Lateral acceleration tests during circular driving maneuvers and double lane change

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Abstract. The paper presents the analysis of lateral acceleration based on a vehicle traveling in a circle with a double lane change. The maneuvers of driving in a circle and double lane changes were chosen not by accident. Tests were carried out on a popular brand passenger car on wet and dry surfaces. The vehicle is equipped with high-class electronic equipment that records vehicle motion parameters such as lateral acceleration, longitudinal acceleration, speed and others. In the study, the results of maneuvers were statistically analyzed and tabulated in order to compare and influence the comfort of travellers.

Keywords: vehicle dynamics, vehicle movement, acceleration

1. Introduction

One of the key elements faced by modern vehicle systems is passenger comfort and safety. Side rollover accounts for about 2.5% of the total number of road accidents. This type of event occurs when the vehicle rotates ninety degrees or more about its longitudinal axis. In this case, it is worth paying attention to the fact that the side rollover of the vehicle is influenced by the design and operational properties. The most important of them are the turning characteristics, traffic parameters, wheel track and tire characteristics [1]. Unfortunately, the course of such accidents is becoming more and more popular, and their course is complex. The constructed models are necessarily based on the approximation of the nonlinear elastic-plastic characteristics of the impact processes, especially during the transition from the compression phase to the deformation restitution phase. Obtaining such characteristics requires a lot of experimental research, which is also not an easy process and leads to obtaining specific answers to specific situations [9]. A modern car is a complex device, built with the use of the latest achievements in such fields as: mechanics and machine construction, electrical engineering, electronics, information technology, automation and chemistry. Along with the development of technology, the share of electronic systems controlling the work of assemblies, subassemblies and individual devices is constantly growing. There is a rapid, very drastic evolution in the automotive world, which consists in providing the best devices or components that will be primarily an element of active safety, but at the same time will be an element of protection in the event of the consequences of already existing road incidents. This fundamental change in the technical parameters of motor vehicles and their optimization has a significant impact on today's selection of the optimal vehicle. Particularly important issues related to active safety are steering and vehicle stability.
Many years of steering and stability tests contributed to the recognition and improvement of the vehicle properties and were the basis for determining the directions of modernization and development of vehicle structures [7]. Taking into account the methods of testing controllability, developed over many years in various research centers, they focus mainly on the properties of the steering system, especially the vehicle as a dynamic element. In this case, it is worth paying attention to the issue related to the tires. As you know, the wheel in the vehicle is the element through which the vehicle comes into contact with the ground. The characteristics associated with the appropriate selection of tires are very wide. It depends primarily on the grade, type, size and performance of the tire. The undisputed advantage of pneumatic tires is, of course, their resistance to flattening, which is typical for pneumatic tires and often leads to an accelerated need to replace them due to the rapid and extreme wear of the tread. Most of today's tires are made of rim, structure and tread components. Currently, tubeless tires are used in most passenger vehicles, which are able to ensure maximum safety in road traffic with the appropriate selection of parameters [8]. Along with the development of simulation studies, new research possibilities were created that allow to learn about various processes of phenomena affecting the behavior of the vehicle in various road conditions, even extremely unfavorable or unfavorable, and taking into account the actions of the driver. The aim is to equip the vehicle with assistance systems so as to be able to compensate for the defects and wrong decisions of the driver [2].

The introduction of newer and newer driver assistance systems is associated with solving problems with dynamics. In terms of control of the so-called longitudinal dynamics, these elements are already well developed and widespread in the latest vehicle designs. Such systems include, among others ABS, ASR, ICC, Lane Assistant and others. Unfortunately, the development of curvilinear motion control systems is still quite difficult. It is true that there are more and more concepts, developments of new systems (e.g. crosswind assistant, ESP), which are already introduced as additional equipment during the production of vehicles, unfortunately they are far from the level that would allow them to be thoroughly researched, modernized and permanently introduced to the production system as part of the basic equipment [2]. Among the solutions to this problem, two directions should be distinguished and presented. The first is where the classic system components of controlling the deviation need to be improved. The second direction could be the model of the driver, using the so-called optical flux method. It consists in the fact that while driving, the driver adjusts the track to the course of the road, compares the position of the car and its movement with the ideal state assumed by him. However, in critical situations, he can act in panic, make bad decisions, act too abruptly. In such situations, the car, and in principle the systems installed in it, should support or possibly correct the driver's actions, but its operation should not be predictable for him and ensure the ability to accurately follow the assumed trajectory. In situations leading to accidents, extreme road conditions are the most common. The double lane change maneuver was selected for the analysis. This maneuver is basic test performed during vehicle evaluation. It consists in driving the tested vehicle over a certain section of the test track compliant with the appropriate standard and at a constant speed. Currently, tests are carried out on the basis of ISO standards [5].

