ARCHIVES OF TRANSPORT *ISSN (print):* *0866-9546*
Volume 58, Issue 2, 2021 ***e-ISSN (online):*** *2300-8830*
DOI: *10.5604/01.3001.0014.8798*

AN EXAMPLE OF A POWER-OFF MANEUVER OF A VEHICLE WITHOUT A STRAIGHT LINE MOTION CONTROL

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Abstract:

In this paper some selected results related to motor vehicle dynamics have been presented basing on the computer simulations of a sports two-seater performing a power-off straight line maneuver with different road conditions and the lack of a straight-line motion control having been included. All simulations have been performed in the MSC Adams/Car environment and the adopted maneuver was performed at the instant speed of 100km·h-1. The selected phenomena have therefore been observed along the road long enough to relate them to different aspects of vehicle dynamics and the road traffic safety research. The adopted vehicle's model moved along the flat and the randomly uneven road with the almost similar and the almost different profiles for the left and the right wheels. Additionally, two values of the coefficient determining the maximum amplitude of road irregularities have been selected, i.e., 0.3 for the lower and 0.9 for the higher irregularities. This meant that the road conditions have been considered as one of the main factors possibly affecting disturbances of the motor vehicle's motion. Such research seems valuable from the point of view of the road safety and the vehicles' maintenance.
A power-off straight maneuver is not very often performed during the normal road traffic and might seem useless. However, in this case it seemed essential to test the response of a vehicle's model to such factors as, e.g., the uneven loading, suspension characteristics, etc. This in turn might prove valuable when considering, e.g., the additional concentration of a driver to overcome the external disturbances acting on a moving vehicle. The presented research is the second part of the paper (Kisilowski, 2019) where the power-off maneuver was considered but with the straightforward motion control. Here, the straight-line control has been switched off to examine an untypical situation where, for example a driver loses consciousness, and the vehicle moves freely along the road.

Keywords: *vehicle dynamics, power-off, no straight-line motion control*

To cite this article:

Kisilowski, J., Zalewski, J., 2021. An example of a power-off maneuver of a vehicle without a straight line motion control. Archives of Transport, 58(2), 63-80. DOI: https://doi.org/10.5604/01.3001.0014.8798

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1. Introduction

The aim of this paper was to present the selected aspects of the possible motor vehicle's response to the random disturbances affecting its motion based on a computer simulation with the use of a two-seater vehicle's model. The adopted maneuver was a power-off straight line course without the straight-line control which could be a factor increasing the discussed phenomena. Additionally, various road conditions have been considered along with the selected loading configurations of the vehicle. This means that the results presented in this paper will be compared to the ones in (Kisilowski, 2019). This exemplary analysis was to present to what extent the road conditions along with the speed and the loading of a motor vehicle may affect its motion and, possibly, the road safety. The discussed case presents rather slowing down than braking nor accelerating, although the initial speed was 100km·h-1.

The straightforward power-off maneuver has been considered before in (Kisilowski, 2019) but with the straight-line motion control which allowed the maintenance of the desired direction of motion. However, the case presented here could reflect the more serious traffic event when, e.g., the driver loses consciousness, and the vehicle moves freely without any control of the direction of motion. This particular task is only one problem of the broad scope of research on the road traffic safety and vehicle dynamics.

Like in the previous works by the authors, e.g., in (Kisilowski, 2018) and (Kisilowski, 2019) attention has been paid to the influence of the randomly uneven road on the motor vehicle's motion. This has previously been a scope of research, e.g., in (Múčka, 2020).

Considering the broad scope of research on vehicle dynamics some of the latest results cover e.g., the importance of the computer simulations and modelling of vehicle dynamics and the road traffic safety, e.g., in (Gao, 2019) where a model for lane changing specified for the Advanced Driver Assistance System has been presented. As for the simulations and modelling, e.g., (Genta, 2016) focused on both the theoretical background of vehicle mechanics and simulations and the skills necessary to perform them. Another example can be (Dukkipati, 2008) where an overview of dynamics of the motor vehicles regarded as mechanical systems has been discussed.

A mutual attention in road traffic has also been considered, e.g., in could be (Kiss, 2019) where the concept of the connected vehicles, both human-driven and automated, has been considered.

A great part of research on the road traffic safety is related to accelerating or braking, e.g., when approaching the road intersections. Some works relate directly to road-vehicle cooperation, e.g. (Pokorski, 2019) where a method of measuring the coefficient of adhesion between a tire and a road has been presented and, e.g. (Kobayashi, 2020) where an example of using the energy equilibrium has been considered when the forces acting on a tire are generated with the use of a brush model. The forces occurring between tires and a road has also been considered in other cases, e.g., an electric vehicle braking (Sun, 2018).

Stability is also an important part of the vehicle dynamics. Such works as, e.g. (Karnopp, 2016) and (Kisilowski, 2018) contain multiple information and results of the analyses on this subject. Of course, not only motor vehicles can be regarded as, e.g., in (Setlak, 2019) where the main goal was to design a multi-rotor control system to maintain the course of the unmanned aerial vehicles with a high-speed wind acting on them, which may be related to analysis of the external disturbances acting on a multibody system.

Considering the problems mentioned above, this paper also presents the selected results of the external disturbances acting on a multibody system which, in this case, is a motor vehicle.

2. General assumptions

The vehicle's model (Fig. 1) has been laden with both a driver (m_1 = 90kg) and a passenger (m_2 = 54kg) with the additional mass of a baggage (m_B = 14kg) located in front part of the vehicle because the engine and the drive sub-system is in the rear part of the given vehicle (rear-wheel drive).

To provide the valuable results of the simulations both the mass and the inertia parameters of the vehicle's body have been changed by adding the additional load. This also altered the spread of mass in the whole vehicle.

In table 1 coordinates of the centre of mass and the moments of inertia and deviation before loading have been presented in relation to the 'origo' point (Kisilowski, 2016). It is an origin of a coordinate system located on the road but moving along with the vehicle itself (Fig. 2).

In table 2 the same parameters for the vehicle laden as in fig 2 have been presented. The main changes here related to the moments of inertia, both in case of the vehicle's body and the whole vehicle. As for the moments of deviation there has not been a significant change due to the little mass of the baggage. Despite it was in front of the vehicle it could not have altered the deviation moments significantly. The aim of such a vehicle's loading was to present the simulation results more relevant when reflecting the real situation in motor vehicle traffic.

As for the adopted maneuver, in table 3 each configuration of the road conditions adopted for the simulation has been presented. At this point the aerodynamic forces acting as motion resistances have not been included, having assumed that the maneuver was realized in the normal conditions without strong wind gusts that might disturb the desired direction of a vehicle.

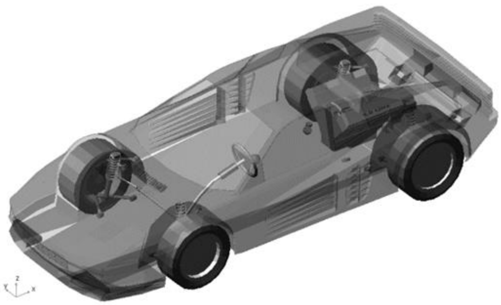

Fig. 1. The sports two-seater used in the power-off simulations [MSC Adams/Car]

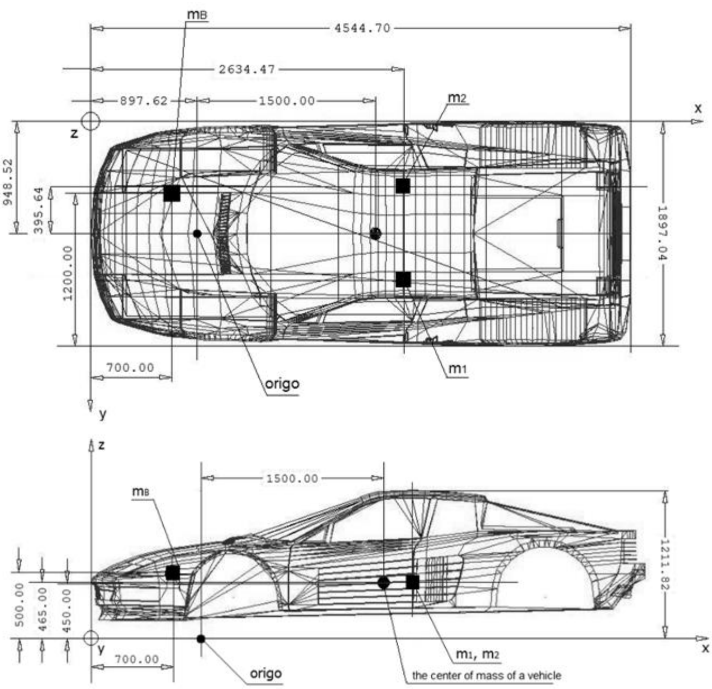

Fig. 2. Location of the additional masses in the vehicle's body and the 'origo' point (Kisilowski, 2019)

