Modern active and passive safety systems in cars – chosen aspects

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Abstract

This article presents chosen aspects connected with road traffic safety. The basic aspects have been covered: active safety connected with the development of motor technology, driving systems and systems aiding the driver's skills, e.g. ABS, EBD, ASR, ACC, CAS. Chosen elements of passive systems have also been presented in this article, e.g. seat belts, cushions, deformation zones, other protective configurations. The article also encompasses figures and pictures, which graphically illustrate the presented issue.

Key words: road traffic safety, active safety, passive safety.

Introduction

Road traffic safety and its safe design are currently one of the most important problems of motorization. The aim of the contemporary road safety research is preventing accidents or reducing their effects. In this case, the most important issues are ***active safety*** (preventing accidents) and ***passive safety*** (reducing the effects of accidents). In 2011 [2,9], drivers have caused 32.188 accidents (80.3 % of the total), in which 2841 people (67.8 % of the total) have died and 41.803 have been injured (84.4 % of the total). Pedestrians have caused 4.377 accidents (10.9 % of the total), 754 people have died (18 % of the total who died) and 3.718 people have been injured (7.5 % of the whole).

The most important areas, in which control and profilactic activities have been organized and carried out in Poland by the police, are in particular:

- adhering to speed limits,
- adhering to the ban on driving vehicles under the influence of alcohol or substances with similar effects to alcohol,
- adhering by pedestrians and bicycle users to the rules of road traffic and executing proper relations between them and the people driving vehicles,
- using passive safety devices by the drivers and the passengers (seat belts and devices for safe carriage of children),
- education about communication.

The article presents the chosen systems enhancing safety elements, both concerning active and passive safety. A characteristic feature of currently used automated and electronical safety systems is the possibility of collecting data about the vehicle's state of motion, of processing this data, and subsequently generating signals warning the driver about a potential threat, or even to conduct preventative activities by this system itself, and sometimes even taking over the steering of the vehicle [15]. The development of electronics and the technologies connected with it has cause the fact that highly advanced data processing technologies may be used on a mass scale as standard vehicle equipment. The effectiveness of newer solutions and their influence on improving safety on the global scale will be possible to assess after a few years.

1. The main elements influencing the safety level

The main elements that can be considered as influencing the process of improving active safety are:

- optimal usage of the traction,
- accelerating the time of the driver-vehicle system reaction time as far as the changes on the road are concerned,
- increasing the number or size of data for the driver about the vehicle's motion state and its surroundings.

The possibilities of a human being as an element realizing the steering in the driver-vehicle-surroundings system are limited, mainly due to the possibilities of the human organism. Thus, the struggle to support the human activities by various automatic-electronical safety systems, collecting data about the vehicle's motion, analyzing it, identifying the threats and, when the need arises, warning the driver or correcting his errors.

1.1. The optimization of using the wheel traction

Driving a car occurs thanks to the tangential forces occurring between the wheels and the surface [13]. The scale of these forces that is possible to be used depends on the vertical wheel load and the surface traction characterized by the surface traction coefficient μ_m. The dependency between the maximum figures of the longitudinal forces F_x and the lateral forces F_y, and the vertical wheel load F_z can be presented by approximating the surface in a conical shape (fig. 1). The cuts of this surface given for various scales of the vertical force F_z give an image with the dependency:

$$\sqrt{F_x^2 + F_y^2} \leq \mu_m F_z \qquad (1)$$

The optimal conditions for supplying tangential forces will occur when the traction of all wheels will be used to a similar degree (fig. 2). In a traditional car construction, the drive is transferred from the engine to the wheels via shafts and differential gears, ensuring a stable drive force division between the individual wheels. Steering of the driving direction takes place due to the steering linkage binding the wheels strictly together. The braking systems that are used ensure the same

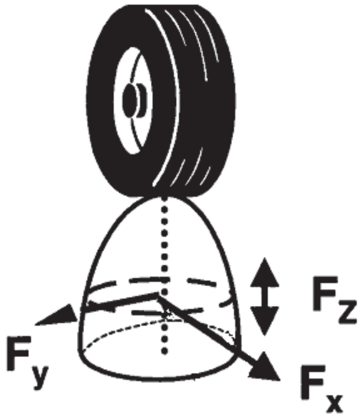

Fig. 1. The dependency between the tangential forces F_x and F_y and the vertical force F_z

