Solutions for increasing the comfort in road vehicles based on improving the construction of the seats

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Abstract. To reduce the harmful vibrations to which passengers and drivers are exposed when traveling in road vehicles, various suspension systems for the vehicle, chassis or seats may be used. Most research and development is focused on reducing vertical vibrations. When the vehicle is cornering, lateral acceleration occurs, which causes discomfort to passengers. According to a number of studies, the value of lateral acceleration can be reduced if the vehicle or seats lean towards the center of the turn. This study looks at some solutions to increase comfort in road vehicles based on improving the design of the seats. New design solutions for a child tilting seat, which were developed by the authors, are presented. Road experiments have been carried out to demonstrate that the use of these seats when the vehicle is cornering can reduce the value of lateral acceleration.

1. Introduction
The passengers in road vehicles are exposed to vibrations that affect their comfort and health. In a car, the vibrations acting on the passengers have a high frequency range and are caused by various sources. For example, the internal combustion engine and the transmission mainly cause high frequency vibrations [1]. The road surface can cause both high frequency and low frequency vibrations [2]. The frequency range of vibrations caused by the road surface depends on the parameters of the road profile: slopes, bumps, microprofile and roughness. The function of the car suspensions is to reduce the effect of the road bumps and microprofile. The action of conventional seats is also in this direction – the vertical. In addition to the vertical vibrations when the car is accelerating or braking passengers are exposed to longitudinal accelerations. When the car is cornering, lateral accelerations act on the passengers.

In this paper some existing seat design solutions leading to improved comfort by reducing vertical and lateral impacts are considered. In addition, new seat design solutions developed by the authors are proposed and examples of their implementation are shown. The proposed solutions lead to a reduction in lateral acceleration when the car is cornering. Their application as conventional seats in the car is more difficult as it requires serious changes in car body design. For this reason the constructions are realized as tilting child car seats. Furthermore motion sickness in road vehicle is a very common experience, with high incidence of vomiting, particularly in young passengers between the age of 2 and 12 years [3]. Low-frequency lateral accelerations (0.1-0.5 Hz) have a major influence on the presence of these symptoms. The results of road tests proving that the proposed designs of tilting child car seats lead to a reduction in acceleration values.
2. Existing seat design solutions
The most commonly used seat constructions ensure the comfort of the driver and passengers in the vertical direction. In conventional passive seats, this is done by the appropriate choice of elastic and damping parameters of the seat cushion. Air-suspended seats are often used for seats used for truck and bus drivers. This is necessary due to the stiff suspension of these vehicles. In addition, the difference in load between them is greater when the vehicle is empty and full and the necessary comfort cannot be achieved with the suspension of the vehicle. In these vehicles, the driver works in professional conditions and has to drive for a long time every day. In this way, the time during which the driver is exposed to vibrations is longer and this can seriously damage his health. The natural frequency of the air suspension of the seats is independent of the driver's mass. There are studies and developments of various designs of seats with semi-active [4] or active suspension [5, 6]. Active seat suspension systems are more efficient, but are more expensive to implement and are difficult to install in existing conventional vehicle seats [7].

In addition to dampening vertical vibrations, there are seats with suspension that reduces vibrations in the horizontal direction. In [8] a design of passive lateral seat suspension for off-road vehicles is proposed. Field testing and ride quality evaluation of the prototype were carried out and for this purpose the seat is mounted on a quarry dump truck. In [9] a design of active seat suspension with two degrees of freedom for military vehicles is proposed. For this purpose, two electric motors are used, mounted under the seat surface to reduce the vibrations in lateral and vertical direction. The results show that the comfort can be improved by about 39% in comparison with a passive seat for the vertical dynamics and by 16% for the lateral dynamics.

The lateral acceleration acting when the vehicle is cornering can be compensated by tilting. This method has long been applied to trains by tilting car body. Source [10] discusses the possibility of using this method in cars. The principle is used in the S-Class Coupé model of Mercedes-Benz. To achieve a compensation in the range 1-2 m/s², this would only be possible by implementing (separately or additional) seat tilting [10].

