Research of Light Vehicle's Electronic Stability Programs and Semi-Active Suspension Comprehensive Control

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Abstract. With the development of science and technology, active safety of vehicles is receiving more and more attention. Currently, active safety products that have already been developed and applied to vehicles include ABS (Anti-lock Brake System), ASR (Acceleration Slip Regulation), TCS (Traction Control System), and ESP (Electronic Stability Program), etc. The application of semi-active suspense can control changes of vehicle's gestures while turning and braking, and also achieve good frequency response both in cross pendulum and side pour. If the ESP and semi-active suspension can be combined during the process of design, it can not only better improve vehicles' operation stability and comfort of riding, but also reduce the decline of dynamic performance caused by the excessive participation of ESP in vehicles. This paper will analyze the coupling relations between ESP as well as semi-active suspension and the vehicles' yaw control and gesture control during the process of turning in detail, propose ESP-SAS comprehensive control method based on linear assignment weights, and establish simulation model of integrated control unit.

Introduction

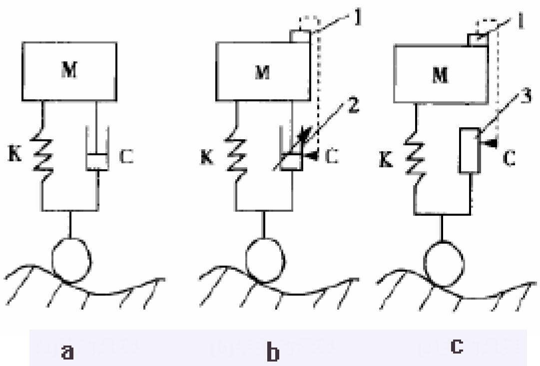
When the vehicle is driving, if the vehicle's driving path is inconsistent with the driver's desired track, the ESP system will begin to work and change the vehicle's movement intervention of the brake pressure or adjusting engine torque. If the actual motion of the car at the radius of the curve radius is less than the driver's desired trajectory, namely, car over steer characteristics, ESP systems will be long queues at the front of the car and exert a braking force. One hand brake on car produces a roll aligning torque; on the other hand brake force increase will make the wheel lateral force decrease, and thus produces a roll aligning torque. In the presence of both yaw aligning torques, the car will be back to the driver's desired path. When cars are understeering, ESP has two intervention methods. The first is to apply a braking force at the rear inner wheel in the car, making the car a yaw movement increased, and make the car return the driver's desired track; the other method is to reduce the engine output torque, the driving force will also be reduced accordingly, and the vehicle decelerates. This is bound to cause axle load transfer. The normal force in the front axis will be increased, the normal force in the rear axis will be decreased; and the yawing force in the corresponding front axis will be increased, and the yawing force in the rear axle will be reduced. As a result, the yawing motion of vehicle is increased, making the actual motion state of vehicle get closer to the driver's desired value, and improve the directional stability and active safety of vehicle driving.

Most of the early vehicle stability systems are applied to fancy cars or commercial vehicles. In 1997, Mercedes-Benz equipped the ESP system on the A-Class car, which was the first time the ESP was applied to economy cars. In 2003, Volvo developed the roll stability control system (RSC) based on ESP, in order to control the roll stability of the vehicle, and equipped them in SUV with higher centroid , such as Volvo XC90, Lincoln Aviator and Navigator. Currently there are six auto parts manufacturers manufacturing ESP in the world, including Germany Bosch, Japan Denso, Germany continental TEVES, United States, and Delphi Japan Aisin Seiko and United States TRW. ESP Assembly rate varies between various countries and regions, according to Bosch's statistics, 2005 Germany car ESP Assembly rate is about 72%, Western Europe's average new car Assembly was about 44%, in Japan and in North America, this number is a little lower, about 21% in North America, Japan is about 15%. While the current assembly rate is still relatively low, it is approximately 3%.

Thus, it can be seen that vehicle stability control system can prevent vehicles from a sudden steer, which has great significance to maintain stability of vehicle operation under extreme working conditions, reduce traffic accidents and reduce fatalities.