Table 1. The mass – inertia parameters of the unladen vehicle's model [own research].

parameter	the vehicle's body	the whole vehicle
mass	995 kg	1528 kg
center of mass location relative to the 'origo' point	xc=1.500m, yc=0.000m, zc=0.450m	xc=1.750m, yc=-0.0014m, zc=0.430m
moment of inertia (Ix) relative to the x axis passing through 'origo'	401.00kg·m^2	583.00kg·m^2
moment of inertia (Iy) relative to the y axis passing through 'origo'	2940.00kg·m^2	6129.00kg·m^2
moment of inertia (Iz) relative to the z axis passing through 'origo'	2838.00kg·m^2	6022.00kg·m^2
moment of deviation (Ixy) relative to the axes x and y passing through 'origo'	0.00kg m^2	-1.90kg·m^2
moment of deviation (Izx) relative to the axes x and z passing through 'origo'	671.00kg·m^2	1160.00kg·m^2
moment of deviation (Iyz) relative to the axes y and z passing through 'origo'	0.00kg m^2	-1.30kg·m^2

Table 2. The mass – inertia parameters of the laden vehicle's model [own research].

parameter	the vehicle's body	the whole vehicle
mass	1153 kg	1686 kg
center of mass location relative to the 'origo' point	xc=1.508m, yc=0.0012m, zc=0.452m	xc=1.730m, yc=-0.0004m, zc=0.434m
moment of inertia (Ix) relative to the x axis passing through 'origo'	435.00kg·m^2	617.00kg·m^2
moment of inertia (Iy) relative to the y axis passing through 'origo'	3357.00kg·m^2	6546.00kg·m^2
moment of inertia (Iz) relative to the z axis passing through 'origo'	3221.00kg·m^2	6405.00kg·m^2
moment of deviation (Ixy) relative to the axes x and y passing through 'origo'	2.08kg·m^2	0.17kg·m^2
moment of deviation (Izx) relative to the axes x and z passing through 'origo'	785.00kg·m^2	1275.00kg·m^2
moment of deviation (Iyz) relative to the axes y and z passing through 'origo'	0,62kg·m^2	-0,67kg·m^2

Table 3. The configurations adopted for the power-off maneuver [own research].

configuration	the road surface	the road type	the profile similarity (corrl)
configuration 1	dry ($\mu = 0.8$)	flat	-
configuration 2	icy ($\mu = 0.3$)	flat	-
configuration 3	dry ($\mu = 0.8$)	uneven (intensity 0.3)	0.8
configuration 4	icy ($\mu = 0.3$)	uneven (intensity 0.3)	0.8
configuration 5	dry ($\mu = 0.8$)	uneven (intensity 0.9)	0.8
configuration 6	icy ($\mu = 0.3$)	uneven (intensity 0.9)	0.8
configuration 7	dry ($\mu = 0.8$)	uneven (intensity 0.3)	0.2
configuration 8	icy ($\mu = 0.3$)	uneven (intensity 0.3)	0.2
configuration 9	dry ($\mu = 0.8$)	uneven (intensity 0.9)	0.2
configuration 10	icy ($\mu = 0.3$)	uneven (intensity 0.9)	0.2

It has also been assumed that, contrary to (Kisilowski, 2019) all of the presented results concern the simulations without the straightforward motion control, so that during the power-off maneuver the vehicle could move in a more unforeseen way (Fig. 3). Hence one of the aims of this paper is to present the possible consequences of the random disturbances disturbing the vehicle's direction of motion. The random nature of road irregularities has so far been widely used in similar analyses, e.g. in (Múčka, 2020) or (Kisilowski, 2018) which deal with using the random profiles of the road in simulations of motor vehicle performing different maneuvers.

On the basis of the presented results it can be concluded that the intensity 0.3 means the amplitudes of the irregularities can reach as much as 0.015m and for the intensity 0.9 they can be up to 0.025m high. These assumptions can be made provided that the wheel is considered to be stiff and the irregularities smaller than the area of the contact between the wheel and the road are not taken into account.

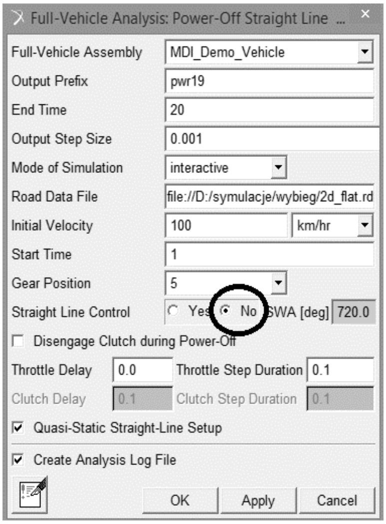

Fig. 3. Performing all the adopted simulations without the straight-line control [MSC Adams/Car]

3. Discussion on the selected results

When concerning the behaviour of a vehicle in various road conditions during the considered power-off maneuver the authors paid attention to the phenomena that can alter the initially desired, straight-line motion causing the lateral deviations. Comparing to (Kisilowski, 2019) the authors also wanted to examine whether the uneven spread of mass in the vehicle's model can increase the lateral phenomena and to what extent, especially if the straight line motion is not controlled.

In Fig. 4 a set of trajectories for the configurations 1, 2, 7, 8, 9 and 10 (table 3) have been presented, i.e. for the motion on a flat road and for the uneven road with the almost different road profiles for the left and right wheels. In this case the cor_{rl} was 0.2 and indicated almost differet profiles. As it can be seen, contrary to the straight-line control (Kisilowski, 2019) there have been significant differences in these trajectories. Alomng the 450m path the vehicle on a flat and dry road deviated by up to 2m from the straightforward motion. Meanwhile on the icy and flat road the same vehicle deviated by about 12.5m in the direction opposite to the motion along a dry road. To compare, the results in (Kisilowski, 2019) indicated the deviaton no greater than 0.014m for the motion along the dry and the icy road. As it can be seen the random irregularities, although related mainly to the vertical motion of the wheels, can cause the lateral phenomena as well.

The last four configurations from table 3 reflect the simulations with the almost different road profiles for the left and the right wheels. In Fig. 4 the results for the configurations 7 and 9 have been presented, i.e. the motion along both the dry and the randomly uneven road. The maximum deviations from the initial straight-line course were about 3m for the configuration 9 and up to 5.5m for the configuration 7 which, taking into account the almost different road profiles for the left and the right wheels and the lack of straight-line control, was a lot more contrary to (Kisilowski, 2019) where for the same configurations this deviation reached as much as 0.012m even for the higher intensity of the irregularities.

As for the configurations 8 and 10, i.e. the motion along the randomly uneven and icy road with no straight-line control, the results have also been presented in Fig. 4. Here the same tendency has prevailed because the deviation from the desired straight-line course reached up to 5.5m for the configuration 8 (lower irregularities) and about 3m for the configuration 10) higher irregularities. However, the results obtained in (Kisilowski, 2019) for the same parameters but with the straight-line control on showed the deviations reach as much as 0.014m. However it seems as if the icy road caused less lateral effect than the dry road. It is necessary to remind that the profiles for the left and the right wheel were almost different.

Taking into account the nearly similar profiles of the irregularities for the left and the right wheels indicates the less realism of the considered maneuver (configurations 3, 4, 5 and 6 from table 3). In Fig. 5 the lateral displacement in a power-off maneuver for the lower (intensity 0.3) and the higher (0.9) amplitudes of the irregularities has been presented, taking into account the cor_{rl} coefficient defining the similarity of the road profiles for the left and the right wheels (in this case the cor_{rl} was 0.8 and indicated almost similar profiles). Contrary to the results obtained in (Kisilowski, 2019) where the deviations form the initial course were up to 0.025m, here they amounted to 0.5m on an icy and randomly uneven road.

