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The influence of four-wheel steering system on vehicle behavior

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Abstract

This paper presents influence of four-wheel steering system on lateral vehicle acceleration, yaw rate, lateral slip, and also constant radius cornering. The influence is perceived using MSC Adams/Car software package, with Ferrari Testarossa (MSC Adams/Car – Demo Vehicle) used for simulations. In all simulations rear wheels are steered in the same direction as front wheels. Simulations were created based on double lane change maneuver. At the end, a comparison of mentioned parameters is shown, in case when vehicle is equipped with this system, and when it is not. The comparison showed that, depending on the speed of the vehicle and the value of the steering angle of the wheels, the system has a significant impact on the vehicle stability. In simulations where vehicle was moving at lower speeds and there was no disturbance of vehicle stability, this system has decreased compared parameters. Based on this comparison, it was possible to determine the optimal values of the steering angles of the wheels, to make the rate of decrease as high as possible.

Key words

Four-wheel steering
Lateral acceleration
Lateral slip angle
Yaw rate
Double lane change maneuver

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1. Introduction section

The influence of rear wheel steering systems on the vehicle dynamics was the main reason for their implementation. Other reasons for implementation were maneuverability of the vehicle, as well as agility. Later attention was focused on increasing the stability of the vehicle itself. To perceive the influence of rear wheel steering on vehicle behavior, a dynamic model was created, using MSC Adams/Car software package. Rear suspension system has been modified and the model of rear steering subsystem has been created, it is shown in Figure 1. To create rear wheel steering system, two parts where made. The first part is connected to tie rods and brings them into motion. For simulations this part has been made like steering rack. Another part is rack housing, it connects whole subsystem with vehicle chassis. When the geometries of both parts were defined, it was necessary to make a translational joint, which would allow the translation of the rack in relation to the housing. An actuator has been added to the joint, which will, based on the given function, bring the rack into translation, as well as prevent the movement of the rack during the simulation, when necessary, to ensure that the steering angles are zero.

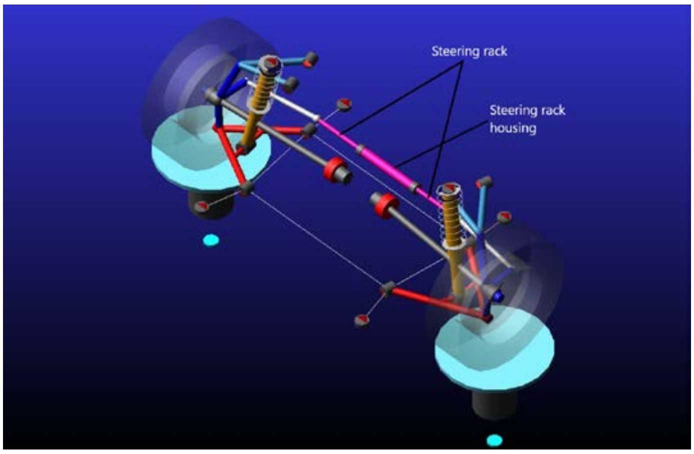

Figure 1. Rear steering subsystem overview.

2. Vehicle simulation parameters

First simulation represents double lane change maneuver of the vehicle, and second one represents constant radius cornering. Simulations were made using Event Builder, because the operation of the actuator is defined as a function of time. In both simulations STEP functions were used for steering rack actuation, functions are shown in Figure 2. In Figure 3 is shown the trajectory of the vehicle corresponding to the given STEP functions of actuator. Vehicle speed during simulations were 20, 25 or 30 m/s (72, 90 or 108 km/h). Rear rack travel was 8, 10 or 12 mm, depending of maneuver and vehicle speed. These values correspond to the rear steering angles of about 3^0, 3.7^0 and 4.5^0, respectively.