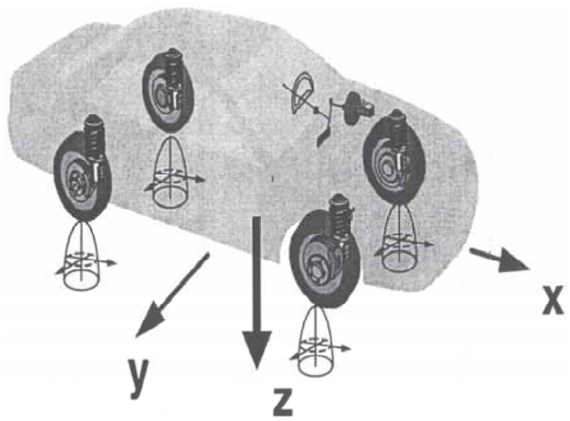

Fig. 2. Usage of traction of the individual wheels in a car [14]

braking force of the left and right wheel on the given axis, and the division of braking forces between the axis by the sensors working on a mechanical basis. Because the vertical wheel loads may change, such a traditional car construction does not allow for optimal using of the traction of all wheels.

The optimal traction usage may be achieved when fluently regulating the tangential forces depending on the current vertical wheel load for each of the wheels. In practice, this means, that each of the wheels should be driven, braked and steered individually, and an appropriate usage of the tangential forces and lateral forces steered by central electronic steering system should be achieved. Such a solution, although technically possible, is still not used in practice yet. In contemporary cars, more and more often there are visible devices which modify the functioning of traditional car mechanisms in such a way as to improve the traction usage and at the same time prevent losing the driving stability. Among such solutions are well-known systems which are present on the motor market for some time now:

- ***the system preventing wheel blockage when braking*** (so-called **ABS**). This system distributes the braking force in such a way as to maximally use the traction by keeping the circumferential within the limit of maximal slipping with respect to the vehicle's speed [1,9,12],
- ***the system of electronic brakeforce distribution*** (so--called **EBD**), which has the task of distributing the braking force to a varying degree on both axes depending on how strong the brake is pressed, on the vehicle speed and the road conditions in order to improve braking efficiency [1,9,12],
- ***the traction control system*** *by the drive* (so-called **ASR** or **TCS**). This system regulates the drive force in such a way as to maximally use the traction of the drive wheels, limiting the skidding in rapid acceleration by influencing the engine feeding and the braking system [1,9,12],
- ***a system known as the electronic stability program*** (so-called **ESP**) improving stability when driving through a turn by appropriately dosing (depending on the car's angular speed, lateral acceleration, wheel skidding) drive forces and the braking forces [5, 9], an example has been presented in (fig. 3).
- t***he system steering the braking force*** (so-called **EBV** or **AFU**) electronically steering the braking force due to increasing the brake fluid in the case of rapid braking, when it "presses" the break instead of the driver [1,9,12],
- t***he electronic differential lock*** (so-called **EDS**) allows for safe car start, when one of the wheels is on a surface with a different grip than the other one [1,5,8],
- ***the system regulating the steering system support force*** (so-called **DAV**) works depending on the driving speed, the bigger the speed, the smaller the assistance force and vice versa [1,5,9,12].

2. Shortening the reaction time of the driver-vehicle system

The so-called BAS (Break Assist System) can be enumerated as an example of a system which may enable the shortening of the driver-vehicle reaction time as concerning road risks [13]. The rule concerning the functioning of this system relies on identifying a situation of alarm braking up to the traction border, and subsequently to increasing the braking force, in practice up to the level set by the ABS system functioning. An important issue here is the identification of the risk condition; diversifying panic braking from the normal process of braking.