Taking into account the shape of the trajectories, they indicate that the vehicle initially attempted to return to the straight line motion but failed, and in the end the deviation for the straight-line motion decreased but only by 0.2 to 0.3m. For the configurations 3 and 5 form table 3 (Fig. 5) the lateral deviation versus the covered distance on a dry and randomly uneven road has been presented. Although the maximum deviation was about 0.3m, still it was larger than in case of straight-line control (Kisilowski, 2019) where it was less than 0.025m. When comparing to Fig. 4 it seems that the random irregularities similar for the left and the right wheels could have caused the maneuver more stable as if the road prevented the vehicle to deviate further. It is necessary to mention that the trajectories from Fig. 5 have been obtained for both the lower and the higher irregularities of the road (intensity 0.3 and 0.9 respectively).

As for the motion on an icy road for the same conditions (configurations 4 and 6 in Fig. 5) the results obtained in (Kisilowski, 2019) presented a deviation of up to 0.014m (even for the higher irregularities) while those obtained here indicate that the lateral deviation from the straight-line course was up to 0.5m. What is interesting, it occurred for the motion along the road with the lower amplitudes of the irregularities (intensity 0.3). The higher amplitudes tended to increase the lateral phenomena on the icy road however, for the almost similar left and right wheels' profiles.

In Fig. 6 the changes in the lateral velocity versus the covered distance have been presented for the configurations 1 and 2, i.e. the motion on a flat road (both dry and icy). It is obvious that on the icy road the lateral phenomena had the greater impact on the vehicle's motion than in case of the dry road. It is necessary to remind that these phenomena occurred without the straight-line motion control.

However, the lateral velocity here was relatively small, even on the icy road (about 0.85 $m\ s^{-1}$ which is about 3km h^{-1}) and it changed smoothly. In comparison, the results obtained in (Kisilowski, 2019) showed that this velocity for the configurations 1 and 2 reached only about 0.012 $m\ s^{1}$ for both dry and icy road.

Let us consider if the road irregularities had any greater impact on the lateral motion of the given vehicle. In Fig. 7 the changes in the lateral velocity for the configurations 3 and 5 and in Fig. 8 the same set but for the configurations 4 and 6 have been presented. This division has been made in order to differ the motion along the dry and the icy road because, as it can be noticed in Figs. 7 and 8, there are almost no differences in the magnitude of the velocity, however both of the courses are more turbulent than those from Fig. 6. This means that the road irregularities with the almost similar profiles for the left and the right wheels can eliminate the lateral phenomaena by e.g. reducing the lateral velocity component affecting the straightforward motion, regardless the amplitude of these irregularities which, in there four cases (configurations 3 to 6) reached between 0.11 and 0.17 $m\cdot s^{-1}$. In (Kisilowski, 2019) the values for the same configurations were close to 0.07 $m\cdot s^{-1}$ which is about half less.

On the contrary, the almost different road profiles with the random irregularities (configurations 7 to 10) can increase the discussed phenomena (Fig. 9) but the greater amplitudes seem to decrease them to some reduced extent (configurations 9 and 10, Fig. 9). However, the obtained maxiumum lateral velocity was about twice as low as in case of the configurations 1 and 2. However, in (Kisilowski, 2019) the maximum values of this velocity was about 0.07 $m\cdot s^{-1}$ for the same configurations as well.

The lateral acceleration changed though more rapidly, even in case of the motion along the flat road, as presented in Fig. 10. It seems obvious that the amplitudes of the lateral acceleration should have oscillated about the value close to zero, taking into account the trajectory that the vehicle marked (Fig. 4).

However, the acceleration deviated from this average to some minor extent on the icy road (reaching only about $0.14 m\cdot s^{-2}$) which was enough to deviate from the straight-line motion by almost 12m. Of course, this took place on a flat road, with no irregularities to prevent or at least reduce the lateral phenomena. The same sets of results in (Kisilowski, 2019) showed the maximum acceleration reach as much as $0.05 m\cdot s^{-2}$ at the beginning of the maneuver.

As for the lateral acceleration in case of the configurations 3 – 10 (Figs. 11 – 14) the changes were similar, reaching the greatest amplitudes 4 and $5.5 m\cdot s^{-2}$. Even though there were differences between the maximum lateral accelerations, the courses of its changes for all eight configurations (3 to 10) were similar, i.e. turbulent without any signifincant deviations from the zero average. It should be mentioned that the maximum values of the lateral acceleration in (Kisilowski, 2019) were between 3.5 and 4.5m·s^{-2} for the same configurations, which is 1m·s^{-2} less than in the here presented cases.

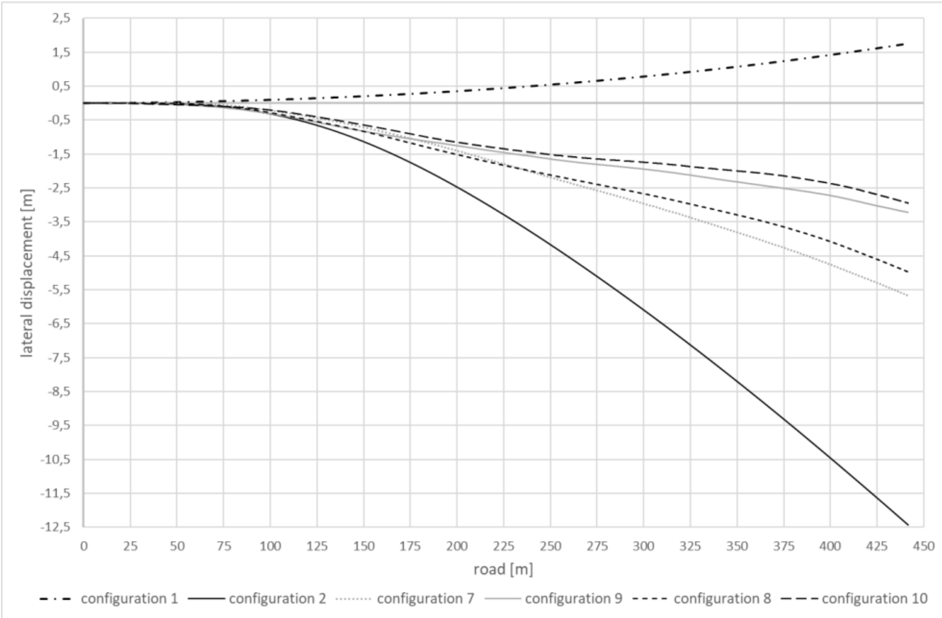

Fig. 4. Trajectories on a dry and icy as well as flat and randomly uneven road surface with the almost different left and right profiles of the irregularities (cor_{rl} = 0.2) [own research]

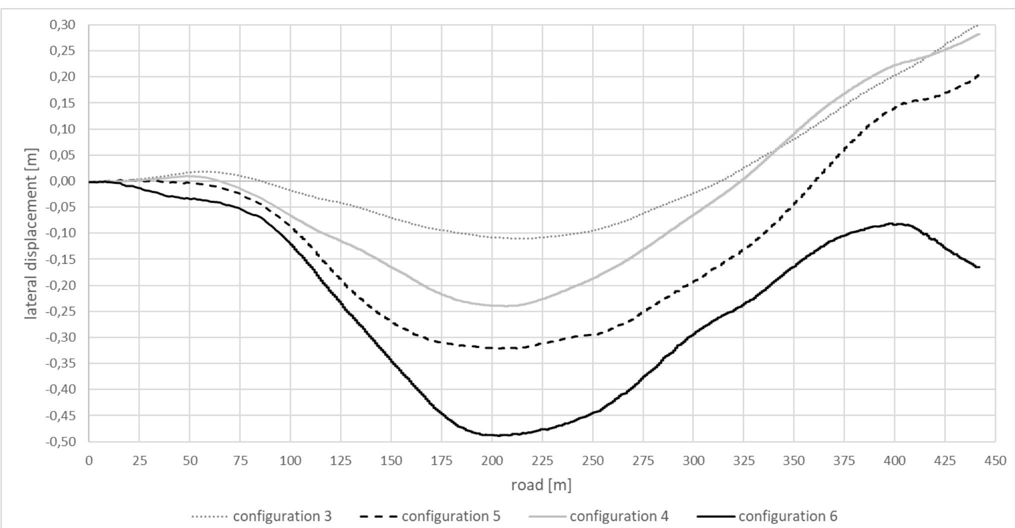

Fig. 5. Trajectories on an icy and randomly uneven road surface with the almost similar left and right profiles of the irregularities (cor_{rl} = 0.8) [own research]

These results proof that due to the lack of the straight-line control the vehicle's model was able to perform more rapid lateral phenomena and deviate to much greater extent from the initially adopted straightforward motion. In order to related the obtained results, the previously published work (Kisilowski, 2019) has been used as a reference point. The presented deviations were transferred to the absolute values, because the minus on the vertical axes in the above figures indicated only the lateral displacement to the right instead of the left side of the road. Moreover, these results indicate that a driver forced to drive a vehicle in similar conditions would have to perform more activity that for the motion of the evenly laden vehicle and without the random irregularities.

