EXPERIMENTAL STUDIES OF FORCES IN THE STEERING RODS

ROBERT JANCZUR[1], ALEKSANDER KURANOWSKI[2], PAULINA NOGOWCZYK[3], WIESŁAW PIENIĄŻEK[4]

Cracow University of Technology, Special Vehicles

Summary

The article presents the methodology and results of the studies of forces in the steering rods in real traffic situations. The particular attention was paid to the drive through the roadside, which is lowered in relation to the roadway. Such a situation is dangerous due to the road safety, because when returning from the roadside to the roadway, the torque of the steering wheel, regulated by the power steering, is so small that it helps the driver to perform too great turn of the steering wheel, so that the car can be found on the lane of the opposite direction or it can leave the roadway. The aim of this paper was to identify the distribution of forces in the rods and to propose suitable reversing of the power steering system with the use of these forces.

Keywords: experimental studies, steering system, steering rods, torque on the steering wheel, paved road surface, unpaved road surface, ground surface, roadside, steering effort

1. Introduction

Modern, small cars are often equipped with electrical supporting devices. The torque sensor, which is a part of this system, is installed in the steering shaft and generates a suitable signal regulating the level of the power steering. However, the torque sensor reacts to the total torque, which is transferred to the steering wheel and derives from both steered wheels. This sensor is not able to "recognise" the distribution of forces on the individual steering rods, which depend, among others, on the swivel resistance of the corresponding wheels. Thus, the same torque assisting the steering wheel is produced when the swivel resistance on both wheels are numerically close to each other and when one "double" great torque is produced on one wheel, and the second wheel does not resist swivelling. The second dangerous accident occurs in the critical states of a moving

[1] Cracow University of Technology, Faculty of Mechanical Engineering, Institute of Automotive Vehicles and Internal Combustion Engines, al. Jana Pawła II 37, 31 864 Kraków, e-mail: robertj@mech.pk.edu.pl

[2] Cracow University of Technology, Faculty of Mechanical Engineering, Institute of Automotive Vehicles and Internal Combustion Engines, al. Jana Pawła II 37, 31-864 Kraków, e-mail: aleksader.kuranowski@poczta.onet.pl; The Jan Sehn Institute of Forensic Research in Kraków, ul. Westerplatte 9, 31-033 Kraków.

[3] Special Vehicles, ul. Bestwińska 105A, 43-346 Bielsko-Biała, e-mail: paulina.nogowczyk@gmail.com

[4] Cracow University of Technology , Institute of Automotive Vehicles and Internal Combustion Engines (retired adjunct), ul. Powstańców 38/43, 31-422 Kraków, e-mail: wiesiek@mech.pk.edu.pl

car. The extremely diverse torques on turning wheels (and varied forces in the steering rods) also appear during the asymmetrical braking – with one wheel on a slippery and the second one on an adhesive road surface (this case is classified in the literature as μ-split). The wide variation of forces in the steering rods occurs when one wheel pulls over to the often lowered and bad quality roadside (the adopted English in subject literature term: *edge drop-off*).

According to the practice in case of accidents, it is known that the most dangerous, and relatively often encountered ones, include the situations, in which the driver moves with the right wheels to the lowered bad quality roadside, and then tries to get back to the roadway turning left. This return is facilitated due to the power steering. It appears that the car getting back to the roadway with four wheels rapidly recovers the adhesion and pulls over the right side of the roadway. Then, there is a head-on collision with the vehicles driving from the opposite direction, or the drive is ended outside the roadway on the left side. Most often, the accidents, which result in the most tragic consequences, are described by the sentence – *the driver pulled over to the left side of the roadway for unknown reasons*. The unintentional pulling over with right wheels to the (lowered) roadside can be "recognised" by the measurement of forces in the steering rods. The comparison of forces in the steering rods should lead to reversing the supporting devices and appropriate limitations of the supporting torque – in order to hinder the driver's *rapid* return to the roadway. Driving along the roadside and gentle deceleration so long that the return of the right wheel to the roadway takes place at the speed, which prevents uncontrolled pulling over to the left side of roadway, is definitely less dangerous than the rapid entry to the roadway.