The main aim of the research was to achieve the maximum lateral acceleration during the tests, to achieve the limit values of lateral acceleration, the inability to pass the track without damaging the track infrastructure elements (cones, columns). The data will depend on how a given driver feels about his safety limit. It is enough for the driver to behave dangerously or in a dangerous situation and the issue of driving changes drastically. During the maneuvers driving in a circle, the driver did not have a specific steering wheel angle and the radius on which the vehicle was to move was not set. Table 1 below summarizes the track dimensions for each vehicle type. Passenger cars are most often intended for private use and transport up to five people. They have a luggage space, either directly or indirectly separated from the passenger compartment, depending on the vehicle structure. In each of these cases,
the most important factor will be comfort and both positive and negative feelings during the journey, thanks to which passengers will be able to classify the journey as successful or less or unsuccessful in a given environment, vehicle. Therefore, it was decided to carry out research on a passenger car, the type of which has the highest percentage in terms of usability in city traffic, with the possibility of transporting up to five people and the possibility of loading a fairly large amount of luggage.

Table 1. Track dimensions for individual standards [5]

| Norm      | Section number | Length | Width   | Traverse shift | Remarks                                      |
|-----------|----------------|--------|---------|----------------|---------------------------------------------|
| ISO 3888-1| 1              | 15 m   | 1,1 x B+0,25 m |                |                                             |
|           | 2              | 30 m   |          |                |                                             |
|           | 3              | 25 m   | 1,2 x B+0,25 m | 3,5 m         | The total length of the test track is 125 m |
|           | 4              | 25 m   |          |                |                                             |
|           | 5              | 15 m   | 1,3 x B+0,25 m |                |                                             |
|           | 6              | 15 m   | 1,3 x B+0,25 m |                |                                             |
| ISO 3888-2| 1              | 12 m   | 1,1 x B+0,25 m |                |                                             |
|           | 2              | 13,5 m |          |                |                                             |
|           | 3              | 11 m   | B+1 m    | 1 m            | Total measurement track length 61 m. For vehicles up to 3500 kg. |
|           | 4              | 12,5 m |          |                |                                             |
|           | 5              | 12 m   | 1,3 x B+0,25 m |                |                                             |

The track according to ISO 3888 - 1 standard, the diagram of which is presented below, was selected for testing the vehicles.

![Double lane change track according to ISO 3888 - 1](image)

Figure 1. Double lane change track according to ISO 3888 - 1

2. Methodology
The test object was an Audi A6 Avant passenger car Fig. [2] tab. [2]. The power unit used for the in-line cylinder is a diesel engine with a six-cylinder 2957.00 cm³ and a power of 176 kW, which was produced in 2009. The vehicle is equipped with a turbocharger and an intercooler. Injection takes place directly via the Common Rail system. The car is equipped with a gearbox, permanent all-wheel drive, as well as air suspension. The vehicle ran on tires for years. In fig. 2 The vehicle used for the test is shown together with its technical data.
Figure 2. Audi A6 Avant passenger car

Table 2. Motor vehicle dimensions.

| Parameter [m] | Car  |
|---------------|------|
| Length        | 4.93 |
| Width         | 1.85 |
| Height        | 1.46 |
| Weight        | 1920 |
| Drive         | quattro |

The vehicle was moving on paved asphalt both when driving in a circle and when changing lanes twice. Depending on the needs, the surface was dry or wet. Driving in a circle is arranged to the left and right, and on dry and wet surfaces. The two-lane shift was performed on a dry and wet surface at a speed of 50 km/h. The speed was determined on the basis of road traffic regulations for vehicles moving in city traffic. During the measurement of vehicle, motor vehicle, access control, access control, from which the control was carried out. The vehicle is equipped with a clock device consisting of: a) Corrsys Datron S-350® Aquare on-board optoelectronic system, which registers elements of motion, including the clock measurement of the vehicle, b) control of TAA® clock traffic, registration of the measurement system in the X, O direction, Y, Z, TANS® sensor for measuring the linear and angular measurement of the X, Y, Z axis; c) DatronEEP12® data acquisition station with tablet, connection and ARMS®. The measurement system recorded data at a frequency of 100 Hz. Data.

![Figure 3a](image1.png)  
**Figure 3a** Lateral accelerations recorded during the maneuver of driving in a circle on a dry surface to the left

![Figure 3b](image2.png)  
**Figure 3b** Lateral accelerations recorded during the maneuver of driving in a circle on a wet surface to the right

3. Results
Taking into account the exemplary curves of lateral acceleration during the maneuver of driving in a circle
circle, it is worth noting that when the vehicle is moving on dry asphalt, the range of values is between 0.5 and 0.98 m/s². However, when driving the vehicle on a wet surface, the range of values is in the range of 0.55 to 1.05 m/s². The wide range of ranges is mainly due to the fact that in the first case the driver moved to the right - it is harder to hold your own body during sudden maneuvers, because there is no greater point of support - than to the left, where our body rests on the door upholstery. In addition, it can also be concluded that the driver feels safer when moving the vehicle to the left, because he has a greater range of visibility in relation to the vehicle and the road.

