Advances in Active Suspension System

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Abstract: Suspension systems are now one of the inevitable sections in the automotive industry which are accountable for the ride safety and comfort and progressive research and development in this field seems unremitting. This paper bullseye the active suspension systems of an automobile. It addresses how active suspensions overthrow the conventional passive suspensions and its advancement for practical implementations. It focusses on the need, concept and current trends of the active suspension system. This is a study which encompasses the growth of active suspension, enunciating the best available choices of actuators and control methods in these suspensions and directing towards the possibilities of further improvements.

***IndexTerms* – Active suspension system, passive suspension system, actuators and control methods.**

I. INTRODUCTION

The suspension system of an automobile connects the vehicle's body to their wheels in a way which allows relative motion between them and minimises road shocks and vibrations which would otherwise be transferred to the chassis. The two principal objectives of the suspension system are to provide comfortable rides and to keep the contact between the road and the tires firm ensuring good handling performance that means drive safety.

Until the technology of active suspension came, the vehicle's suspension system acted on the mercy of the road profile. Active suspension system ascendance the vertical movement of the wheels relative to the chassis, keeping the tires' contact patch as maximum as possible and allowing better traction and control.

The motivation for this paper is to understand the state-of-the-art in active suspension control mechanisms and approaches, so as to give an overview of current trends and an indication of future directions in research and development.

II. ACTIVE SUSPENSION

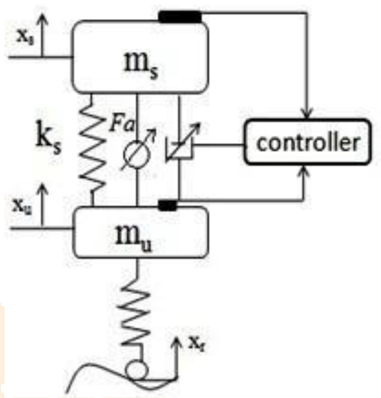
An active suspension reckons the skyhook theory, i.e., to have the vehicle maintain a stable posture as if suspended by an imaginary hook in the sky, unaffected by the road conditions. The imaginary line (of zero vertical acceleration) is calculated based on the value provided by an acceleration sensor installed on the top of the vehicle. Since, the dynamic elements are only made up of the linear damper, no complicated calculations are necessary. The active suspension incorporates an actuator that furnishes active force, which is synchronized by a control algorithm using data from sensors attached to the vehicle as explain in Figure 1.

Spring holds the static load of sprung mass and actuator supply the needed reactive force to lessen or assimilate deflection caused by surface irregularities. If the active actuator works mechanically in parallel with the spring, it belongs to the high-bandwidth active suspension controlling both the sprung mass and the un-sprung mass. If the active actuator works mechanically in series with the spring and the damper, it is the low-bandwidth active suspension controlling the sprung mass. The required bandwidth decides the cost of active suspension. A limited bandwidth active suspension costs lesser. There is a frequency domain where human beings are most sensitive to vibration, which is called "human sensitivity band". 4-8 Hz is the human endurance limit of frequency band to vertical acceleration, thus for improving the ride comfort, acceleration gain characteristic in this range is given more attention. Due to the distribution of this actuated force, active suspensions do not let the chassis experience a thing.

Different control algorithms (PID, Adaptive, Robust) are to be used control the action of actuators. Depending upon type of actuators used active suspension system is named. Active suspensions commercially implemented in automobiles today are based on the hydraulic or pneumatic one. Actuator parallel with spring is high bandwidth and in series is low bandwidth active suspension system. Active force in active suspension gives active body control in this high damping with best ride control is obtained. Active suspension labours by continuously sensing changes in the road surface and passing on that information, via the ECU, to the outlying components. These components then modify the characters like adjusting shock stiffness and spring rate. To improve ride performance, drivability and responsiveness, the ECU collects, analyses and interprets the data in every 10 milliseconds. They are substituting the spring and damper system entertained in the vehicles with linear electromagnetic motors controlled by microprocessors and special mathematical equations. In this way, they can do away with the compromises and shortfalls of the old damped harmonic oscillator system. No more compromises between handling and comfort; it's soft when you need it and hard when you need it.