The additional benefits associated with the measurement of forces in the steering rods include signalling the increased rolling resistance related to the reduction of the tyre pressure level. The increase of the steering rod force will take place in case of the wheel, in the tyre of which the pressure decreased. In order to reduce the impact of the spontaneous reaction of the driver who can disrupt the established vehicle trajectory – the supporting torque of the steering wheel should be also limited then.

On the contemporary built expressways and motorways, the right continuous edge line (rumble strip) P-7b has the deliberately implemented corrugation, which makes that the tyre entering the line produces a very distinctive sound that has to draw the driver's attention to the dangerous pulling over to the right (the intention of which is to *wake up the driver*). It was experimentally found that the surface corrugation results in the noticeable increase of the force in the right steering rod. This fact can be used by additionally warning the driver with a signal inside or event limiting the power steering in order to avoid the spontaneous, exaggerated turn left.

In Figure 1, a diagram of the proposed solution to the control system of the torque on the steering wheel, in which the strain gauge measurement of forces in the steering rods was applied.

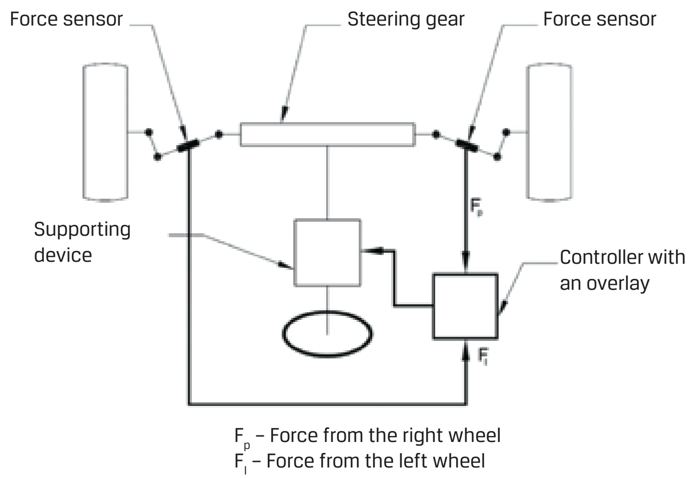


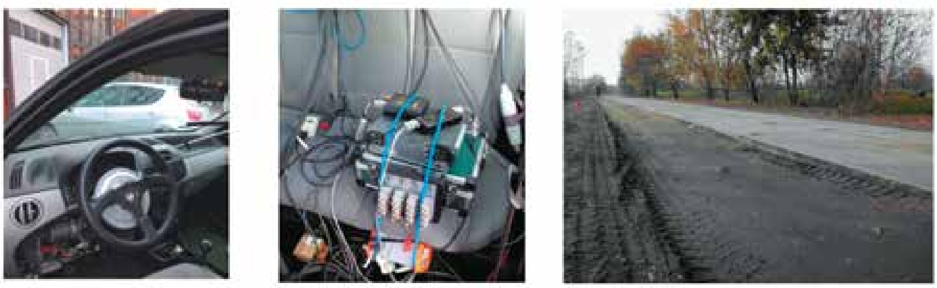
Fig. 1 Schematic diagram of the proposed solutions to the control system.

2. Course of road tests

FIAT Punto car was tested during the asymmetric pulling over to the right lowered ground roadside. The tests were conducted for two values of the pivot point radius regulated with washers put between the rim and the wheel hub. The diversity of forces in the steering rods which allows to offer the logical procedures that were previously mentioned in Chapter 1, and to use them to control the supporting device of the steering system, was found.

2.1. Vehicle's equipment for testing

In order to measure forces in the steering rods, the resistance strain gauges, which were



a b c

Fig. 2. A set of instruments (a measuring steering wheel and AD32 processing and re-cording device) as well as a sample view of the test track (a concrete-surface road with the lowered ground roadside)

stuck to each rod in the full bridge circuit, were applied. Electrical signals from strain gauges were amplified and recorded. In addition to the signals from the rods, a number of other parameters, the most important of which, from the point of view of the purpose of this paper, are: the angle of rotation and torque on the steering wheel as well as lateral acceleration, were synchronously measured and recorded.

2.2. Trials conducted during testing

In the test programme, analogous trials to the double lane change (the right side wheels temporarily drove through the ground roadside), as well as the rapid, irregular (random), temporary pulling over to the lowered ground roadside with the right side wheels were performed. These trials were conducted during driving, engine braking (easing the foot off the accelerator) and freewheeling (with the released clutch)

Fig. 3 showed the variation of the measured values obtained in the trial, which was conducted with the drive at the speed of 40km/h, with the power steering off, and in case of Fig. 4, in the trail, which was conducted in similar conditions but with the standard power steering on.