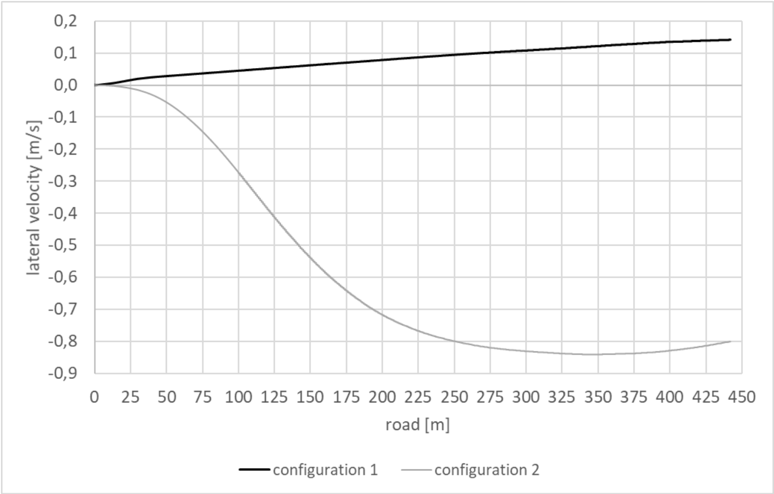

Fig. 6. Lateral velocity on a dry and icy flat road surface [own research]

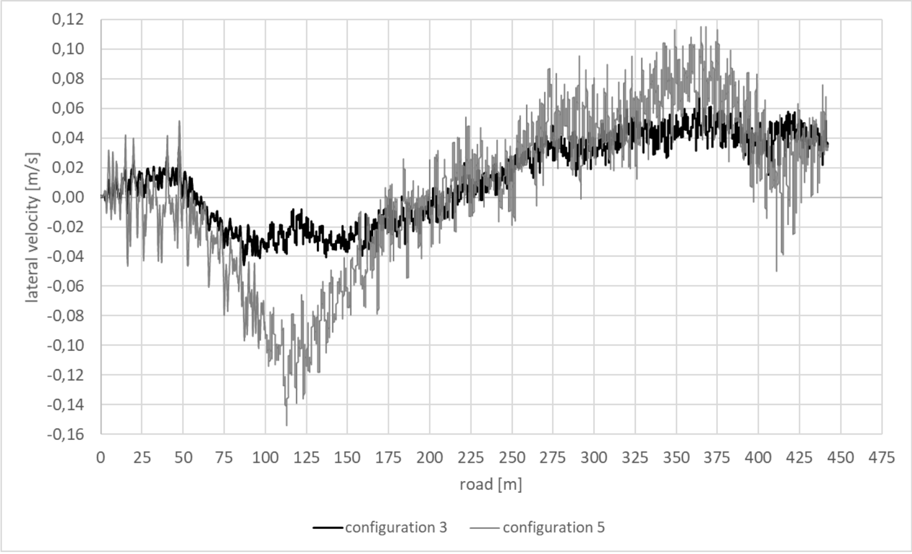

Fig. 7. Lateral velocity on a dry, randomly uneven road surface with the almost similar left and right profiles of irregularities (cor_{rl} = 0.8) [own research]

Some more selected results prove the greater neccessity to focus on driving along the more uneven road. In Figs. 15 – 19 the vertical acceleration of the vehice along the more or less uneven road has been presented. In this case it is only a confirmation that the vehicle moved alon the road having the same amplitudes of the irregularities as in (Kisilowski, 2019). Similarily as in (Kisilowski, 2019) the vertical acceleration reached the absolute value from almost 2.25 $m \cdot s^{-2}$ for the flat road to as much as almost 6 $m \cdot s^{-2}$ for the random road profiles, eithr almost similar or almost different for the left and the right wheels.

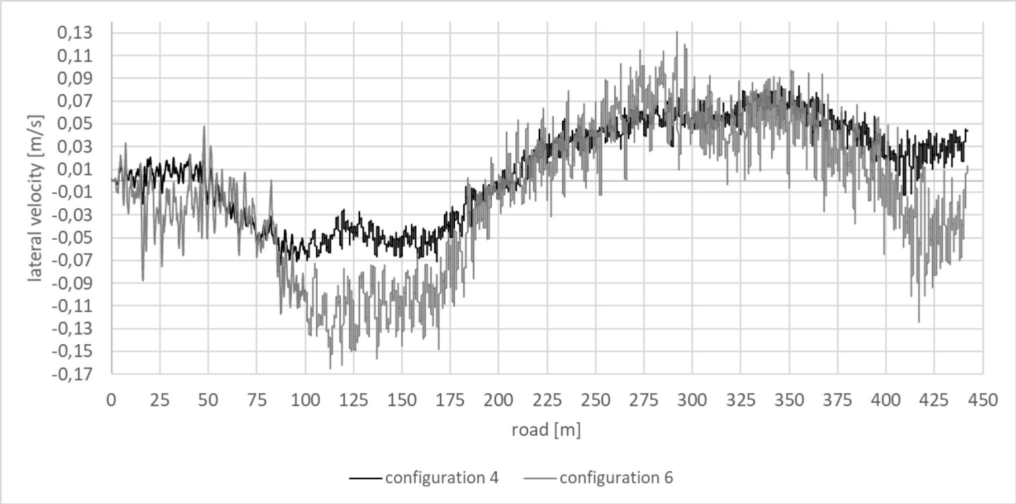

Fig. 8. Lateral velocity on an icy, randomly uneven road surface with the almost similar left and right profiles of irregularities (cor_{rl} = 0.8) [own research]

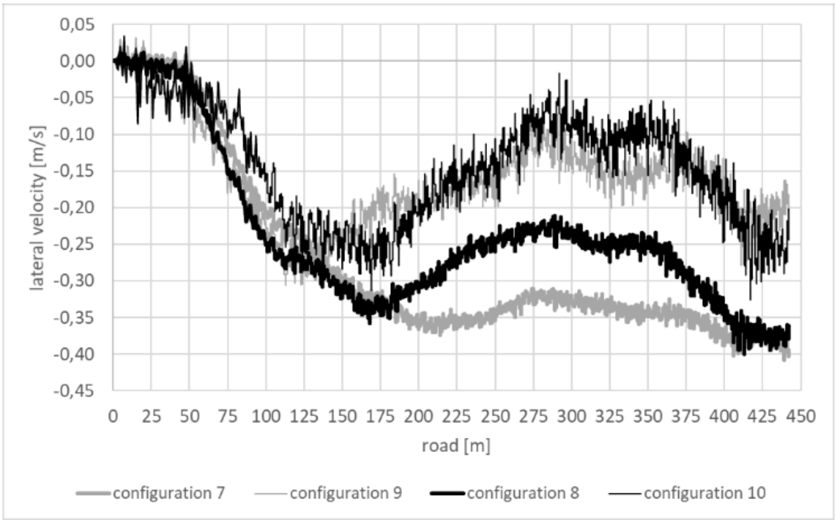

Fig. 9. Lateral velocity on a dry and an icy, randomly uneven road surface with the almost different left and right profiles of irregularities (cor_{rl} = 0.2) [own research]