In practice, the signal on the basis of which the steering unit identifies such a situation is the speed of pressure increase of the braking system or the speed of the movement of the membrane of the vacuum servo power unit. The main

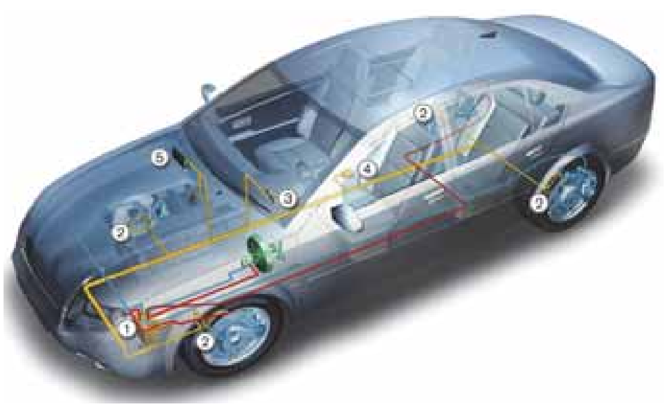

Fig. 3. The elements of an ESP system by Bosch: 1. the hydraulic unit, 2. wheel speed sensors, 3. steering angle sensor, 4. car swerve and acceleration sensor, 5. engine steering processor [1]

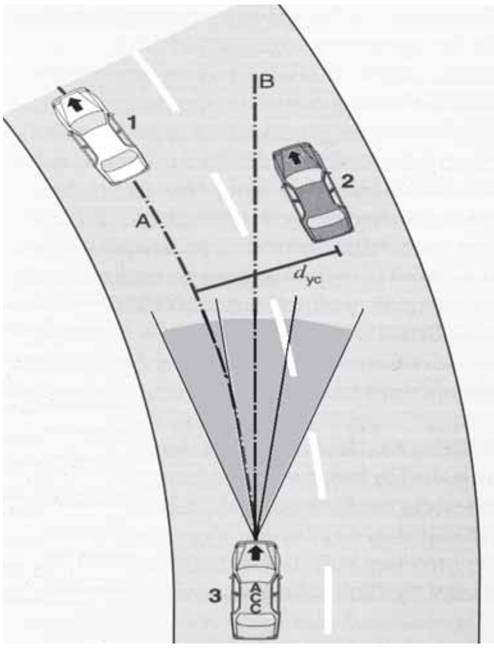

Fig. 4. Motion of a vehicle with the ACC system. The supposed driving track (A) and identifying objects on the collision course (1 or 2). B – vehicle axis, dyc – supposed distance from the vehicle in the adjacent lane [4, 13]

executor here is the vacuum servo power unit, which is set into maximum assistance mode, or, in a more advanced solution, into the ESP system elements.

2.1. Convoy steering systems

Systems maintaining a speed automatically programmed by the driver are known for a long time and they are useful when driving through expressways. However, driving in a convoy with great speed, e.g. through a highway, is connected with a certain type of risk. The drivers in this case usually keep a safe distance from the vehicle driving in front, equal to the road covered in an average reaction time (1...2 s) [8,13]. Such a distance allows to safely stop the vehicles driving in the convoy in case of rapid braking of one of them in average good road conditions and under adequate psycho-physical well-being of all the drivers. Worsening of the road conditions (e.g. fog, sleet) or a prolonged reaction time of any of the drivers may lead to a collision, initiating collisions between the other vehicles, driving in the back, where the drivers are not able to brake because in the changed situation the relatively safe distance turns out to be too small.

A system enabling ***automatic maintaining of a chosen speed and a safe distance*** from the vehicle in front is a system called **ACC** [4]. Usually radar sensors are used here to measure the distance from the preceding vehicle and the relative speed.

Although the ACC system is designed for steering the longitudinal motion of a vehicle on expressways, it should function properly also on turns, which may occur along these roads. This requires precise identification of not only of a given vehicle's state of motion, but also of the preceding vehicles, so that it is possible to choose the one which is driving on the collision course. In order to achieve this, it is necessary to set a supposed driving course for a given vehicle and the preceding vehicles (fig. 4). In order to set its own course, the ACC system uses the signals from the ESP system (longitudinal speed, angular speed, lateral acceleration). Setting the course of other vehicles [4] is possible due to the fact that the radar sensor emits three light beams in directions under a certain angle. This allows not only for measuring the distance and relative speed but also for the measuring of lateral movement, and eventually for choosing the vehicle which is on collision course, according to which the distance and speed should be regulated.