By analysing the variation in a given figure, it is possible to identify the considerable difference of forces in the left and right steering rod. The force in the left steering rod is higher. The left wheel rolled on the asphalt roadway. The right wheel entered and rolled on the approximately 5 cm lowered, hard ground roadside (the adhesion coefficient of this surface is about twice lower than the asphalt roadway). According to the provided in literature equitation of torques, which affects the swivel resistance (see, e.g. [1,7]), the

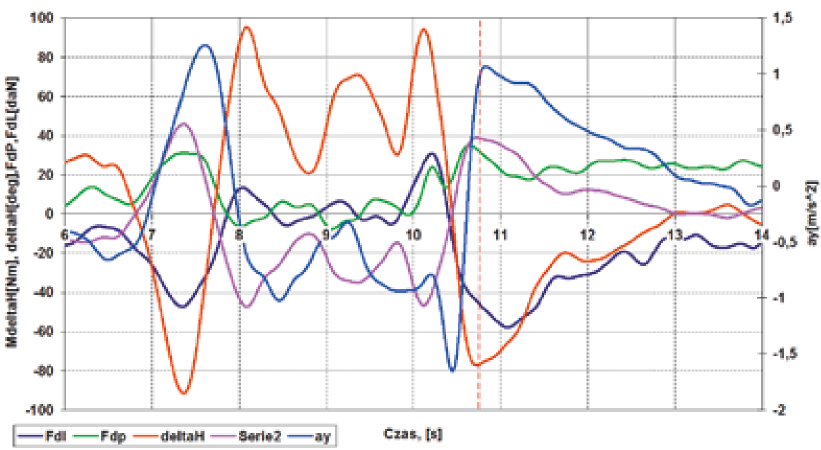


Fig. 3. Drive through the lowered roadside. Speed 40km/h, Power steering off. Symbols: FL – force measured in the left steering rod, FP – force measured in the right steering rod, deltaH – driving wheel rotation angle, MdeltaH – rotation torque on the driving wheel, ay – transverse acceleration, t - time

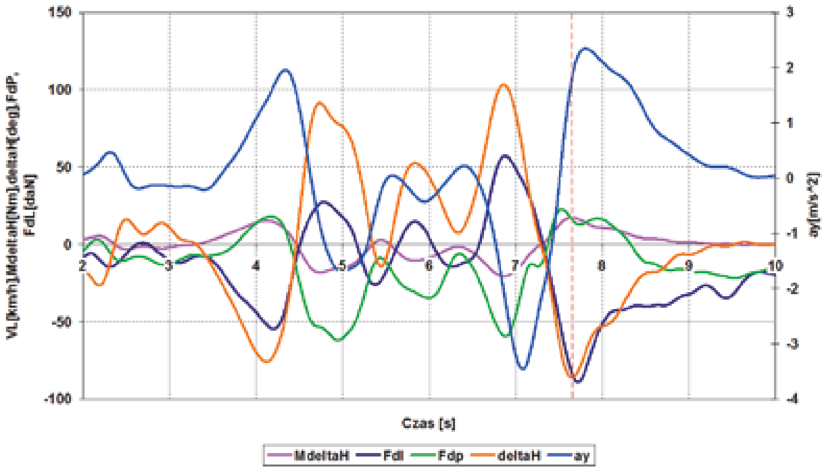


Fig. 4. Drive through the lowered roadside. Speed 40 km/h, Standard power steering on. Symbols as in figure 3

largest value includes the torque of adhesive forces occurring in the point of the tyre to roadway contact. Therefore, the force in the left rod is greater (for the driven wheel).

Fig. 5 comparatively showed the variation of forces in the steering rods on the drive, engine braking and freewheeling, and in Fig. 6 presented the impact of the pivot point radius on the values of forces in the steering rods.