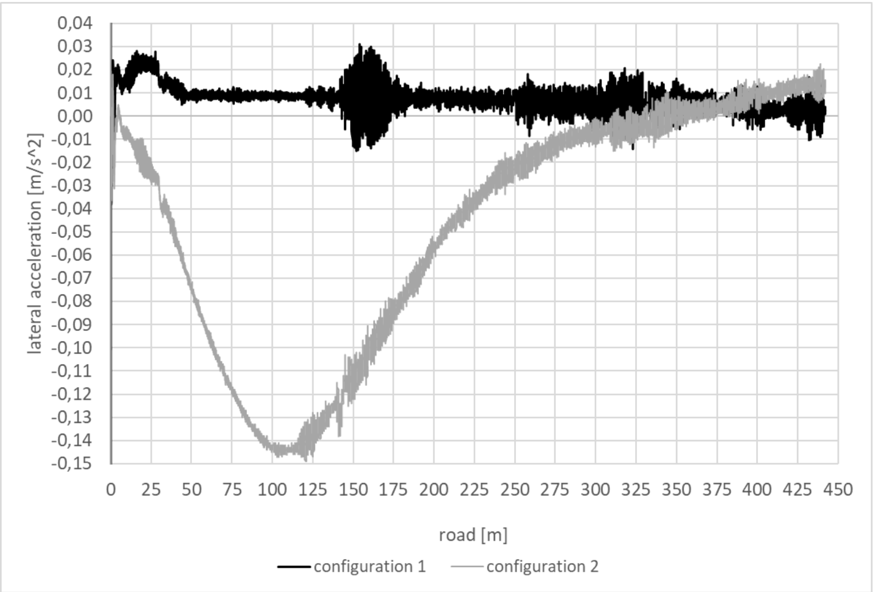

Fig. 10. Lateral acceleration on a dry and an icy flat road surface [own research]

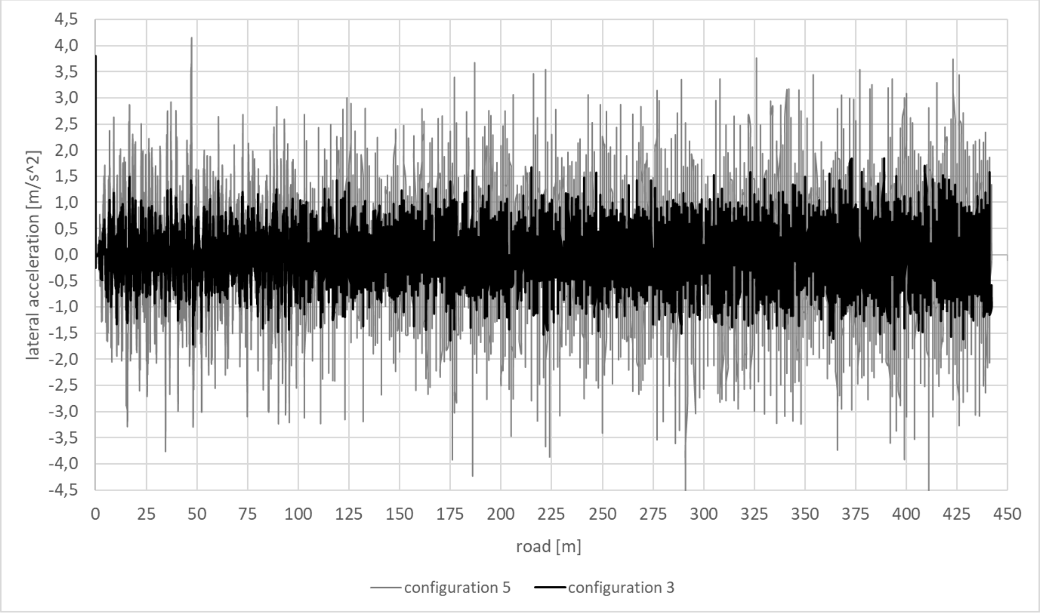

Fig. 11. Lateral acceleration on a dry, randomly uneven road surface with the almost similar left and right profiles of irregularities (cor_{rl} = 0.8) [own research]

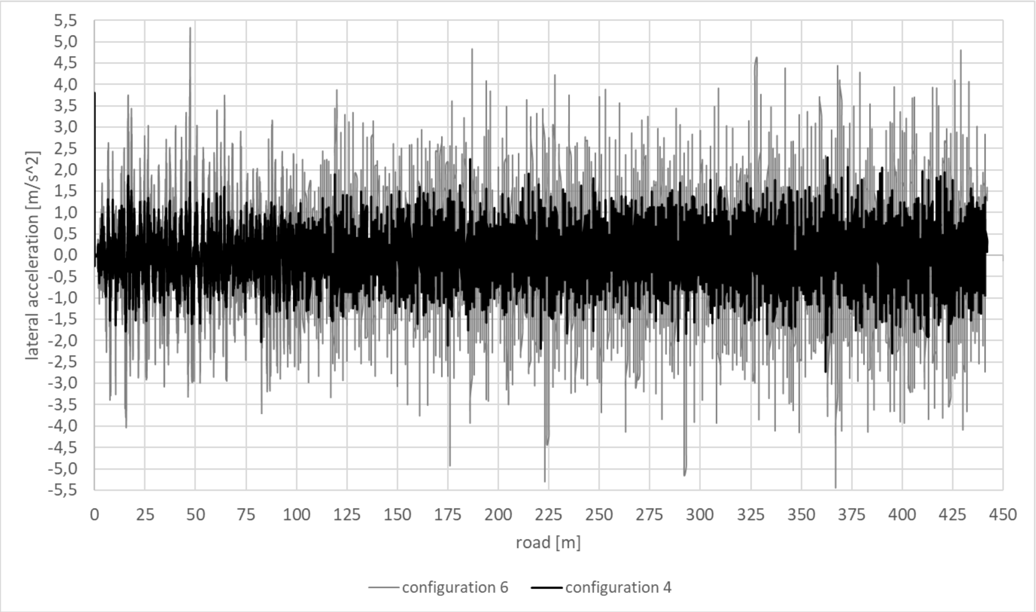

Fig. 12. Lateral acceleration on an icy, randomly uneven road surface with the almost similar left and right profiles of irregularities (cor_{rl} = 0.8) [own research]

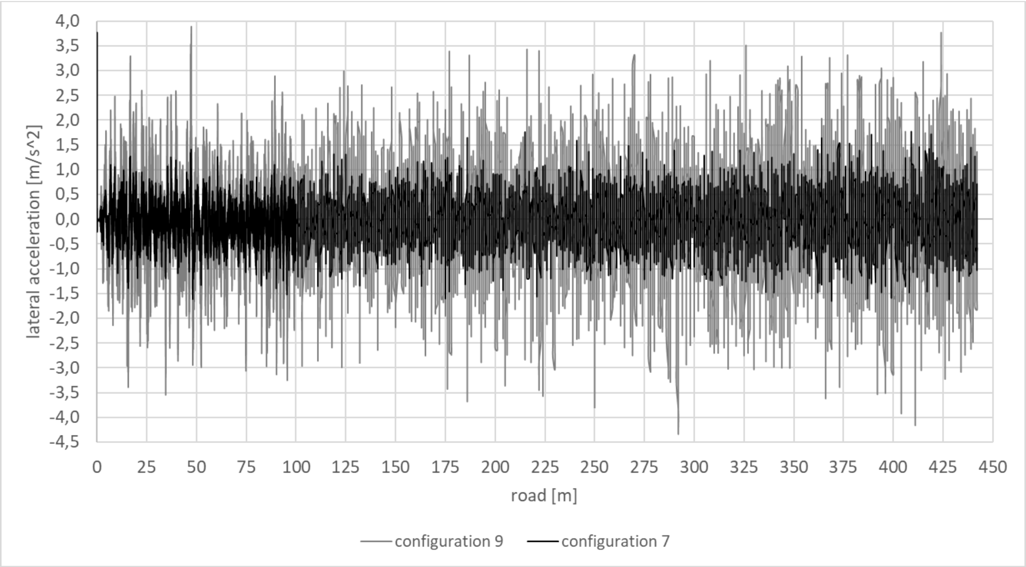

Fig. 13. Lateral acceleration on a dry, randomly uneven road surface with the almost different left and right profiles of irregularities (cor_{rl} = 0.2) [own research]