3. Systems warning the driver

The possibility of automatic identification of obstacles on the road may be used in order to warn the driver about a possible collision with another vehicle, pedestrian or an immobile object. ***The systems carrying out the driver warning function*** are called **CAS** (collision avoidance system). They may be particularly useful in preventing collisions in which the rear of the preceding vehicle is hit, where the most common defensive maneuver is braking or braking with an attempt of passing the other vehicle. The basic parameter used in programming the driver warning systems is assumed on the basis of the vehicle's state of motion and the time concerning the period preceding the collision. The threshold value of this time is usually assumed to be equal to 4s. The system sends a warning signal, if the value of this time goes below 4s. As research shows, most drivers in normal conditions start braking earlier [13].

4. Passive safety elements in cars

According to the notes in [17], the duty to use seat belts by all carried passengers who are taking seats equipped with these (apart from persons mentioned in par. 2). This also concerns the persons sitting in the back seats.

4.1. Safety belts

According to the definition within an act concerning car seat belts, i.e. in [10] and in [17]:

A safety belt *is a system of belts with a lock, regulating and fastening elements, able to be put inside a vehicle and used in order to limit the risk of harm to the user during an accident or during rapid slowing of a vehicle by limiting body movement. Such a system is generally termed as "the belt setting". This term also incorporates any device used for taking in energy and rolling the belt band.*

4.2. Construction, aim, limitations

A car safety belt in the European system is a basic device protecting the user and preventing body motion during a road accident. It serves its purpose mainly in head-on collisions or near head-on collisions. It also has a protective function during a car's falling on the roof [6].

The safety belt construction, the used materials, should ensure that a user with a body with the following measurements should be held by the belt:

- user weight 76 kg,
- user height 175 cm,
- vehicle delay during collision: within the range of 28-32 g, occurring in the time period of up to 80 ms.

The first basic limitation to seat belt construction are the ***human biomechanical resistance parameters***. It is possible to construct a seat belt which will prevent body motion under all conditions. However, only the prevention of body

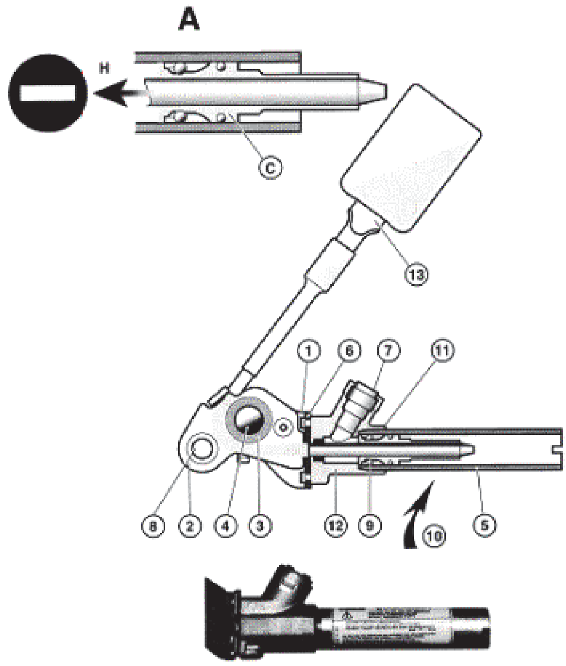

Fig. 5. The construction of a pyrotechnical belt tensioner and the way of blocking the piston after ignition in order to prevent it from reversing: 1 – plate, 2 - support, 3 - reel, 4 – reel rivet, 5 - tube, 6 – fastening bolt, 7 – gas generator, 8 - backing, 9 - beads, 10 – information sticker, 12 – code and production date, 13 – cable and latch [1]

motion, does not mean the chance of surviving. A load on internal organs (brain, heart, lungs) coming from big overloads, may cause death without any visible damage to the body structure.

The second basic limitation in seat belt construction is the so-called ***surviving sphere*** which a deformed construction and the car body are able to provide. This means that the seat belts should not allow for too much body movement of the users towards the front. The basic type of a seat belt is a 3-point lap belt. This type of belt ensures the above-mentioned safety conditions for the user's body.