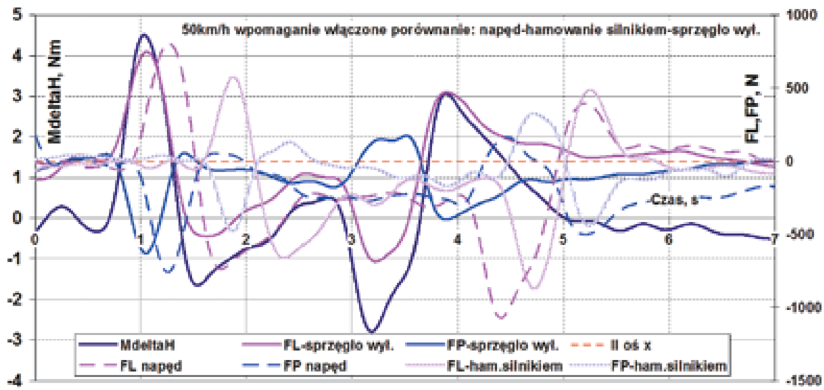


Fig. 5. Comparison of forces in the steering rods on the drive, engine braking and free-wheeling. Drive through the lowered ground roadside. Speed 50 km/h, Power steering on. Symbols: FL – force measured in the left steering rod, FP – force measured in the right steering rod, MdeltaH – rotation torque on the driving wheel

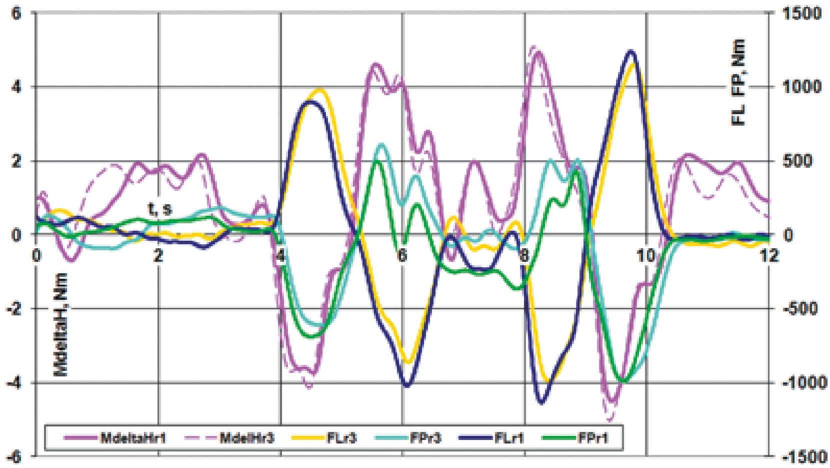


Fig. 6. Comparison of forces in the steering rods at two extreme values of the pivot point radius – standard (r1) and maximum (r3). The drive through the roadside at a speed of 50 km/h and the switched on supporting device. FLr1, FPr1 – forces in rods with Mdel-taHr1, MdeltaHr2 – rotation torque on the driving wheel with the maximum pivot point radius, FLr3, PFr3 – forces in rods with MdeltaHr3

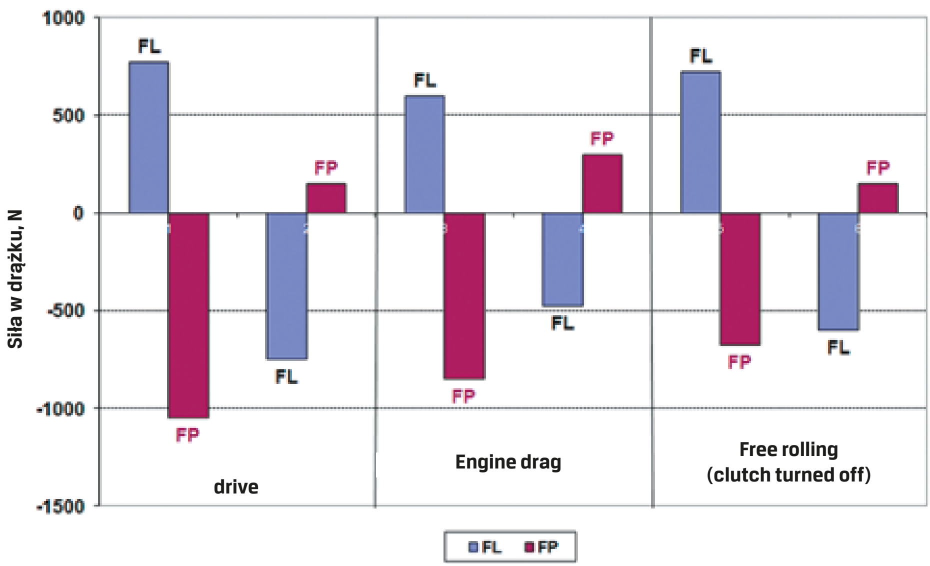


Fig. 7. Forces in the steering rods at various workloads of the tangential forces of front wheels of the car. FDL – force in the left rod, FDP – force in the right rod

