Simulation Analysis of Active Roll Stabilizer for Automotives Based on AMESim

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Key Words: active roll stabilizer, roll angle, AMESim model, simulation

Abstract: In order to provide theoretical analysis for the active roll stabilizer (ARS), the simulation model based on AMESim is developed in the paper. The simplified vehicle rolling motion model is derived firstly, and then the entire ARS control system model is constructed. Furthermore, the simulation is implemented to confirm the roll control effect. The simulation results show that the derived model can be used as theoretical analysis for developing components of ARS control system.

Notation

a: active roll bar link length
b: active roll bar length
c: suspension spring joints distance
F_a: actuator force
F_c: centrifugal force
F_s: spring force
h: height of body center of gravity to roll center
J: moment of inertial of vehicle body roll
k: spring stiffness
L: wheelbase
m: vehicle body mass
R: turning radius
T_f: front actuator output torque
T_r: rear actuator output torque
v: vehicle speed
Θ: roll angle
δ: steering angle
ϕ: actuator rotary angle

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1. Introduction

Vehicle roll is the motion which designers would not desire. Too much roll motion of vehicles seriously influences driving safety, handling, and passenger comfort. According to National Highway Traffic Safety Administration of USA, rollover crashes are a significant and growing contributor to fatal crashes, and in 2000, rollover crashes killed 9,873 people, almost one-third of the total deaths of occupants of passenger cars and light trucks. Therefore, it is rather significant to suppress roll motion as concerning, especially with high driving speed. The suspension is considered to have the unique ability among other automotive subsystems to affect roll motion.

Active suspensions use an actuator to replace the traditional combination of a spring and a damper (or called shock absorber), which can generate arbitrary direction and amplitude force in the working range. As results, active suspensions can not only benefit in ride comfort and handling control, but also improve vehicle body roll motion by adjusting output forces. Unfortunately, active suspensions, up to now, stay the stage of theoretical research and prototype, not being practically applied.

As far as passive suspensions are concerned, the roll motion of the vehicle body can be reduced by means of increasing spring stiffness, however, which, in turn, leads to deterioration of ride comfort due to stiff suspension stiffness. Hence, anti-roll bars, also referred to as stabilizers or sway bars, are used to reduce body roll during cornering. They add to the roll resistance of suspension springs for a higher overall roll resistance, while not increasing suspension vertical stiffness. In order to further reduce or eliminate roll motion, an actuator, with types of electric motor, hydraulic motor, or hydraulic cylinder, is introduced to construct the active roll stabilizer. The active roll stabilizer can produce the opposite torque to relieve the roll angle.

In the process of developing the active roll stabilizer control system, computer simulation is necessary to assist design and analysis. In the paper, the basic physical model of ARS is built by using AMESim software platform, which is of great benefit to developing components of ARS. The layout of the paper is as following. The vehicle rolling model is at first built in the second section. In the third section, the active roll stabilizer control system is modeled based on AMESim, and then simulation is performed to confirm the roll motion control effect. The conclusion is given in the last section.

2. Vehicle rolling model

Vehicle roll involves complex geometrical motions of various suspension components. However, the simplified vehicle rolling model can make designers easily understand roll motion relation and construct its dynamic model. In this research, the fundamental roll motion model will be built according to the physical vehicle rolling model illustrated in Figure 1.

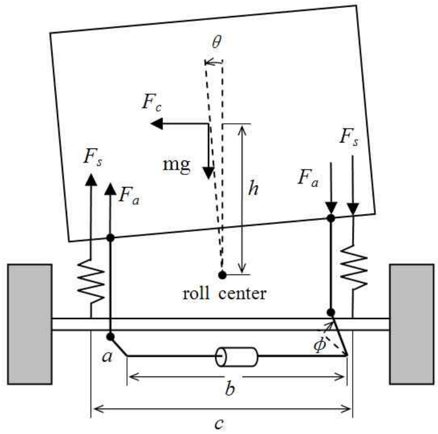

Fig. 1 Vehicle rolling model

When concerning, the vehicle body rolls around its roll center due to the lateral acceleration applied on the body mass center. The lateral acceleration depends on the vehicle driving speed and the turning radius, or steering angle. The centrifugal force acting on the vehicle body mass center can be expressed as following.

$$F_c = m\frac{V^2}{R} = m\frac{V^2}{L}\delta \qquad (1)$$

where the turning radius is approximately considered as inversely proportional to the steering angle if the vehicle bicycle model is utilized.

The suspension damper is neglected in the present model. Thus suspension springs provide spring forces to counterbalance the roll angle induced by the lateral acceleration. If the roll angle is not too big, the response spring force can be calculated as

$$F_s = k\theta\frac{c}{2} \qquad (2)$$

If the anti-roll actuators of the front and rear axles are operated simultaneously, they also can generate resistance forces for the body roll motion, namely

$$F_a = (T_f + T_r)\frac{1}{a} \qquad (3)$$

Above three types of forces, as well as the vehicle body gravity, together impose on vehicle body as concerning, and then the vehicle body reaches an equilibrium roll angle. The dynamic differential equation (4) can express this process.

$$F_c h\cos\theta + mgh\sin\theta - F_a b - F_s c = J\ddot{\theta} \qquad (4)$$

Considering the geometrical structure, the relation of the roll angle and the actuator rotary angle is described by following equation.

$$\phi = \theta \frac{b}{2a} \qquad (5)$$

The anti-roll torques generated by the front and rear actuators are determined by the individual pressure drop cross the actuators. The pressure drop is computed according to the hydraulic circuit of the ARS control system in the next section.