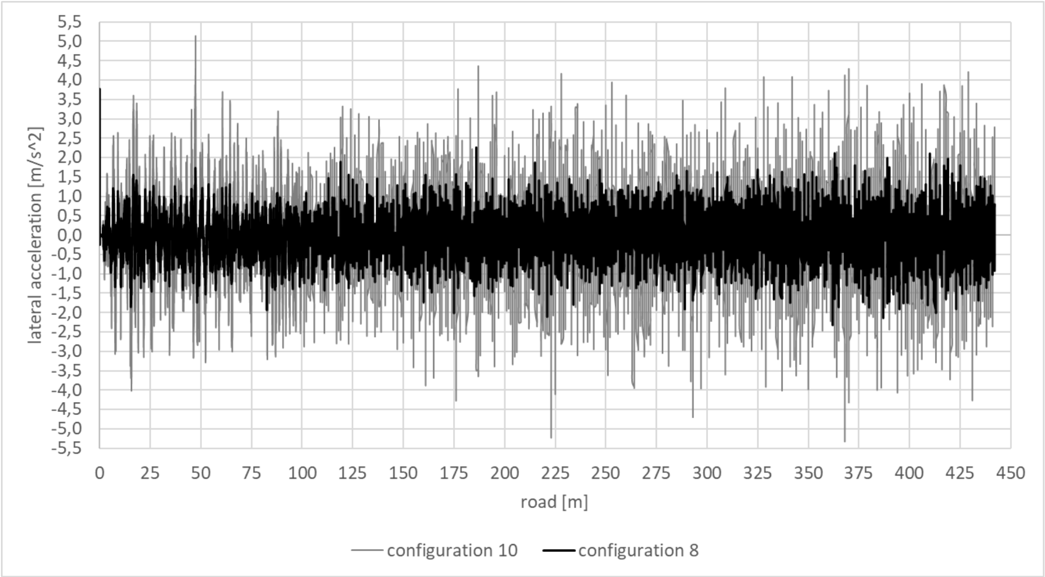

Fig. 14. Lateral acceleration on an icy, randomly uneven road surface with the almost different left and right profiles of irregularities (cor_{rl} = 0.2) [own research]

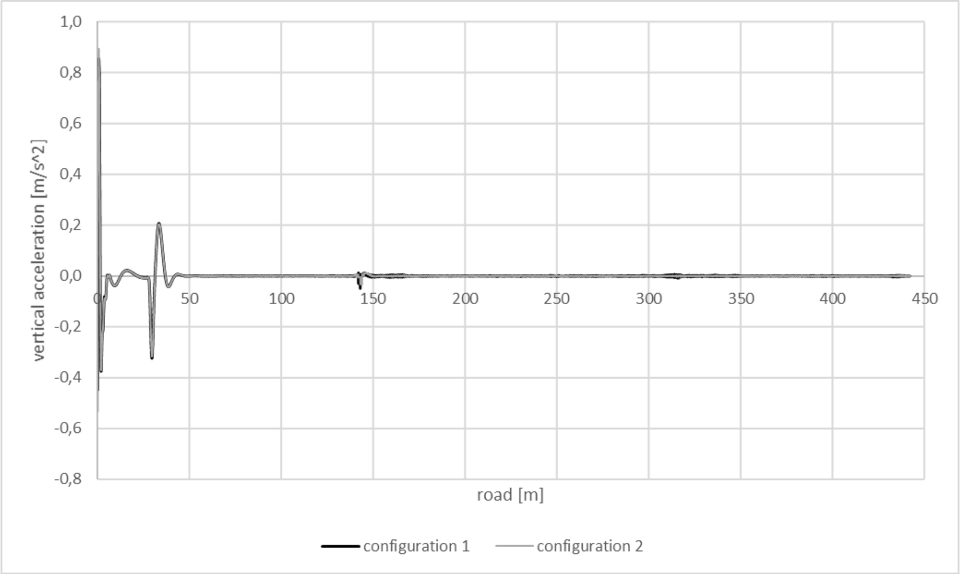

Fig. 15. Vertical acceleration for the motion on a dry and icy flat road [own research].

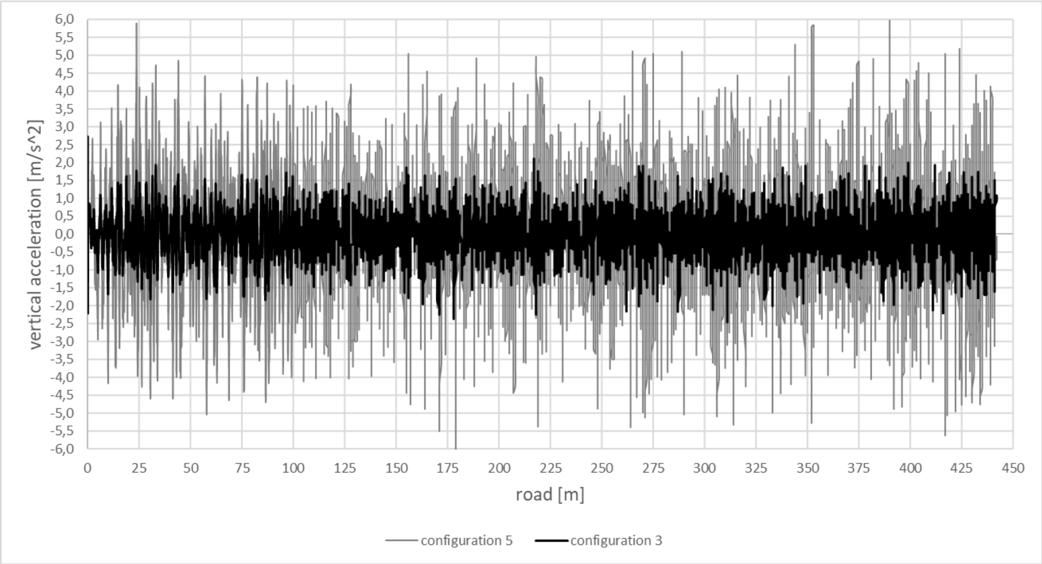

Fig. 16. Vertical acceleration on a dry, randomly uneven road surface with the almost similar left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

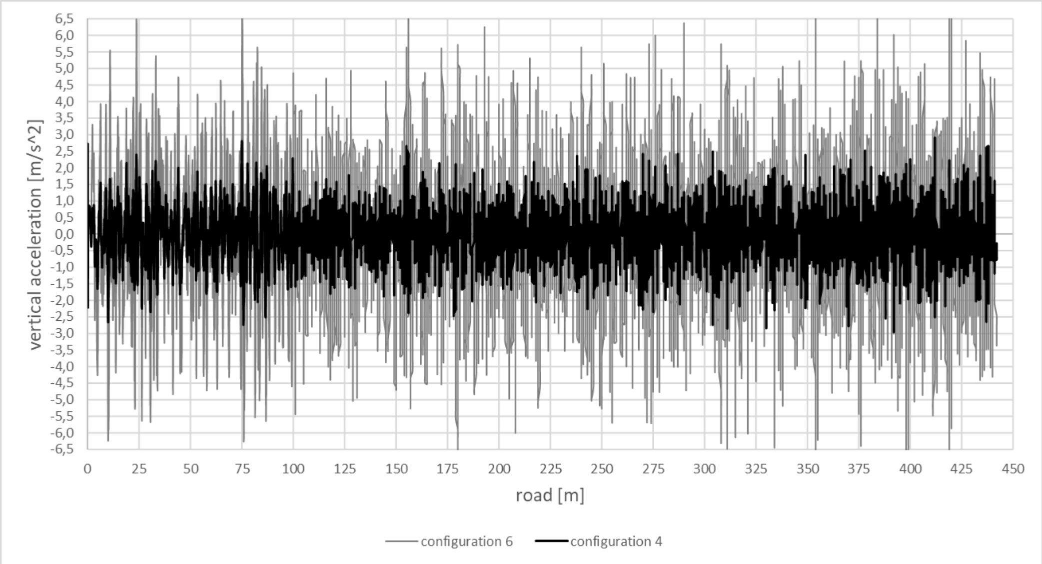

Fig. 17. Vertical acceleration on an icy, randomly uneven road surface with the almost similar left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