Setting the steering rack actuator algorithm in this mentioned way has it lack. During the vehicle movement on the given radius, the value of the rack travel remains unchanged. If the driver corrects the steering angles of the front wheels, this may affect the obtained results, the stability of the vehicle may be disturbed.

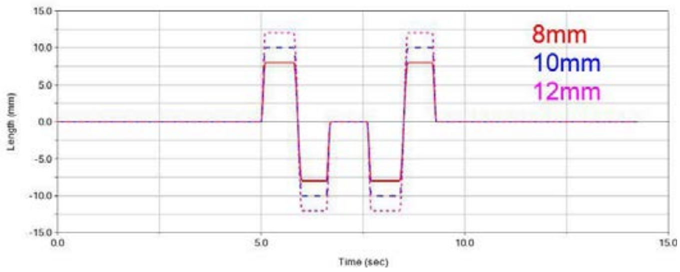

Figure 2. Functions for the actuator operation algorithm.

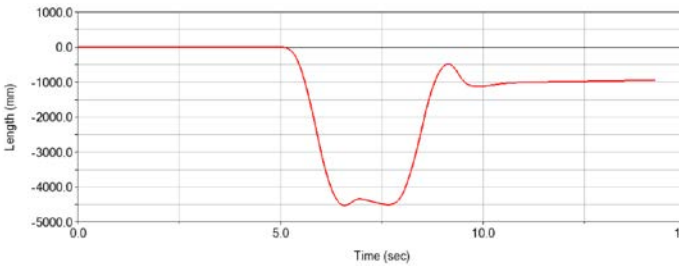

Figure 3. Trajectory of the vehicle for first simulation.

3. Comparsion of the results

3.1. First simulation – Double Lane change

- Lateral acceleration

At both vehicle speeds rear wheel steering subsystem had influence on lateral acceleration. In Figure 4 comparison is shown for vehicle speed of 72 km/h, and in Figure 5 for vehicle speed of 90 km/h.

The greatest advantage of this system is reflected when returning the vehicle to the straight line, in those moments the lateral accelerations have values of zero. This means that the vehicle is more stable in the first instance while in the latter case the values are higher than zero at those moments and, therefore, the vehicle is more unstable.

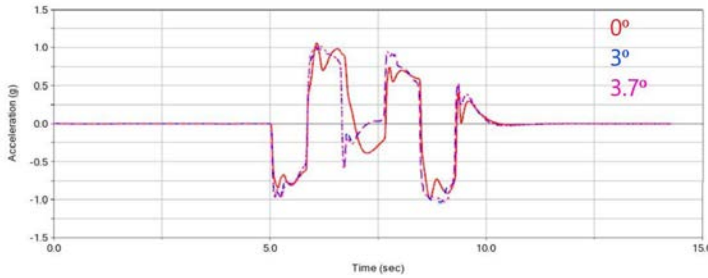

Figure 4. Vehicle lateral acceleration for vehicle speed of 72 km/h.

As can be seen in Figure 5 and Figure 3, there were no major deviations of values during the vehicle movement on curved parts of the track. When the vehicle is moving at the straights, the values corresponding to the vehicle with the rear steering subsystem reach zero values of lateral acceleration in shorter time intervals. It means that vehicle establishes stability faster. The most favorable case corresponds to the values of the rack travel of 10mm. At the time of returning the vehicle to the first straight line, it is difficult to reach lower values of lateral acceleration, which means that the vehicle is more difficult to establish stability in relation to the case of the lower values of speed. This is inferred from the higher frequency of maximum values, at that time interval.

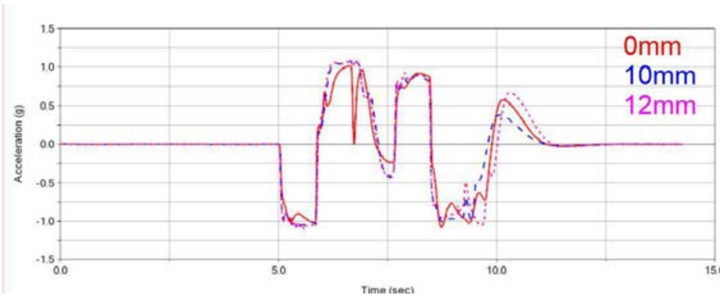

Figure 5. Vehicle lateral acceleration for vehicle speed of 90 km/h.

