ACTIVE ROLL CONTROL DEVICE FOR VEHICLES EQUIPPED WITH HYDROPNEUMATIC SUSPENSIONS

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Abstract: This paper presents a new active roll control device. This device uses an original hydraulic actuator, based on two tandem pumps, designed to be used in addition of a reduced anti-roll bar. The actuator control strategy is also original. It is based on hierarchical and hybrid control with a supervisor, a feedforward and a feedback loop whose robust controller is synthesized thanks to the CRONE control methodology. Because of the severe specifications sheets in term of power consumption, the simulated performances are thus limited but interesting.

Keywords: Vehicle dynamics, robust control, hydraulic actuators, feedforward control.

1. INTRODUCTION

While cornering, a vehicle rolls. It is a well-known phenomenon that is linked to the transversal acceleration of the vehicle and that is more significant as the vehicle center of gravity is high. In the worst cases, the roll can lead to rollover. In most cases, the roll motion is "only" uncomfortable for the vehicle passengers. For these reasons, car manufacturers have tried several means to limit the roll while cornering. Studies have been made to change the car mechanical characteristics to improve roll stability (Takano, *et al*, 2003), but the most used solution is the passive anti-roll bar which delivers an anti-roll moment proportional to the car relative roll angle (the roll angle between the body and the wheels axle). The main disadvantage of the anti-roll bar is that the stiffest it is, the less roll the car gets, but, the most uncomfortable the vehicle becomes in case of road irregularities.

Some active solutions have also been proposed, e.g. active anti-roll bars (Abe, 1994). In this paper, a new active roll control device for vehicle equipped with hydropneumatic suspension is studied. This active roll control system is designed to be used in addition with a reduced anti roll bar.

The objective is to improve the comfort by decreasing the anti roll bar stiffness but with only small power consumption (less than 1 kW).

The principle of operation of this system is described in the second part, after this introduction. A particular hydraulic actuator, constituted by two tandem pumps and change over valves, was chosen. Its description is given in the third part. The fourth part is devoted to the car rear axle modelling and to the actuator control. The possibility of a dynamic decoupling between the roll motion and the heave motion is shown there and then a hybrid control method based on state chart and CRONE control (CRONE is a french acronym for Robust Control of Non Integer Order) (Oustaloup, 1991) is proposed.

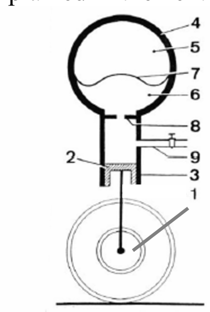
The simulation results are shown in the fifth part.

2. PRINCIPLE OF OPERATION

2.1 Vehicle description

The active roll control system studied here is designed to be used on vehicle equipped with hydropneumatic suspension, especially "hydractive" suspension.

The principle of hydropneumatic suspension consists in replacing the traditional mechanical springs and dampers by hydropneumatic components. Figure 1 presents a hydropneumatic suspension, composed by a hydraulic accumulator (also called sphere) and a hydraulic resistor. A hydraulic channel allows to add oil to the suspension. This oil can come from a self-leveller device or from the active roll control system, as it is explained in the next part.



1. Wheel
2. Suspension jack
3. Suspension cylinder
4. Sphere
5. Nitrogen
6. Oil
7. Membrane
8. Hydraulic resistor
9. Hydraulic channel

Fig. 1. Hydraulic suspension representation.

The hydraulic accumulators are nonlinear components. The relation between the gas pressure $P_S(t)$ in the hydraulic accumulator and the oil volume $V(t)$ which has entered into the accumulator between the initial time and time t is given by the thermodynamic law of gas evolution:

$$P_S(t)\left(V_{st}-V(t)\right)^{\gamma}=P_{st}V_{st}^{\ \gamma}\,, \qquad (1)$$

where P_{st} is the hydraulic accumulator static pressure and V_{st} is the hydraulic accumulator gas static volume. γ is a thermodynamic coefficient which characterises the gas evolution (γ = 1 for an isothermic evolution, γ = 1.4 for an adiabatic evolution). In case of small volume $V(t)$ i.e. of small jack deflection, an equivalent stiffness k_2 of the accumulator can be defined from the linear approximation of its force – deflection behaviour (Serrier, *et al*, 2005)