Low bandwidth active systems are characterized generally by an electrical linear motor or a hydraulic cylinder installed in the system to generate forces independently, bandwidth approximately being 5 Hz. When their bandwidths are exceeded, they tend to become stiff. The energy consumption of the system is in the range of 1–5 kW. In High bandwidth active systems, the passive damping element can be substituted by an actuator with a bandwidth of 20 Hz or more. The main drawback of fully active suspension systems is high energy consumption, typically in the range of 4–20 kW. Adaptive suspension systems comprise of slowly varying spring and damper characteristics, where this variation depends on vehicle velocity. Lowering the center of gravity of the vehicle provides a better sporty road holding capability. This type of suspension has been incorporated in the Porsche Panamera (2009 model) via the use of airsprings. In 1989, Citroen presented the hydractive suspension which offers slow adjustment between different airspring characteristics and adjustable discrete settings for the damper characteristics. The power consumption depends mainly on the energy wanted to vary the spring stiffness. Level control systems are used for compensating various loading levels. These systems operate quasi-statically and autonomously to adjust and keep the distance between the chassis and the road according to the vehicle load level. The power required for such an automatic level control system is 100–200 W.

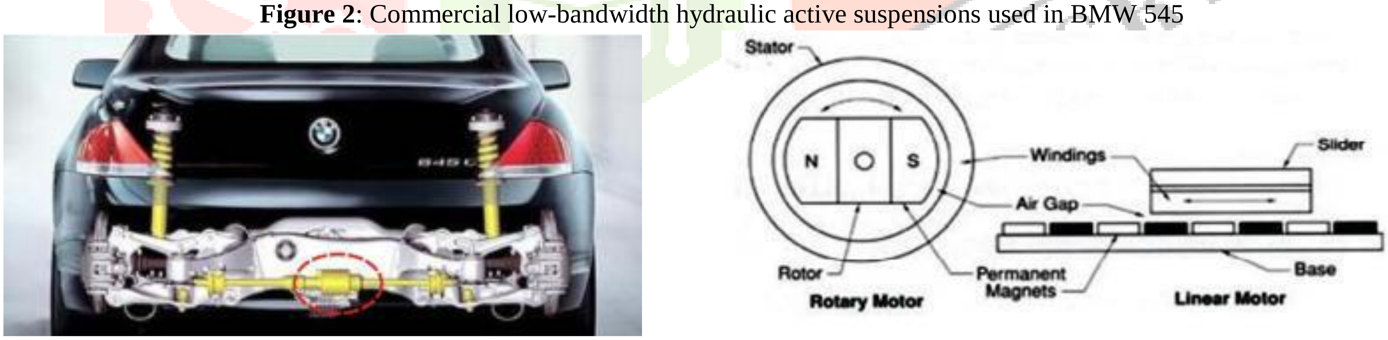
Figure 1: Quarter car model for active suspension (2dof)



III. HYDRAULIC OR PNEUMATIC ACTIVE ACTUATORS

Hydraulic or pneumatic actuator in the hydraulic or pneumatic active suspensions is controlled by electric drives. The battery source or conventional IC engine furnishes with the requisite electric power. It has got high force density, a mature technology and easy design. Also, its various parts are commercially available, which makes the hydraulic systems commonly used in body control systems. As an example in Figure 2, BMW has developed an antiroll control (BMW-ARC) system. They placed a hydraulic rotary actuator in the centre of the antiroll bar at the rear of the vehicle.10 The active body control system of Mercedes can be sought as another example, which utilises high-pressure hydraulics to pre-stress the spring, thus generating antiroll forces without pairing the left and right wheels (as in the case of an antiroll bar). Generally, the hydraulic or pneumatic active suspensions are appropriate for low-bandwidth usage.