A seat belt does not allow for directly stopping the user's head from moving. The influence of the head on the neck causes a rapid increase in the influence of the head on the upper parts of the skeleton in the neck part and of the lower neck parts on the spine. This often causes damage to the cord or to the vertebrae – often these are very painful body damage or sometimes even fatal ones.

More car companies are using belt tensioners than self--rolling belt tensioners, thanks to such a solution at the same time the reins and the breast parts and the stomach are protected. Moving the tensioner piston by 50 mm is expressed by a double drawdown of the belt, which will be shortened by 100 mm. The tensioner functioning takes place in the very early phase of the collision before the passengers start to move. The time of initiation is 20 ms counting from the start of the collision.

Material based on cellulose nitrate is used as a solid explosive for pirotechnical belt tensioners. The gas pressure that occurs due to the chemical reaction moves the pistons in the braking tube. The cables attached to the pistons and to the belt clamps move both the clamps downwards, thus casing the belts to tighten and keeping the passengers' bodies as close to the seat and head-rest as possible.

After blasting off the explosive, the string composed of beads (9) (fig. 5), arranged around the cone (C) opposes releasing the cable in the direction shown by the arrow, and so in consequence releasing the belt holding the passenger.

The explosive ignition is confirmed by the lighting of a control on the indicator panel.

4.3. Airbags

In order to prevent the negative influence of overloads on the neck and the occurrence of strong overloads of the head, the ***airbag*** was introduced, the so-called **SRS** (*Supplemental Restraint System*). This name means that in the European protection system, the airbag is a device assisting the protective functioning of the seat belt (fig. 6). According to the definition contained in [11,17]:

An airbag *means a device which is additionally installed, apart from seat belts and from supporting systems in vehicles, which, in the case of a serious vehicle collision, automatically fills the elastic construction, aimed at limiting, by compressing gasses within it, the load of the contact with one or more of the user's body parts with the passenger compartment*.

Statistical research proves that an airbag does indeed fulfill its protective function during collisions with the speeds bigger than 20-25 km/h (the speed of collision with an immobile and a not deformable obstacle). With small collision speeds, which are often observed, an unjustifiable operation of the airbag may cause quite severe face or head injury. The most frequently used airbag classification of airbags are, inter alia, the following types [1,3]:

- ***Passiv-Airbag*** – a complete, modular one, widely used in the West,
- ***Aktiv-Airbag (Eurobag)*** – used as a supplementary one with the seat belts fastened,
- ***Compact systems*** of the SRP, ESME types, air curtains.

The side airbags play an important role in the protection system and in protecting the vehicle user's body. Ensuring proper protection during collateral collision is a particularly difficult task with respect to a limited deformation zone, in which the hit energy may be spread. Thus the particular role of side airbags in the user protection system. The resilient functioning of the seat belt and the airbag may cause, in the final phase of the collision, rapid body movement of the user backwards.

The torso's kinetic energy will be absorbed by the seat support. The head's kinetic energy may be absorbed by the head-rest. In modern car seat constructions, so-called ***active head-rests*** are used, which during the torso's pressing on the seat, move forwards, limiting the distance from the head and the disadvantageous neck twist.

4.4. Devices protecting the carriage of children

A particularly important problem in the carriage of passengers is the appropriate protection of children [6]. This problem is strictly connected with choosing a protective device which is appropriate for the child's body mass.

The following mass groups are used: ***0***, ***0 +***, ***I*** , ***II***, ***III***. In all of the above-mentioned mass groups, seat belts for adults

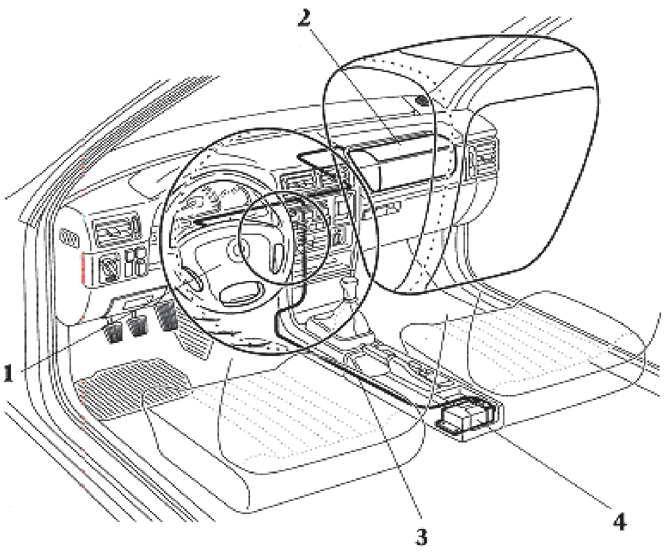

Fig. 6. A typical system with two airbags: 1 – driver's airbag, 2 – passenger's airbag, 3 – bunch of cables, 4 – sensor steering device [6]