As it results from Fig. 5, the diversity of forces in the steering rods of the same nature occurs both on the drive and engine braking, as well as during freewheeling. However, the values of these forces are slightly different when returning from the roadside to the roadway, as it is shown in Fig. 7. It is important to take into account the reduction of speed in the last two cases.

3. Analysis of results and proposal of the control algorithm

As a numeric indicator of assessing the change of dynamic parameters while returning from the roadside to the roadway by *the steering effort E*, defined by F.O. Jaksch [5,8], as the product of the gradient torque on the steering wheel and the angle of rotation of the steering wheel, in relation to the lateral acceleration; $a_{yN} = a_y/g$ (g – gravitational acceleration):

$$E = \left| \frac{\partial M_{\delta H}}{\partial a_{yN}} \frac{\partial \delta_H}{\partial a_{yN}} \right| [Nm.rad] \qquad (1)$$

Table 1 listed the amounts necessary to calculate the steering effort while returning from the ground surface to the concrete roadway (the values of parameters were read in the moment marked in the figures with the dotted line.

Table 1. List of parameters characterising the movement for drives by registration of Fig. 3 and 4

Characteristing parameter	Power steering	
	Off (Fig. 3)	On (Fig. 4)
$M_{\delta H}$, Nm	37.3	16.2
δ_H, deg	-76.8	-85.7
a_y, m/s^2	1.1	1.84
Fdl, daN	-50.6	-87.8
Fdp, daN	27.0	21.3
$M\delta_H/a_{yN}$, Nm	332.6	86.4
δ_H/a_{yN}, rad	11.95	7.97
E Nm•rad	3975	688.4

The comparison of the respective E values of Table 1 shows that while the power steering is on, the steering effort is 80% lower than when it is off. The power steering fulfilled its role by reducing the driver's effort. It is not beneficial in the case discussed in Chapter 1 of this paper – the return to the roadway is facilitated by the power steering. It occurs that the car recovers the adhesion under the right side wheels and it can pull over to the left side of the roadway. In case of other motion parameters – switching on the power steering did not have any significant impact. It is very apparent, because the forces in the rods are dependent on the surface and the driving technique, and they do not depend on switching on or switching off the supporting device.

One of the possible control parameters in the control algorithm of the power steering can include lateral acceleration of the car a_y and the difference of forces in the steering rods ΔF, which is defined by the formula:

$$\Delta F = |(|F_{dl}|-|F_{dp}|)| \quad [\mathrm{N}] \tag{2}$$

where F_{dl} and F_{dp} are the forces measured in the respective rods.

The controller programming algorithm is shown in Fig. 8.

Alternative parameters can constitute derivatives of changes of forces in the rods at the deliberately extended sampling period. This procedure can detect these changes of forces that are long-term ones – neglect short-term changes that occur regardless of the surface on which the wheel rolls. Such trials were conducted.

In order to perform the control of the supporting device of the steering system, the car should be equipped with an additional lateral acceleration transducer. It is also necessary

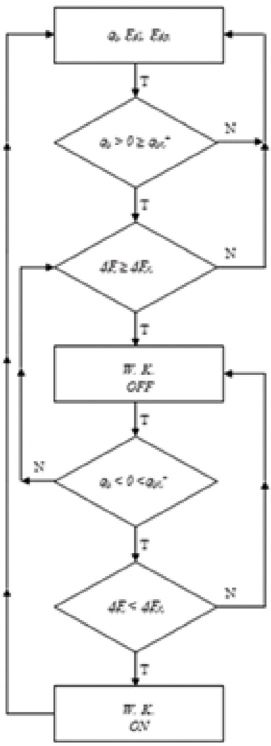


Fig. 8. Block diagram of the power steering controller. ΔF= |(|F_{dl}|-|F_{dp}|)|, index r ap-plies to the reference values, ay - lateral acceleration, ayr+ - reference value of the lateral acceleration while pulling over to the roadside (right turn – lateral acceleration sign "+'", in the block diagram $a_y>0$), a_{yr}- - reference value of the lateral acceleration while returning to the roadway (left turn – lateral acceleration sign "-"– in the block diagram $a_y<0$), W.K. (power steering) – power steering, OFF – turned off (power steering), ON – turned on (power steering)

to determine the reference quantities a_{yr} for the lateral acceleration and ΔF_r for the difference of forces in the steering rods.