According to the recorded minimum values of a vehicle moving on a wet surface, during the maneuver driving in a circle, they reach the value of 7.17 m/s² to the left, and the minimum values to the right reach 7.36 m/s². As you can see, the minimal lateral accelerations of a vehicle moving left and right on a wet surface are very close to each other. When the vehicle moves in a circle to the left, the maximum values of lateral accelerations are 9.19 m/s² and to the right - 9.12 m/s². The difference between the maximum and minimum values is, respectively, 2.02 m/s² for driving in a circle to the left and 1.76 m/s² for driving in a circle to the right. The situation is quite similar when it comes to driving in a circle on dry asphalt. To the left, the minimum values are 7.91 m/s², and to the right, 7.55 m/s². For the maximum values of lateral accelerations for driving in a circle to the left, the values are respectively 9.6 m/s² for driving to the left and 9.42 m/s² for driving to the right. The difference between the maximum and minimum values is 1.69 m/s² for driving to the left and 1.87 m/s² for driving to the right, respectively. As you can easily notice, higher differences between the maximum lateral accelerations are indicated by driving in a circle on a wet surface to the left, while when driving to the right, greater differences in values are indicated by driving in a circle on a dry asphalt to the right.
The results of the presented research show that the values of lateral acceleration are mainly influenced by the type of surface on which the vehicle is traveling. The values presented in the article clearly show that changes in the maximum lateral acceleration significantly affect the concept of comfort and discomfort for passengers of given vehicles. The data obtained in this way were subjected to statistical analysis, the results of which are presented in Table 3. It presents the minimum and maximum values of lateral accelerations depending on the type of maneuver and the surface on which a given vehicle was driving while driving in a circle.

**Table 3. Summary of minimum and maximum accelerations for circular maneuver, double lane change and road surfaces**

| Car Surface          | Dry asphalt | Car Wet asphalt |
|----------------------|-------------|-----------------|
| Acceleration         | min | max | min | max |
| Double lane change   | 4.47 | 4.87 | 4.75 | 6.11 |
| Circle left          | 7.91 | 9.6  | 7.17 | 9.19 |
| Circle right         | 7.55 | 9.42 | 7.36 | 9.12 |

For a passenger car, the minimum values of lateral acceleration were recorded while driving in a circle on the left side on a wet surface. They are 7.17 m/s². The maximum acceleration values were recorded while driving in a circle to the left on a dry surface of 9.6 m/s². The minimum values obtained during the double lane change maneuver on a dry surface were 4.47 m/s², and on wet asphalt the minimum values were 4.75 m/s². The maximum values achieved on the dry surface were 4.87 m/s², and on the wet surface - 6.11 m/s². The values of lateral acceleration recorded during driving in a circle and during a double lane change were characterized by large differences. The minimum acceleration with a double lane change was 4.47 m/s², while the maximum was 9.19 m/s² while driving in a circle. The difference between the minimum and maximum values is quite large and amounts to 4.72 m/s².

4. **Conclusion**

The performed tests of lateral acceleration were divided according to the type of surface and the type of maneuver. Analyzing the obtained data while driving in a circle, both to the left and to the right, as well as in terms of the type of surface - wet or dry, it results that the highest values of lateral acceleration are obtained on a dry surface. Minimum values for double lane change maneuvers and the maximum values of a vehicle running on dry asphalt are similar. However, in the case of a vehicle running on wet asphalt, the difference between the minimum and maximum values is much greater and amounts to 1.36 m/s². When analyzing the process of driving in a circle or double lane change and the maximum acceleration values achieved during this maneuver, many factors should be taken into account. One of the main ones is the implementation of the drive in a passenger vehicle. If the vehicle is not equipped with four-wheel drive, the obtained acceleration values may differ significantly from the obtained ones. In addition, the vehicle used for the tests has active safety systems in the form of the ABS or ESP system, which can start working at the right moment and in a given situation, which translates into the results of lateral acceleration (vehicle stabilization). To a large extent, such behavior is influenced not only by the type of surface on which the vehicles traveled, the type of maneuver, but also the characteristics of the passenger car and its equipment. Lateral acceleration is one of the parameters influencing not only the driving comfort but also the stability of the vehicle. Extensive research and tests have a significant impact on the method of production of vehicles and the safety of passengers moving in it. Exceeding certain barriers related to lateral acceleration may have a significant impact on the trajectory of a moving vehicle, and thus the safety of passengers. Therefore, it is very important to carry out laboratory tests with the use of the highest quality equipment and to
obtain real values that can be used in an appropriate way for a cognitive and analytical approach to vehicle safety issues.

5. References
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