are used for holding the protective device protecting the child being inside the car.

In modern cars, a new system of mounting protective devices for children, the so-called Isofix, is used. The baby seat itself has appropriate holders, which are attached to the appropriate 2 or 3 mounting points in the car body. The seat belt is not used then.

5. Systems improving passive safety

The possibility of automatic identification of obstacles on the road also gives a chance to improve the level of passive safety [7,14]. In a situation when, despite undertaking defensive maneuvers, the collision becomes unavoidable, it is possible to undertake actions preparing the car for the expected collision. Improving the protection level of the passengers may depend, inter alia, on:

- setting the seats and the head-rests in an optimal position,
- closing the side and roof windows, or the operation of the protecting devices,
- increasing the seat belt tension, preparing for operating the gas cushions,
- unblocking the door locks,
- constructional usage of the so-called folding steering wheel column,
- cutting off the gas supply,
- construction of the vehicle with a crumple zone (fig. 7) from materials, e.g. of the THLE type.

6. Perspectives on car driving automation

The ACC system [4] may be considered to be a system of automatic car movement steering, though one limited only to carrying out one function, i.e. regulating the driving speed. In order for the automation of the lateral movement to also be possible, it is necessary to provide much more information. Apart from the already carried out functions by the ACC system:

- setting the vehicle position with respect to other road users,
- keeping a safe distance from the preceding vehicle,
- In this case it is also necessary to:
- set the vehicle position with respect to the road (the traffic lane),
- keeping the vehicle in the appropriate lane,
- identifying and avoiding obstacles,
- overtaking the slower moving vehicles,
- identifying the road signs and reacting accordingly to them.

The possible concepts of storing information about the road are considered here:

- providing the roads with systems steering vehicle traffic (e.g. additional ducts), and the vehicles with appropriate communication systems,
- the so-called autonomous drive system in normal roads, of the autopilot type.

The second system is particularly interesting also from the economic-social point of view, because in order to drive it, no changes to the road infrastructure are required, apart from putting appropriate road signs and appropriately placing them.

Signals from radar sensors, e.g. GSP, are currently insufficient for the automatic steering of a vehicle motion. A video camera may provide more information, from which the video is digitally processed, or in the system of satellite navigation, e.g. of the Carminat type [13].

Conclusion

The theoretically developed and introduced into realization research programs [14], will ultimately lead to a considerable development in the systems of automatic car motion steering. These systems will initially relieve the driver of some functions when driving a car, and in the more distant future will be able to fully substitute the driver, which will be a factor increasing road safety level and will improve the traffic fluctuation.

Apart from identifying the vehicle position and road conditions, an automatic steering system has to substitute the driver in planning and in making decisions. The condition for carrying out all of the above is the integration of all the information fragments in a complete view of the vehicle motion and its surroundings. This will be possible after integrating the steering systems with individual part of the car into one central steering system.

The system of measuring the distance from the preceding vehicle may warn the driver if the distance is smaller than the safe distance. Similarly, the possibility of recognizing the lines, marking the lanes, allowed for developing a system of warning about the risk swerving from the driving lane.

