Intelligent systems of the vehicles’ suspension

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Abstract. The article is devoted to the current condition of car’s active suspension system. It presents the tendencies in development of the active systems of suspension system, adjustable elements incorporated in them and the companies succeeded in designing such systems. It also mirrors the problem of impact of active systems on car’s safety and their importance for the driver. Advantages and disadvantages of the most common types of active elements are being described, analyzed and compared. The author concludes about the perspectives of these systems’ development.

1. Current level of car’s active systems. The essence of active systems of suspension system for the driver

The modern system of car design has improved strongly since the last 25 years. The most car parts are equipped with individual control systems, behavior algorithms and active actuators. The systems can decide themselves on changing widely the components’ properties improving their efficiency, safety and comfort of a car.

From the technical point of view the most significant development occurred in chassis system, transmission, engine and systems of active security. But for the driver or passenger car’s comfort, stability and handling remain the most important characteristics. Thus one of the key aspects during the implementation of a car active system is its’ influence on the mentioned characteristics. From this point of view the work of suspension system is important for driver’s comfort, his or her tiredness and control over the vehicle. This is the essence of active suspension system as a driver assistant system.

Strong vibrations that affect passengers in cars with badly adjusted suspension lead to quick driver’s tiredness and shortens the working time. The same is true to the control over the vehicle. Such chassis’ disadvantage as enlarged dynamic corridors makes driver stay highly concentrated and constantly correct the path during driving. Meanwhile even well adjusted suspension not always can solve the problem of driver’s tiredness because any chassis’ passive adjustment is a compromise between stability, control and driving comfort. Thus at some driving regimes this compromise can provoke some negative effects in car’s behavior and driver’s perception. Similar situations can occur in different states of a car. For example the suspension system is usually adjusted for a situation when a car carries two passengers (or even one) and a small amount of baggage. But if the car drives with full load (five passengers and baggage) all elements of suspension system work under high load beyond their well-balanced characteristics. There also exists a possibility of accumulating of usage of suspension system elements’ (such as shock absorber, bushing and spring). In case when usage of these elements doesn’t affect the vehicle’s safety such situation is considered to be acceptable but characteristics of stability, control and driving comfort will be significantly worse than the same
characteristics of a new car. In this situation the tiredness of the passengers will be higher, the driver’s control over the vehicle will decrease regardless the basic chassis adjustment. All these problems can be solved by using modern active suspension systems that not only adopt the system’s characteristics to the usage conditions but also can compensate for some elements’ usage from the point of view of their effect on chassis’ work. Thus modern intellectual systems of car suspension provide the driver with significant assistance in driving a vehicle.

2. The suspension system’s configuration
The suspension system includes: springs, damping elements, control arms and stabilizing system (mostly – a torsion bar that connects the car’s body with the wheels of the opposite side). It is called a stabilizer bar and acts as an extra spring element of suspension. In car industry automatic control systems are used in all basic suspension’s components. In this case different technological methods are used to change component’s characteristics. These methods have different types of control input and ways of effecting the suspension’s characteristics

3. Adjustable spring elements of the suspension
Spring elements were the first suspension parts to become an active system. Springs were replaced with air springs that let change the road clearance and stiffness depending on the car’s load. The initial systems were regulated via the switch situated in the cabin, later they received special self-operating algorithms and a control program. The example of pneumatic suspension on figure 1.

![Figure 1. Example of pneumatic suspension.](image)

Besides adjustable road clearance pneumatic suspension has such advantages as progressive performance rate and stiffness’ automatic change in dependence on the load. Modern pneumatic suspension resists roll and shifts flexibility from soft to stiff regime. In case of changing road clearance it happens by adding or removing of gas in pneumatic element but in this case valves open additional gas volumes. Suspension stiffness declines when the gas cylinder enlarges under unchanged pressure and increases when its’ volume is reduced (figure 2).
Gas cylinders separating valve actuates in few milliseconds and in case of determination of car’s angular motion the system can reduce the pneumatic element’s volume and increase the roll stiffness of the suspension. After the effect of heeling force is over the volume returns into initial position in accordance with lesser stiffness to decrease vibrations that affect passengers. This construction is used by Porsche and Mercedes (figure 3 [2]). Continental is acknowledged to be the world’s leader of it’s production.