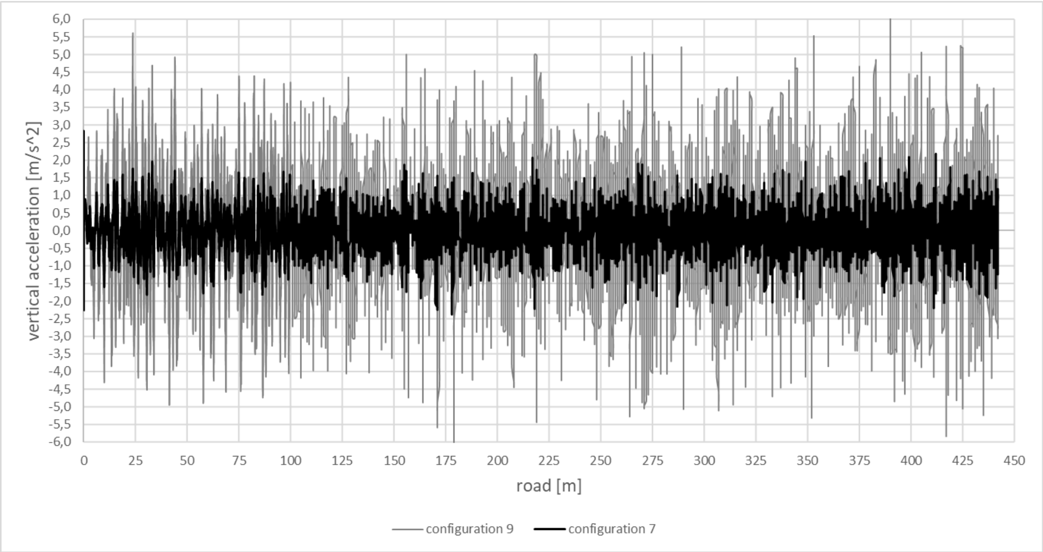

Fig. 18. Vertical acceleration on a dry, randomly uneven road surface with the almost different left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

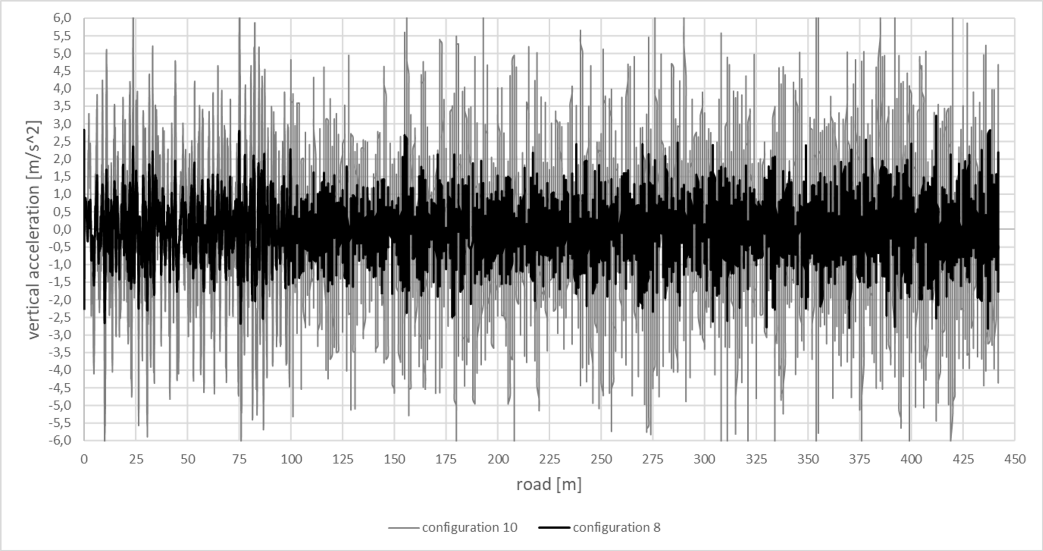

Fig. 19. Vertical acceleration on an icy, randomly uneven road surface with the almost different left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

The last problem that has been discussed earlier in (Kisilowski, 2019) will also be presented for the purpose of this paper, i.e. the changes in angular velocity around the vertical axis intersecting the vehicle's center of mass. In Fig. 20 - 24 it has been presented for the motion on either dry or icy, flat or randomly uneven road surface, depending on the configuration from table 3. Comparing to (Kisilowski, 2019) the changes were not so noticeable here. Although the maximum angular velocity for the motion along the flat road was around 0.08deg·s^{-1} in absolute value for the dry surface, as in (Kisilowski, 2019), but up to 0.34deg·s^{-1} for the icy surface, the rest of the obtained results were similar to the compared paper. The presented changers in the angular velocity for the configurations 3 – 10 do not differ much to those from (Kisilowski, 2019) and none of the obtained values exceeded themaximum value of 1deg·s^{-1}.

It can also be observed that, like in (Kisilowski, 2019) the greater values of the angular velocity were obtained for the higher irregularities on the road having the higher amplitude (intensity 0.9), rather than those with the lower amplitudes (intensity 0.3). The similarity or difference of the road profiles for the left and the right wheel did not play any role here as well.

This can be a proof that, although the maneuver was prepared without the straight line motion control, the random irregularities on the road caused the vehicle rather to drift, slide or slip in the lateral direction than yaw (rotate around the vertical axis intersecting its centre of mass).

4. Conclusions

The presented analysis indicates that the random irregularities on the road can, independently on their maximum amplitude, cause disturbances in the vehicle's motion even in lateral direction despite the fact that the vehicle does not perform any turning maneuver. However, the icy road seems to affect the adopted course of the vehicle more on the flat than the uneven road. Hence, the irregularities, despite causing the greater acceleration, can in case of no steering, reduce the lateral deviation of a vehicle to some extent. It can be observed that for the intensity 0.9 the obtained values of the lateral acceleration were higher than for the intensity 0.3.

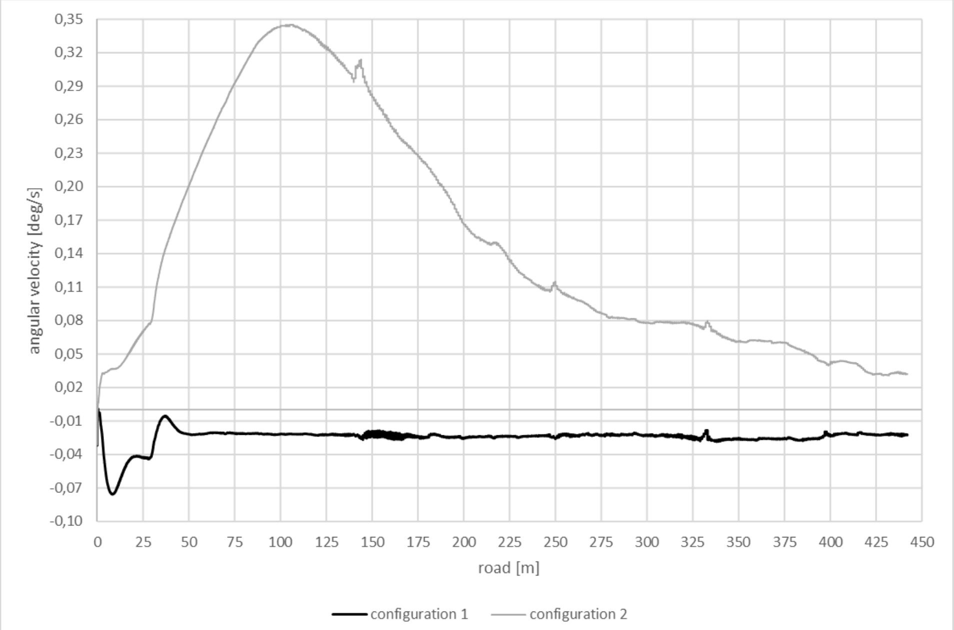

Fig. 20. Angular velocity around the vertical axis for the motion on a dry and icy flat road [own research].