Reference quantities should be chosen experimentally for a particular vehicle model. The main objective of the respective reference is to reduce the power steering, and at the same time – as it results from the above graphs – to increase the torque which should be applied to the steering wheel in order to return to the roadway. The small torque applied to the steering wheel, which facilitates the return to the roadway, was at risk of the described in Chapter 1 of the article loss of stability that results from the recovery of the four-wheeled adhesion with the greatly turned wheels.

4. Conclusions

The conducted experimental studies show that:

- During asymmetrical pulling over to the roadside with the right side wheels of the car, the considerable diversity of forces in the steering rods occurs. The reason for this is mainly different wheel adhesion and varied rolling resistance.
- The roadsides, lowered in relation to the plane of the roadway, resulted in additional forces in the left steering rod at the time of pulling over to the roadside and the return from the roadside to the roadway. In these situations, the power steering which facilitates the return to the roadway is not desirable. The sudden easy return at the reduced by approx. 80% steering effort generated the danger of the loss of stability on the adhesive and smooth roadway. Such phenomena known as edge drop-off are recognised in the literature as being particularly dangerous.
- In the car with the front-wheel drive, forces in the steering rods of the same nature occur both on the drive and engine braking, as well as during freewheeling. However, the values of these forces are slightly different when returning from the roadside to the roadway.
- There was no significant impact of the pivot point radius on the force values in the steering rods, which contributes to the value of the supporting torque on the steering wheel.
- The introduction of continuous measurement of forces in the steering rods and the use of such information, after relating them to the reference quantities, to control the level of the power steering, appears to be reasonable.

References

[1] Kleczkowski A., Kuranowski A.: *Ujemny promień zataczania a stateczność i kierowalność samochodu.* Analiza teoretyczna. Technika Motoryzacyjna 5/79.

[2] Kuranowski A.: *Wpływ parametrów zmiennego wymuszenia wejściowego na charakterystyki elektrycznego urządzenia wspomagającego układ kierowniczy*. VIII Międzynarodowa Konferencja Naukowo–Techniczna. "Problemy Bezpieczeństwa w Pojazdach Samochodowych. Wyd. Polit. Świętokrzyska, Kielce 2012, pp. 175-187.

[3] Kuranowski A.: *Effect of the Variable Input Function Parameters on the Characteristics of an Electric Power Steering System,* monografia: "Automotive Safety Problems", Vol. 1. Wyd. Polit. Święt. Kielce 2012, pp. 53-61.

[4] Kuranowski A.: *Effect of Variable Input and Output on the Characteristics of a Steering System with EPS (Electric Power System)*, Journal of KONES Powertrain and Transport, Vol. 19 No. 1, European Science Society of Powertrain and Transport Publication, Warsaw 2012, s. 215-226.

[5] Jaksch F.O., *Driver- Vehicle Interaction with Respect to Steering Controllability,*SAE Technical Paper 790740, 1970.

[6] Лукин П. П. *Конструрирование и ращёт автомобиля Машиностроение*, Москва, 1984.

[7] Mitschke M.: *Dynamika samochodu.* WKiŁ Warszawa 1977.

[8] Nogowczyk P. *Kształtowanie charakterystyk układu kierowniczego, przy wykorzystaniu przyspieszenia poprzecznego pojazdu*, Praca doktorska, Kraków 2009.

[9] Janczur R., Kurakowski A., Nogowczyk P., Pieniążek W. *Siły w drążkach kierowniczych przy zmianie nawierzchni i zmianie wybranych parametrów zawieszenia.* Badania eksperymentalne

The work was performed within the framework of the research project funded by the National Science Centre No. N509 517640 „*Kształtowanie charakterystyk urządzeń wspo-magających kierownicę dla poprawy bezpieczeństwa czynnego samochodu*" (Shaping the characteristics of the steering wheel supporting devices to improve safety of the active car).