Except pneumatic elements car industry used hydraulic spring elements that compress liquid while working. It becomes possible by putting in a cylinder containing liquid a special needle that fills some volume and makes liquid compress. Such constructions have two crucial disadvantages: overheating and unreliability of seals. These problems don’t let produce constructions satisfying modern requirements to cars’ lifetime.

One should also mention electromagnetic elastic elements of a suspension. Rather popular is their concept worked out by BOSE (famous by its’ sound systems). The company used its’ experience in
producing sound systems in suspension by replacing standard springs and damping elements with magnet coils – linearly electric engines that replace not only elastic elements but also damping ones (general view of the construction – on figure 4). The published video demonstrates exceptional properties of the system. It lets keep the car stable regardless of a maneuver and the road quality and implement a number of special functions. For example, the car can overcome such obstacles like a curb. A car jumps its over by throwing itself up, lifting the wheels before the obstacle and dropping them right after it. The car undergoes incommensurable lesser acceleration than during a run over an obstacle.

![Figure 4](image-url)

**Figure 4.** Construction of electromagnetic elastic elements of a suspension by BOSE.

The system was introduced 15 years ago but serial production didn’t start. The reason was in expensiveness of the system, it’s big weight and enormous power consumption. Nevertheless the technology seems to be rather promising and serial production can be started after solving the problem of car’s power equipment.

Modern technologies used in spring elements advance car’s consumer properties significantly. Pneumatic suspension reduce vibrations that affect passengers and improve ride comfort. Anti-roll system and electromagnetic suspension form systems of driver’s active assistance and let pass problematic roads with low-quality surface without driver being tired.

### 4. Adjustable damping elements of suspension

The first after elastic elements damping elements were automatized. Their function is to damper vibrations of a car’s body and unsprung mass but it often contradicts maintaining comfort or car’s stability so it needs very careful setting. Characteristics of passive damper must correspond with certain frequency and load regimes that shift during driving. But controlled dampers have a range for regulation and an algorithm for its’ automatic implementation what lets to fit the driving situation.

There are two main technologies to change damper’s characteristics: adjustable valve with controlled orifice (figure 5) and a system with fixed orifice and controlled liquid viscosity.
Figure 5. SACHS’ dampers with controlled orifice.

The second type mostly uses magnetorheological liquid that changes its’ viscosity under influence of electromagnetic field by orientation of diffused metal inclusions (figure 6) or electrorheological effect [3,4] when strong electric field is created near orifice valve and makes particles of special oils polarize and enhance viscosity. Electrorheological systems are rather promising but as electromagnetic suspension need more power than modern cars can provide.

Figure 6. Damper with magnetorheological liquid.

In spite of existing difficulties in using damping technologies modern car industry succeeds in these systems’ integration and has no problems with controlling their properties. Regular damper characteristic (force-piston’s speed graph) usually look as it is shown on figure 7A and modern dampers with controlled orifice let change it in dynamics almost in any direction (as shown on figure 7B).
Figure 7. Damper characteristics.

The received characteristic is shown on figure 7C. The characteristic can take any position between boundary curves under different control current. As shown on figure 7C, dampers with controlled orifice have adjustment limits under low speed of a piston. In case of using magnetorheological liquid any characteristic can be received (as shown on figure 7D) because it doesn’t have such problems. Disadvantages of these dampers are expensive liquid and problems while working at low temperatures.

The aim of damping elements as driver assistant system is eliminating vibrations that harm passengers. Damping systems with advanced programmable algorithms make car body almost immovable on a regular road. But in reality it is more comfortable for passengers to feel car body’s moving than to drive in a motionless capsule. Thus modern systems keep frequency of comfortable 1-1.2 Hz and perspective damping systems (such as electrological dampers and electromagnetic suspension) make car body’s behavior comfortable for any driver.