Figure 2: Commercial low-bandwidth hydraulic active suspensions used in BMW 545



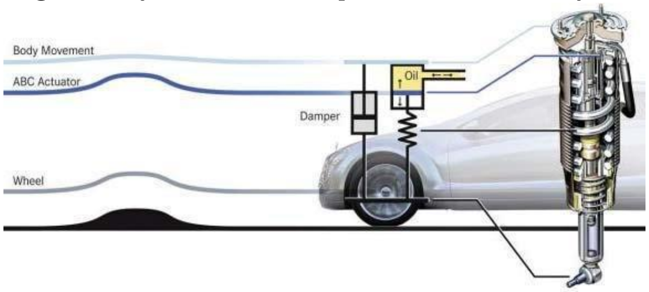
The vehicle engine or the electric motor drives a hydraulic or pneumatic pump to supply the hydraulic or pneumatic energy to the hydraulic or pneumatic actuator involved in the hydraulic active suspension, which creates oscillation-damping forces between the vehicular sprung mass and the vehicular unsprung mass. The hydraulic or pneumatic valve is driven by the low-power electromagnetic actuator, which is controlled by the control unit with the electric converter, in order to regulate the force of the hydraulic or pneumatic actuator.

With the ABC as in Figure 3, the suspension struts are positioned between the wheels and the vehicle body. The hydraulic system is controlled by an electronic unit that analyses numerous sensor signals emitted while the vehicle is moving. The ABS system controls oil flow into the spring struts at each wheel independently. The movement of the hydraulic actuators compensates the unevenness of road and hence the movement of the body is largely reduced. Furthermore, the ABC system slowly lowers the vehicle at higher speeds. However, it is found that these solutions do not satisfactorily solve the vehicle oscillation problem, or they are very expensive and complicated, and increase the vehicle's energy consumption. This expensive and complicated system is used only in luxury automobiles.

IV. ELECTROMAGNETIC ACTIVE ACTUATORS

Suspension system with electromagnetic actuator is electromagnetic active suspension system; consist of spring and electromagnetic actuator arranged in parallel combination within sprung and unsprung mass. This actuator operates with respect to electric supply range provided by embedded control systems. It produces active controlled force to absorb road shocks rapidly, suppress the roll and pitch motions, and improve both safety and comfort. With bidirectional amplifier electromagnetic actuator works as generating and reduces electric power consumption compared to hydraulic actuator.

Figure 3: Hydraulic active suspension for the ABC system



An electromagnetic suspension system is superior than a hydraulic system due to the relatively high bandwidth (tens of hertz), and there is no need for continuous power. It is easy to control and absence of fluids makes it even less messy. Linear motion can be attained by an electric rotary motor with a ball screw or other transducers. However, the conversion mechanism complicates the system. Complications such as backlash and increased mass of the moving part due to connecting transducers or gears that convert rotary motion to linear motion (enabling active suspension). More important, they also stick in infinite inertia, and therefore, a series suspension is preferable. In a parallel suspension, the inertia of the actuator is minimized, thus it's preferable to use such direct-drive electromagnetic system there. For linear control, linear motor with proper adjustments are required. The electromagnetic actuator is impelled by the electric converter and disciplined by the control unit based on the acquired signals and the control algorithms. The actuator gets the power from the battery, which is fed by the I.C. engine driven electric generator. Thus, the complex and expensive hydraulic components are replaced by this battery. At the same time, the energy stored in the electromagnetic active suspension can be supplied back to the battery through the bi-directional amplifier, if the electromagnetic system operates as a generator. It's consumption of energy is lower when compared to the hydraulic ABC system by up to 0.6 L/100 km.