3. AMESim simulation

For convenience, AMESim simulation environment is utilized to construct the hydraulic circuit of the active roll stabilizer control system. In the circuit, the two electrically controlled, normally open proportional pressure valves are used to adjust the maximal upstream pressure of the actuators. The submodel by using several hydraulic components of AMESimis built to implement the function of the proportional pressure valve, whose dead zone effect is realized by setting the spring preload in the submodel. Moreover, the roll angle value is used as feedback signal and sent to the pressure proportional valve as the current input signal. Since the aim of this research is not to develop the control algorithm for the ARS, the current input of the pressure proportional valve is simply proportional to the roll angle. Figure 2 illustrates the detail ARS control system, as well as the vehicle body model build in the last section.

The vehicle driving speed and the steering angle (or turning radius) together determine the lateral acceleration. Therefore, the fixed driving speed (10 m/s) and the ramp steering angle (corresponding turning radius of 40 meter after 3 second), shown as in Figure 3, are set in the simulation. Figure 4 compares the body roll angle responses with and without the actuator operation. The simulation result indicates that the active roll stabilizer obviously relieves the vehicle body roll motion due to lateral acceleration. From about 1.5 second, the roll angle with control is less than that without control because there exists the dead zone in the proportional pressure valves.

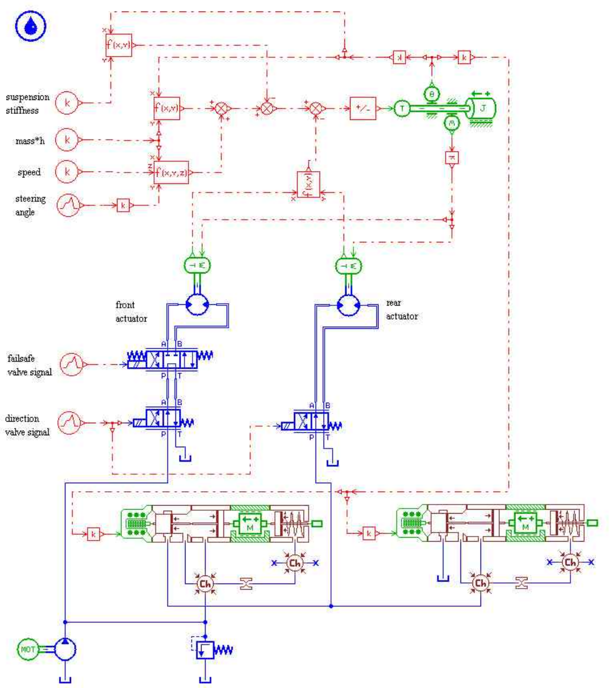

Fig. 2 Active roll stabilizer AMESim model

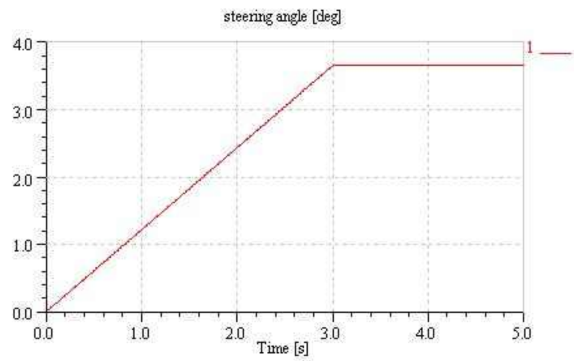

Fig. 3 Steering angle in simulation

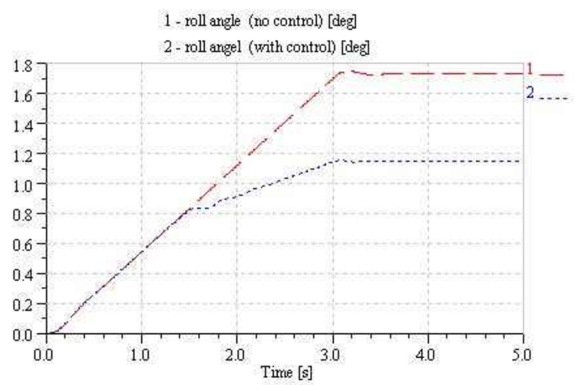

Fig. 4 Comparison of roll angle with and without control

Figure 5 shows the relation between the lateral acceleration and the roll angle, and the result of the actuator operation is also illustrated together. With the active control of the actuators, the roll angle values can be reduced half of the original values.

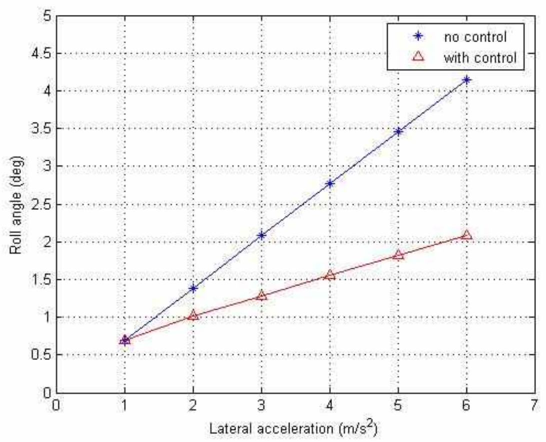

Fig. 5 Relation of the lateral acceleration and the roll angle

4. Conclusion

In the paper, after the vehicle roll model derived, the AMESim model of the active roll stabilizer control system is constructed. The simulation is further implemented to confirm the active roll control effect. The simulation results show that the model is reasonable, and it can be used for theoretical analysis in designing components or developing the control algorithm for the active roll stabilizer system.

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