5. Adjustable systems of car’s roll stabilization

The first after damping adjustment being integrated tendencies shifted towards automatization of car’s roll stabilization systems. Passive roll stabilizer looked like a beam joining car body with wheels on one axle. The stabilizer tried to “untwist itself” in initial state by putting wheels on one axle and car body in zero roll. Stabilizer increases roll stiffness of suspension provided by elastic elements but excessive stiffness leads to losing road traction of one of the wheels what reduces car’s stability and passing ability on smooth surface. Thus the first phase of damper automatization led to usage of clutch on twisted beam (figure 8). It let switch stabilizer on on asphalt road and switch off in tough road situations. Later clutch received an electric motor (figure 9) that could not only cut stabilizer’s stiffness but also boost it by making an extra torque. Schaeffler possess most developed systems but still doesn’t use them on cars with gross weight more than 3 tons.
Figure 8. Stabilizer bar with brake clutch.

Figure 9. Stabilizer bar with electric motor by Schaeffler.

There is a special type of roll stabilization called “system of dampers’ interconnection” that divides the force between suspensions to reduce car body’s roll. Sometimes such systems get extra actuators that generate additional force that tries to compress and decompress the suspension. Tenneco uses such systems (figure 10).

Figure 10. Roll stabilization system by Tenneco [2].
6. **Adjustable systems of suspension arms**

Suspension arms is very difficult to automatize because it has very strict safety and reliability requirements, it undergoes high load and has low characteristics elasticity in area of car’s stability. Nevertheless stock cars’ suspension arms already have active systems. As an example – steering back axle of the latest versions of Audi Q7 (figure 11).

![Figure 11. Audi Q7 rear suspension with steering system.](image)

By using extra actuator on rear suspension the car could change automatically rear wheel slip angle during driving. Earlier rear steering axle was used in BMW 7 Series but in exploitation it turned out to be less reliable what with high price didn’t let the car gain popularity. Moreover modern systems of suspension design let produce elastokinematic suspension schemes that provide high stability and handling properties without using steering axle.

Steering systems are often used in long wheelbase cars to reduce turning radius. But using these systems on high speed can lead to lack of stability. That is why the companies use elements of blocking rear wheels’ neutral position that have strict precision and possible free play requirements.

7. **Prospects of development of active suspension systems in Russia and in the world**

Adjusted suspension systems underwent two active phases of introduction into mass production. The first phase is implementation of pneumatic suspension, the second phase – mass implementation of adjusted dampers. Now one can define the third phase – mass implementation of systems of roll stabilization and systems of high intelligent suspension system control.

Russia is traditionally called a country of military technologies. That is why reliability is more important than comfort. In practice car producers have to pay attention also to suspension adjustment to reduce strong vibrations that affect drivers during long marches. Some cars gained special systems but they turned out to be too expensive for civil technologies. This experience let create basic industries for such technologies and develop specialist’s experience to work with them. Today the leading project in designing active suspension systems is UMP, the NAMI’s project aimed at creating luxurious cars for country leaders.

In general modern intellectual systems let seriously boost quality of car’s transport functions by using suspension systems. It improved quality of passenger transportation, cargo’s safety and reduced driver’s tiredness. Even function of dampers’ hard mode implementation reduces rolling speed by 11% [5]. This could be checked by ADAMS model connected with Simulink model, where the vehicle behavior simulated in ADAMS environments, but the control system of damper described in Matlab Simulink program. In such soft ware could be prepared a program which changes the damper resistance from “soft” to “hard” mode according lateral acceleration. The increased resistance usually simulated by additional damper force sent to each damper. The appeared force presented on figure 12 [5].
The result lateral speed decreasing could be seen on figure 13. Presented graphs show the difference between controlled dampers and passive (not controlled dampers) [5].

Worldwide the quality of car’s behavior is estimated on the basis of a spider graph with ray coming from the center of the diagram and showing the score. The lower the score the closer to the center it stands (and worse it is). The score improves by 1.5-2 points after using intellectual suspension systems on adjusted chassis. Thus the usage of intellectual systems will inevitably continue and in the future their work will let eliminate harmful vibrations affecting passengers.
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