In [11, 12] the effect of passengers’ active head-tilt conditions on the severity of motion sickness in the lateral acceleration environment of cars is examined. The results in this study indicate that a passenger's active head tilt towards the centripetal direction reduces the severity of motion sickness in the lateral acceleration environment of an automobile and thus improves comfort.

There is also a realized patent [13], in which a method for active tilting a seat of a vehicle is proposed. The invention relates generally to a method for tilting a seat of a vehicle and, more particularly, to a method for tilting a seat based on multiple parameters with multiple thresholds. The authors of the patent propose a tilting mechanism of the seating system, which includes gas struts and a pneumatic pump and functions to adjust the angle of the passenger seat to the vehicle under the action of lateral acceleration.

3. New design solutions
Based on the statements of [10-13], the authors of this article have developed two design solutions for passive tilting of seats. One design is of the pendulum type, and the other is by roller supports.

These solutions were developed by the authors and implemented for now as child seats. The reason for this is the easier technical implementation without changing the design of the car and the fact that children are more sensitive to the harmful effects of lateral acceleration when the car is cornering. The design of tilting child car seats is shown in figure 1.

The tilting child car seat of the pendulum type can be tilted when the car is cornering. The tilt is about the axis of a cylindrical joint located above the center of mass of the child sitting in the seat. The tilting child car seat with roller supports is a car child seat that tilts when car is cornering by means of roller supports located at the base of the seat below the center of mass of the child sitting in it.

Both types of seats do not require additional components (sensors, actuators, etc.), as well as energy for their tilting. The tilting car child seats are separate structural units, and their use does not require a change in the design of the car seats.
Figure 1. Design of tilting child car seats: (a) pendulum type; (b) with roller supports.

The shown designations in figure 1 are: $\varphi$ – tilt angle of the tilting seat when the car is cornering; $g$ – the gravitational acceleration; $a_y$ – lateral acceleration; $C$ – center of mass.

4. Road tests and results

Road tests have been conducted in order to analyse the efficiency of the tilting child car seat proposed over the reduction of the lateral accelerations. To avoid health and safety problems, a test dummy was used (figure 2). Equipment, used to measure the accelerations: passive tilting child car seat of pendulum type, test dummy, three axial accelerometers, data acquisition device (DAQ), power supply and mobile computer. The accelerometer and DAQ devise used for data acquisition are shown in figure 3.

Figure 2. Passive tilting child car seats pendulum type equipped for road tests. Figure 3. Accelerometer and DAQ devise used for data acquisition.

Two types of road tests have been conducted. The first test is when entering bend, moving at a relatively constant speed and exiting the bend. Figure 4 shows the results of this test. It can be seen that the lateral acceleration is significantly less when using a tilting seat. The second test was conducted on a curvy cross-country road trip with a duration of about 80 minutes. Figure 5 shows the lower overall level of lateral accelerations obtained on the tilting seat. It can be seen that they rarely
Figure 4. Lateral acceleration on conventional seat (1) and tilting seat (2) when driving in a bend.

Figure 5. Lateral acceleration on conventional seat (1) and tilting seat (2) on a curvy road.

Figure 6. Spectral density of a lateral acceleration on conventional seat (1) and tilting seat (2) on a curvy road.
exceed the value of 2 m/s², indicated as a threshold in [10]. Figure 6 shows the spectral densities calculated in MATLAB of the accelerations time series from the test trip. They also prove that the use of a tilting child seat reduces the intensity of lateral accelerations and thus contributes to improving travel comfort.

5. Conclusions
In this paper some existing seat design solutions with improved comfort in the vertical or horizontal direction have been considered. New technical solutions for seats that reduce lateral acceleration when the car is cornering were presented. They are realized as child seats due to the easier installation in the car as an additional seat. Two constructive solutions have been offered – of pendulum type and by roller supports. The results of road tests performed on the pendulum type seat which prove its effectiveness were shown. Acceleration data show that the use of tilting seats can significantly reduce lateral acceleration and therefore to improve traveling comfort. The authors have submitted applications for utility models for both design solutions and they are working on the implementation of the roller support seat in order to conduct future research.

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