A classic vehicle equipped with hydropneumatic suspension only needs two hydraulic accumulators by axle. A vehicle with hydractive suspension (Guillemard, 1996) has an additional accumulator on each axle. This additional accumulator allows to obtain two operating mode for the suspension:
- a safety mode, which is used while braking, accelerating and cornering. In this mode, each sphere is isolated from the others (figure 2 (a));
- a “comfort mode” which is used when the driver only makes “small” actions (no braking or acceleration and no significant cornering). In this mode, the three hydraulic accumulators of each axle are linked (figure 2 (b)) and the suspension global stiffness is smaller than in the safety mode.

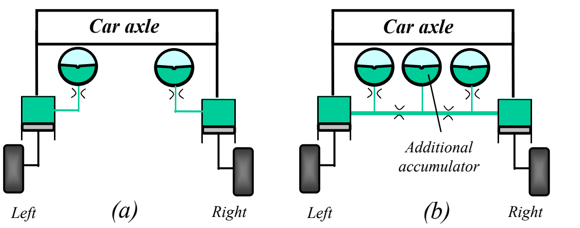


Fig. 2. Car axle equipped with hydractive hydropneumatic suspension in safety mode (*a*) and in comfort mode (*b*).

2.2 Active roll control system principle of operation

While cornering, the vehicle transversal acceleration creates a force which is applied on each suspension. For example, when the driver turns left, upward forces are exerted on the left suspensions (inner suspensions) and downwards forces are exerted on the right suspensions (outer suspensions). Thus the left side of the car goes up and the right side goes down. The car rolls.

A solution to nullify the car roll angle consists in injecting oil in the suspensions which sinks and in withdrawing oil from the opposite suspensions. Figure 3 shows the roll control action on a suspension located at the exterior corner side. Before the corner, if the road is supposed to be perfectly flat and if the car speed is constant, the suspension deflection is at is static equilibrium position (a). When the corner starts, a force F_0 is applied on the sprung mass above the suspension. The oil in the suspension jack moves to the hydraulic accumulator, and the suspension deflection decreases, the sprung mass goes down (b). Some oil is injected in the suspension (c) and make the sprung mass raise (d).

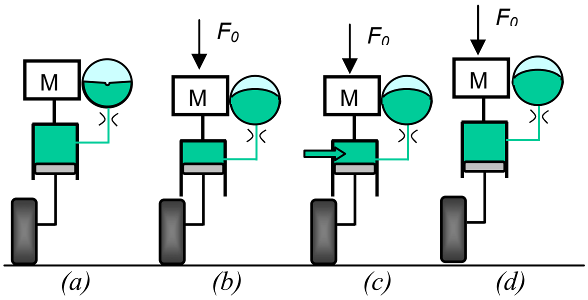


Fig. 3. Active roll control device principle of operation.

In the opposite suspension, some oil is removed to lower the sprung mass and thus to obtain a roll angle equal to zero.

When the corner is finished, the roll control system acts exactly in an opposite way. The oil is removed from a suspension jack and added into the other.

2.3 Practical issues

To minimize the power consumption, the oil is not injected from a tank, because the pressure gap between a suspension jack and a tank would be too important. It is more economical to fill a suspension jack with oil from the opposite one.

However, as the hydraulic accumulator are not linear, the oil volume V_R to remove in a suspension jack is not the same as the oil volume V_A to add to the opposite suspension jack. It can be shown that there is more oil to remove from a suspension jack than oil to inject to the opposite jack ($V_R > V_A$). The solution which was chosen consists in using the additional accumulator as a tank. The oil transfer is made in two phases. During the first phase, the oil is transferred from a suspension jack to the opposite suspension jack. During the second phase, the oil is transferred from a suspension jack to the additional accumulator. Figure 4 summarizes the two operating phases of the active roll control device. Figure 4 (a) shows the first operating phase (transfer between the opposite suspension jacks of the same axle). Figure 4 (b) shows the second operating phase (transfer between a suspension jack and the additional accumulator).