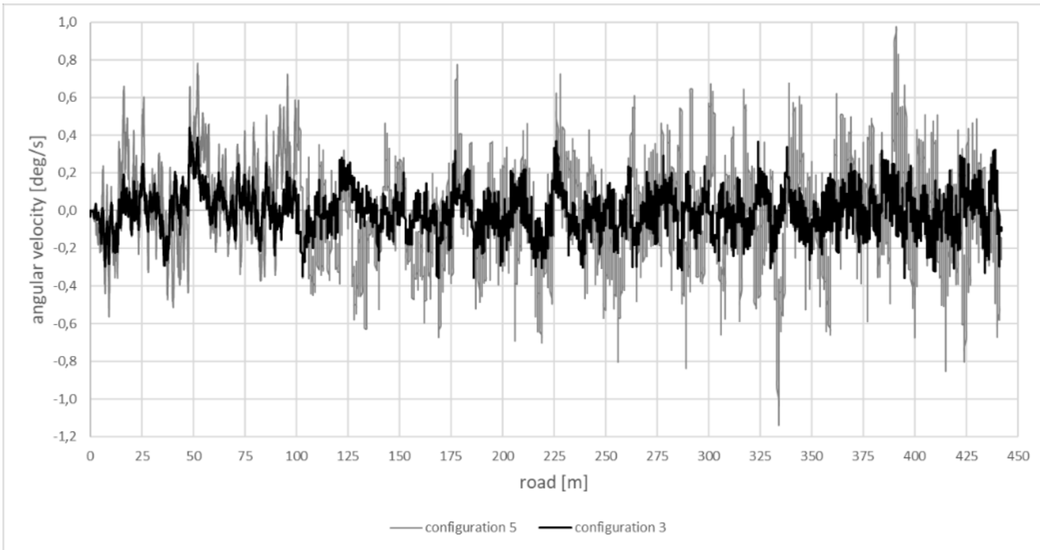

Fig. 21. Angular velocity around the vertical axis on a dry, randomly uneven road surface with the almost similar left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

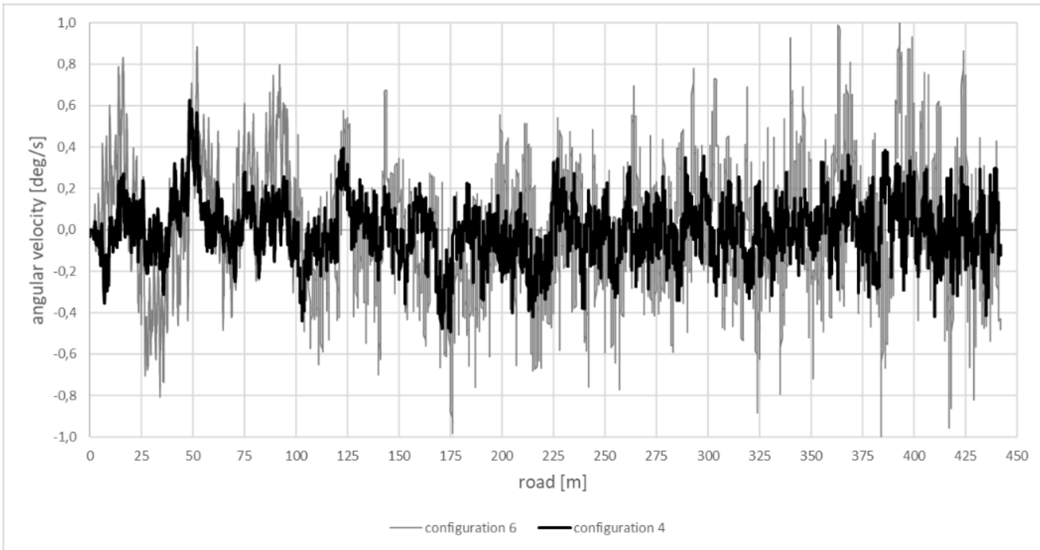

Fig. 22. Angular velocity around the vertical axis on an icy, randomly uneven road surface with the almost similar left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

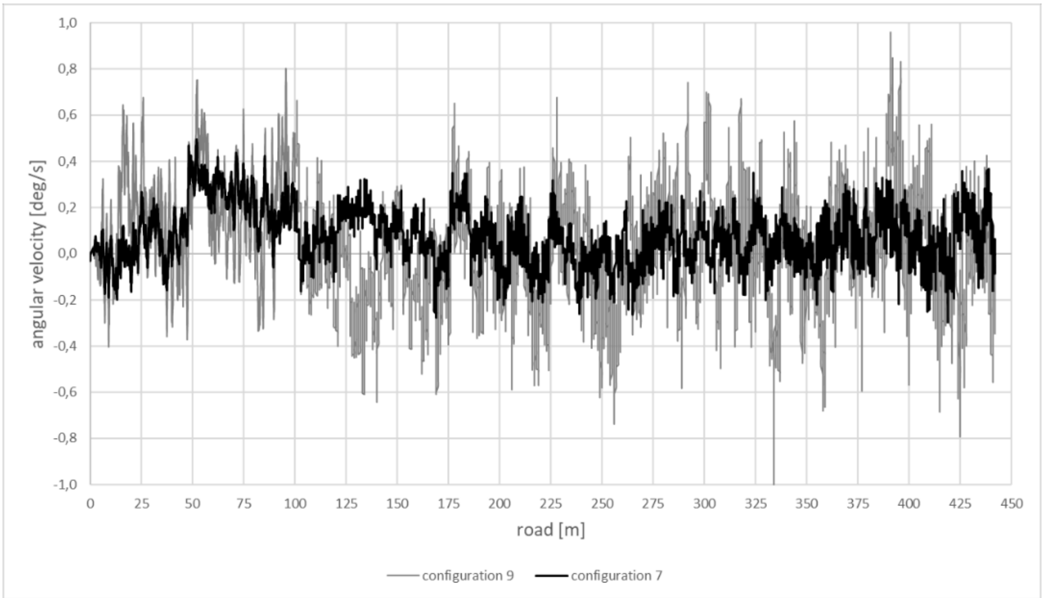

Fig. 23. Angular velocity around the vertical axis on a dry, randomly uneven road surface with the almost different left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

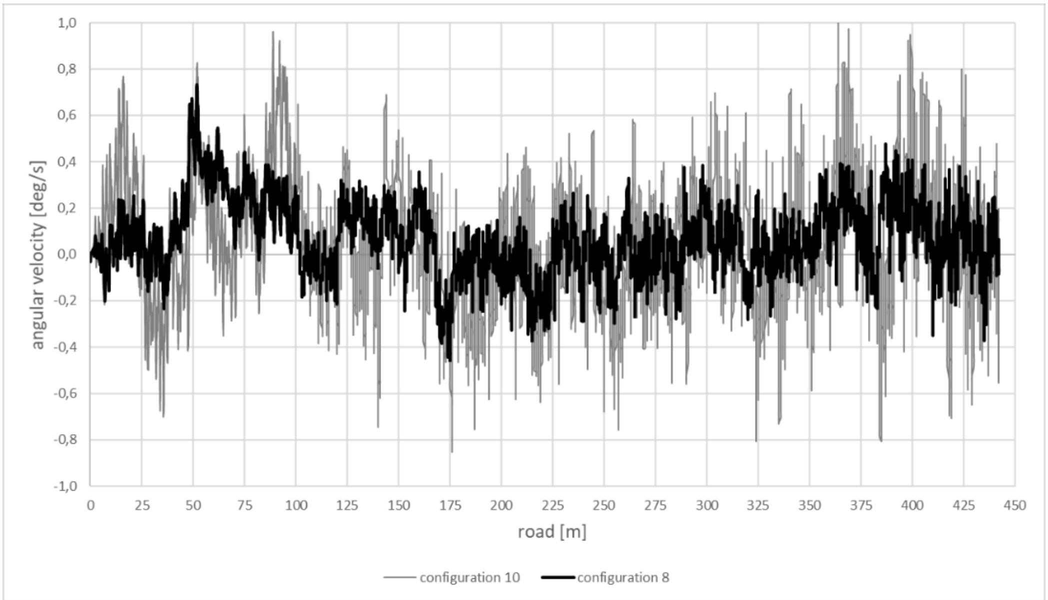

Fig. 24. Angular velocity around the vertical axis on an icy, randomly uneven road surface with the almost different left and right profiles of irregularities as well as different amplitudes of these irregularities [own research].

In further research two major steps will be undertaken. The straightforward motion will be replaced with the power-off while turning and the intensity of the irregularities will be increased in order to examine influence of the adopted road conditions on the behaviour of a vehicle with various speeds adopted.

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