the coefficient of adhesion $\mu=0.8$. It seems that more interesting results will be obtained for running the simulation on the wet ($\mu = 0.5$) and icy ($\mu = 0.3$) road surface, also including randomly occurring road irregularities.

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