- Lateral slip angle

The obtained values of the vehicle lateral slip angles are smaller in the case of vehicle when rear wheels were steered. Differences in values, for a vehicle speed of 20 m/s, are shown in Figure 6.

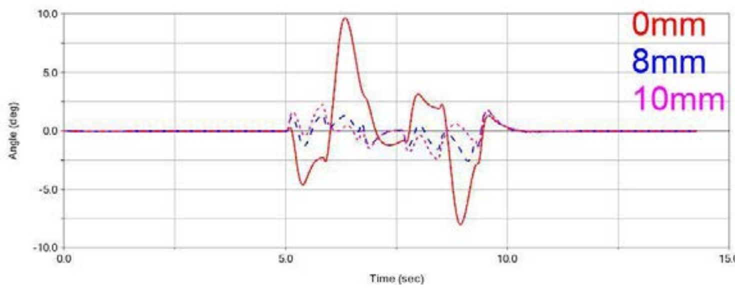

Figure 6. Comparison of vehicle lateral slip angles values.

In addition to the lower maximum values, based on the second two curves from the graph, it can be concluded that the vehicle had a value of the lateral slip angle of 0^0 at a larger number of time intervals. Since the conditions of the simulation represent critical situations, this means that the vehicle was more stable during most of the simulation, compared to the vehicle when only the front wheels were steered. At other time intervals, vehicle stability was less disturbed in case when all wheels were steered.

- Jaw rate

Based on the conducted simulations and the attached graphs, it can be concluded that in case when vehicle is equipped with an four-wheel steering system, the values of the jaw rate are drastically lower that in the opposite case. The difference between these values is presented in Figure 7, for vehicle speed of 25 m/s, also in Figure 8 is presented difference for vehicle speed of 20 m/s.

The amplitude values, which correspond to the moments of the vehicle's return to straight line, are approximately 50% less with this system equipped. In the case of a smaller rear wheels angles at the end of the simulation, the lowest values of this parameter were reached, it takes less time to reach the values of 0 ^{0}/s. It is interesting to note that the jaw rate of vehicle with four-wheel steering system, at a vehicle speed of 25 m/s are close to the values of vehicle without this system, but when the vehicle speed is 20 m/s.

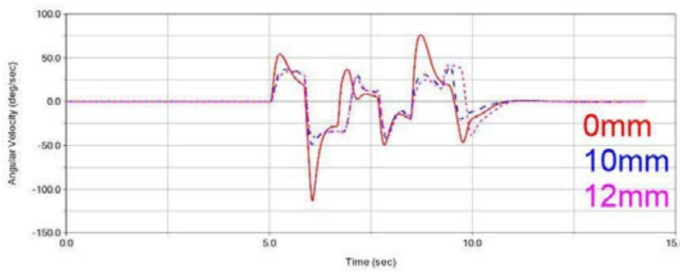

Figure 7. Jaw rate values in case of vehicle speed of 25 m/s.

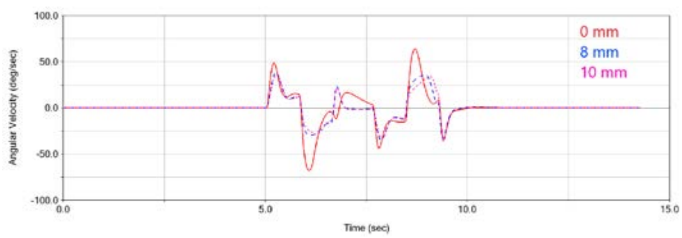

Figure 8. Jaw rate in case of vehicle speed of 20 m/s.