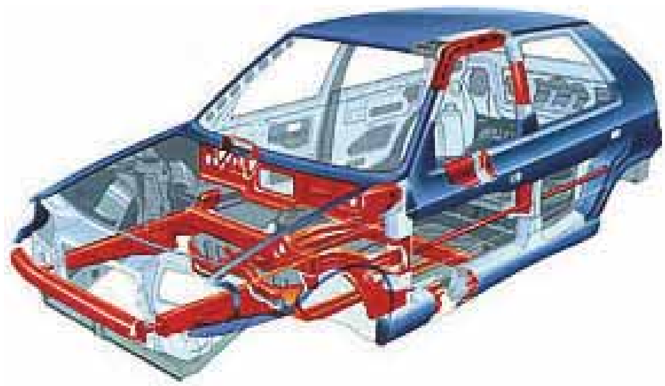

Fig. 7. Framework and side door reinforcement [1]

Using the solutions presented in this work in cars with standard equipment, having the main goal of improving road traffic safety, as well as aiding the driver, has many advantages causing, inter alia:

- shortening the braking distance and shortening the driver's reaction time,
- increasing the stability during braking,
- better usage of wheel traction thanks to optimizing the braking strength,
- braking force adjustments concerning the car and the wagon or the semi-trailer,
- prolongation of the endurance of the individual frictional elements of the braking system,
- improving the driving comfort and car steering,
- lowering the car's weight,
- being the basis for improving the other systems, such as the engine steering system, steering system assistance, the autopilot system,

cooperation with satellite navigation systems.

In the costly research and practical applications of solutions of this type, the leading role is played by high-profile vehicle manufacturers from countries such as: Germany, France, Sweden, England, USA, Japan, Korea. Cars with devices of this type can also be frequently found in Poland, and their majority is purchased/brought from the so-called secondary market.

Bibliography

1. *Archive – the author's own materials and pictures.*
2. *Information newsletter*. V Conference of road safety preventive measures of armed forces vehicles. Koszalin, 2012. CD.
3. Auto motor technology no 6/1996.
4. Bosch R. Gmbh., *Adaptive fahrgeschwindigkeitsregelung ACC*. Stuttgart, 2002.
5. Bosch R. Gmbh., *The Electronic Stability Program ESP*. WKiŁ, Warsaw, 2000.
6. Diupero T., *Using seat belts and other safety means by the driver and the passenger*. Information Newsletter from the IV Conference of road safety of mechanical vehicles of land forces. Grudziądz, 2005.
7. Koichi Fujita et al., *Development of pre-crash safety system*. 18th International Technical Conference on the Enhanced Safety of Vehicles. Nagoya 2003.
8. Mitschke M., *Car dynamics – vol. 1. Steering and braking*. Warsaw 1987.
9. The report of the Polish Police Headquarters for the year 2011.
10. The UN ECE regulations no 16.
11. The UN ECE regulations no 94.
12. Reński A., *Modeling of the driver's actions in the driver--vehicle-surroundings system*. The Research of the Warsaw Technical University. Mechanics. Issue no 184. Warsaw, 2000.
13. Reński A., *Electronic systems of active safety in cars*. Information Newsletter from the IVConference of road safety of mechanical vehicles of land forces. Grudziądz, 2005.
14. Schöneburg R., Baumann K.-H., Justen R., *Pre-safe – the next step in the enhancement of vehicle safety*. 18th International Technical Conference on the Enhanced Safety ofVehicles. Nagoya, 2003.
15. Stańczyk I. T., *Systems of aiding the driver's work. Works of the Vehicle Institute*. Issueno 3 (29) 1998.
16. Szczepaniak C., *The basics of modeling of the human--vehicle surroundings system*. Wydawnictwo Naukowe PWN, Warsaw, 1999.
17. The act from 20 June 1997 (with further amendments). *The traffic code*.

Nowoczesne systemy bezpieczeństwa czynnego i biernego w samochodach – wybrane aspekty

Streszczenie

W artykule przedstawiono wybrane aspekty związane z bezpieczeństwem ruchu drogowego. Omówiono podstawowe aspekty: bezpieczeństwa czynnego związane z rozwojem techniki motoryzacyjnej, systemy kierowania i wspomagania umiejętności kierowcy np. ABS, EBD, ASR, ACC, CAS. Przedstawiono także elementy systemów biernych np. pasy bezpieczeństwa, poduszki, strefy zgniotu, inne układy zabezpieczające. W skład artykułu wchodzą schematy i zdjęcia, które ilustrują graficznie przedstawione zagadnienie.

Słowa kluczowe: bezpieczeństwo ruchu drogowego, bezpieczeństwo czynne, bezpieczeństwo bierne.

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