Figure 4: Block diagram of control for an electromagnetic active suspension

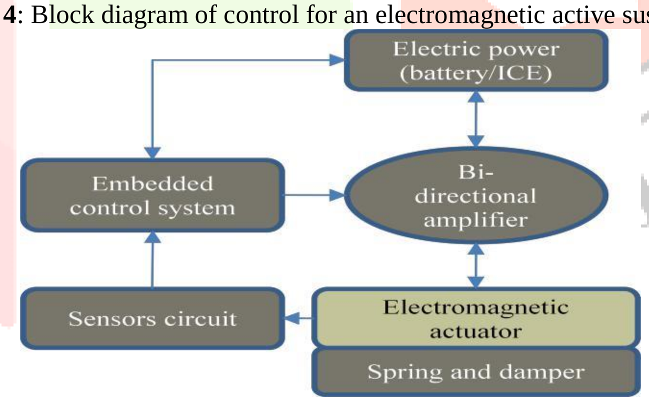


Figure 5: Electromagnetic active suspension developed by Bose Corporation

V. ACTIVE SUSPENSION CONTROL METHODS

The suspension control is considered in a global chassis control framework, which advance interaction and optimization of combined mechatronic subsystems, namely suspension, steering and braking systems. Its productivity depends on the effects of possible synergy due to the interchange of data and interaction between the mechatronic automotive subsystems.

Constrained frequency band

This is a finite frequency method to overcome the actuator time delay problem which gave better disturbance attenuation for the selected frequency range, while sticking to constraints obligated by actual situations was guaranteed in the controller design.

Look-ahead preview control

The controller for the new generation of Mercedes-Benz ABC systems is outfitted with laser scanners to collect preview information on the road profile. The preview approach is able to significantly enhance the performance of the active suspension system.

Predictive control

This controller is devices the idea that only vehicle body dynamics and not wheel dynamics should explicitly be considered in controller design. Accordingly, the cost function of the controller considers only the minimization of vehicle body accelerations and hence the improvement of ride comfort.

Fuzzy logic controls

The vehicle body roll angle is controlled by implementing a fuzzy logic controller. Experimental results show that the roll angle, with and without active control, reduces by approximately 40% and 30% respectively, in regard to a passive suspension subjected to the same excitation.

PID control

A proportional–integral–derivative **controller** is a **control** loop feedback mechanism which is chosen due to its simple structure guaranteeing the system stability and ensures robustness.

Optimal control

An optimal control system is proposed to control dynamic behavior of a vehicle subject to road disturbances.

Robust control

Multi objective $H\infty$ or mixed $H2/H\infty$ control approaches have been considered for the operation of frequency dependent filters that form the frequency response of the controlled system and to gain robustness against parameter changes.

Adaptive control

Adaptive control approaches can quickly plan the controller parametrization in mechatronic suspension systems inline to road excitation or the driving conditions.

Robust adaptive control

A modified adaptive robust control technique is implemented to improve closed-loop stability and performance in the absence of a feedback force sensor. A saturated adaptive robust control (ARC) strategy was proposed to reduce the effects of uncertainties and possible actuator saturation in an active suspension system. The control strategy was fixated by adding an anti-windup block.

Switching control

An adaptive control system which is founded on switching between state feedback controllers depending on dynamic wheel load and suspension deflection is advocated. A formerly constructed nonlinear sliding control law was used in this system. The performance capacity of the adaptive switching control structure for a fully active suspension system was computed. It was found that an ascend in the rapid singular wheel load is critical as it affects ride safety.

VI. CONCLUSION

This paper has rendered a broader understanding into advancements and current trends in the research and development of the active suspensions. Active suspension systems furnish much flexibility in enhancing ride and handling, but higher power requirements have limited its practical implementation. However, if its power requirements can be evidently decreased, large scale implementation can be expected.

Hydraulic actuators have thus far been chosen to in active
Suspensions due to easy availability of various parts and simple structure. However, more recently, electromagnetic actuators have emerged as a potentially superior alternative, showing lower power consumption and higher bandwidth abilities. Active suspension systems that adapt to the road profile have been considered as capable of reckoning larger improvements in ride and handling performance, in distinction to devising the system robust to vehicle parameter fluctuations. For this, look-ahead preview control is being actively developed by motorcar manufacturers. The multiple model adaptive control approach is a control method that is potently appropriate to this type of suspension adaptation.

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