3.2. Second simulation – Constant radius cornering

All parameters were considered in the case of vehicle speed of 25 m/s. Vehicle path for this simulation is shown in Figure 9.

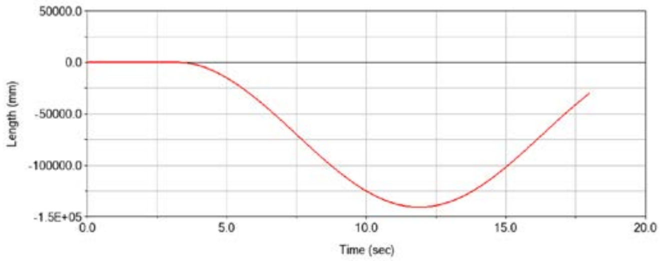

Figure 9. Vehicle path for second simulation.

- Lateral vehicle acceleration

A comparison of the values of lateral acceleration is shown in Figure 10. In both cases when all wheels were steered, the maximum values are close to the values of the vehicle when only the front wheels were steered. Deviations exist at the beginning of the maneuver because the trajectory correction is performed and the rear steering angles remain unchanged. This means that in those moments there was a difference in the corner radius. The benefit of the four-wheel steering system is that less time is required to reduce the amplitude values, the vehicle establishes stability for a shorter period of time and lateral acceleration values tend to constant values, also for shorter period of time, which is concluded from vehicle path and results that are shown in Figure 10.

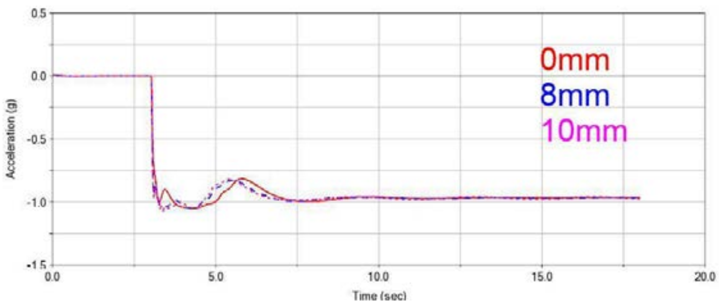

Figure 10. Lateral vehicle acceleration values.

- Lateral vehicle slip angle

Figure 11 shows the changes in the values of the lateral slip angles of the vehicle. Throughout the time interval, the values are drastically lower in case when vehicle is equipped with four-wheel steering system. In the case of a higher value of the rear rack travel, the values of the slip angle are the lowest, which is in line with the previous conclusions that increasing rear steering angles reduces the slip angle of the vehicle. It is concluded that the most optimal values of the lateral slip angles were achieved for the value of the rear wheels rotation angles of about 3.7^0.

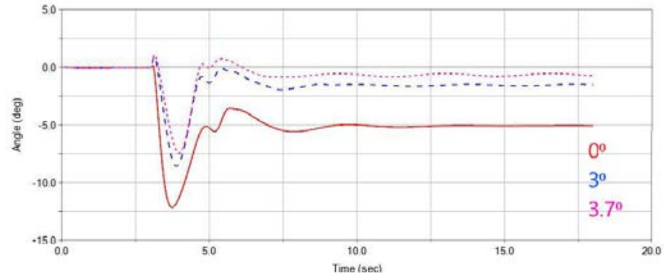

Figure 11. Values of lateral slip angles.

- Yaw rate

Figure 12 shows the comparative values of this parameter, depending on the time.

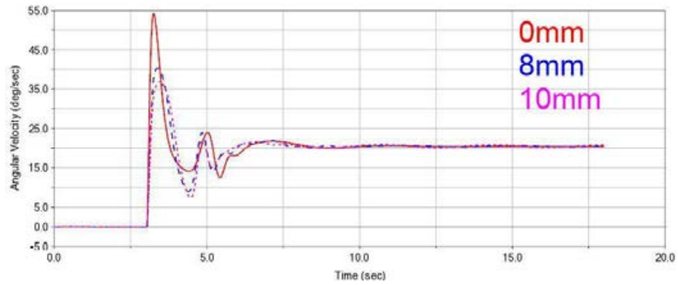

Figure 12. Jaw rate.

The reached values with the added system, which correspond to the moments in which driver acts on the steering wheel, are lower by approximately 15 ^{0}/s. At the rest of the time interval deviations of the values of this parameter are negligibly small. This means that the advantage of the four-wheel steering system is reflected when the vehicle turns are more frequent, when the driver has to act hastily on the steering wheel, which is in line with the results obtained and shown in the previous vehicle simulation.

- Vehicle turning radius

Figure 13 shows the values of the vehicle turning radius. It is concluded that the vehicle to which the rear steering system was added need less time to reach an approximately constant radius value. The vehicle without this system failed to achieve the desired radius of 70 meters, more precisely it reached a value of 71 m. For vehicle with rear wheel steering system, the values are approximately 70.1 and 70.4 m, respectively, depending on the value of the rear wheels steering angles. The achieved values are in accordance with the analyzed values of the lateral slip angles of the vehicle. Increasing the value of the rear wheels steering angles reduces the turning radius, while further increasing the value, vehicle reaches a turning radius that is smaller than the specified. There is a deviation in the time moments corresponding to the beginning of the maneuver, which justifies the deviation of the lateral acceleration value at the same moments, the reason was explained earlier.

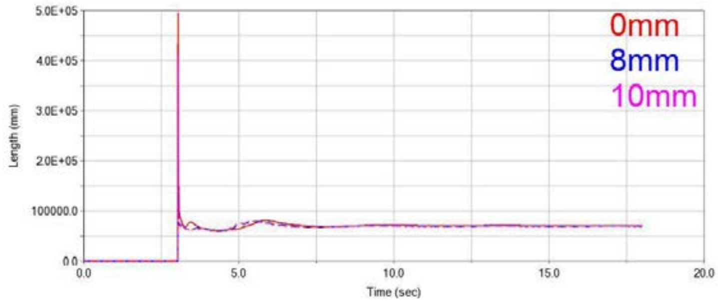

Figure 13. Vehicle turning radius.

4. Conclusion

The paper presents the parameters analysis monitored during the two simulations with and without rear wheel steering system equipped. The results are shown for different vehicle speeds as well as for different values of rear wheel steering angles. In that way, a larger number of cases of vehicle movement were covered.

Based on the represented results of the monitored parameters, it is concluded that the vehicle with four-wheel steering system achieved more favorable results than the vehicle without that system, especially when it comes to the values of the lateral slip angles of the vehicle. In critical situations, when the vehicle in no case has achieved the desired results, it significantly affects the stability of the vehicle, and the ability to maintain control of the vehicle by the driver.

The algorithm for steering the rear wheels, for purposes of this research, needs to be improved, and that is direction for further research, but based on the results shown, the steering algorithm can be determined based on the value of vehicle speed, front rack travel or lateral acceleration. In this way, the slip angles of the vehicle would be reduced to a minimum, and the rear wheels steering angles would not be higher than necessary.

Based on results shown in this paper, it is concluded that there is certainly a need to consider influence of this system on vehicle behavior. It would also be possible to determine one function whose variables will be the vehicle speed, values of front rack travel or the lateral acceleration of the vehicle, which will at any time steer the wheels for optimal angle values, and in desired direction. The directions of further research are determined by the fact that the systems on the vehicle, whose modification was performed, were not optimized, this primarily refers to the suspension system, therefore all the obtained values are less favorable than they should be. With this optimization, with an optimized four-wheel steering system, the most favorable results would be achieved and the vehicle's behavior would be the most optimal.

5. References

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