Semi-Active Suspension

In order to further improve the performance of suspension, people have invented the intelligent suspension system, which includes two categories: active suspension (AS) and semi-active suspension (SAS). Active suspension adopts suspension actuator to change the suspension output, and the suspension actuator has wide frequency band with excellent performance. However, active suspension needs to consume energy with expensive prices. These shortcomings restrict the development of active suspension. Semi-active suspension can only adjust suspension stiffness and damping within a limited frequency range, but it has cheap price and hardly consumes energy. Meanwhile, if optimal control algorithm is used, its performance will also be close to active suspension. Therefore, semi-active suspension system is favored by many vehicle manufacturers. Fig. 2 is the simplified model of passive suspension, semi-active suspension and active suspension. On the basis of passive suspension, semi-suspension replaces normal shock absorber to adjustable damping shock absorber, or spring to the ones whose stiffness can be adjusted. Its basic principle is to adjust damping force of the shock absorber according to some control regulations as well as feedback information like the response of the spring compared with the speed of wheels and accelerating response, or realize the “soft” or “hard” control of the spring’s stiffness. Active suspension is formed by springs and a power generator. Force generators to improve system energy consumption and energy supply systems, the objective is to achieve a high quality isolation system, without systems to make much change, and simply force generators in different conditions according to a certain logic produces an absolute velocity is proportional to the negative of the main power and control objectives can be realized.



1. Sensor 2. Adjustable Vibrator 3. Power Generator

passive suspension semi-active suspension active suspension

Fig. 1 Simplified Models of Three Suspensions

Modeling of Subsystem and Gesture and Stability Control Strategies. Compared with active suspensions, although semi-active suspension (SAS), as one of intelligent suspensions, does not have superior performance, it has relatively simple structure with less consumption of energy and lower costs. Thus, with relative higher cost performance, it is favored by more and more vehicle developers and widely installed on medium and high-end cars. At present, most of the semi-active suspension control algorithms are based on a quarter or half vehicle model, the control algorithm to control the sprung mass is the main object of vertical acceleration, suspension dynamic deflection and wheel dynamic load these three quantity, control target is mostly in order to better improve the riding comfort of the vehicle, and for the vehicle's handling stability control research is relatively few.

At present, the main mechanism through the adjustable damper control vehicle yaw is to change the front and rear suspension damping force to influence or rear axle left wheel of the front axle vertical load, assuming that role in all three dimensions of dynamic forces on the wheels for the xF, yF and zF, the equivalent cornering stiffness of the wheel can be approximated using the following simplified formula to represent:

$$c_\alpha^* = c_{\alpha 0}\left[1 - \left(\frac{F_x}{uF_z}\right)^2 - \left(\frac{F_y}{uF_z}\right)^2\right]$$

Herein, $F_x^2 + F_y^2 \leq \left(uF_z\right)^2$ refers to the cornering stiffness without latero-deviation:

$$c_{\alpha 0} = \alpha_1 F_2 + \alpha_2 F_z^2$$

Modeling of ESP Subsystem and Stability Control Algorithm. Vehicle electronic stability program (ESP) is a new of active security control system, dang car occurred insufficient steering or too much steering Shi, ESP system through sensor signal entered and itself control algorithm to judge car of steering characteristics, on specifies of was controlled wheels for brake pressure of regulation, produced inhibit corresponding of cross pendulum torque, thus avoid dangerous workers condition of occurred, more effective, and more significantly to improve has car of manipulation stability and driving security.

Vehicle's steering characteristics are divided into three types: oversteer, understeer and neutral steering. Is neutral towards the ideal characteristics, and oversteer and understeer is not stable steering characteristic. When the car is in the low adhesion at the turn, if the coefficient of adhesion on the ground do not provide sufficient lateral force, the car will produce excessive oversteer or understeer. When the pilot realized that the General Motors when in excessive oversteer or understeer, and often imposed through the steering wheel operation to control the car, but because of vehicle sideslip angle is always large, the driver through the steering wheel to control the vehicle only effect is not obvious, if not taken the correct action method, auto sharp turn or accidents caused by sideslip occurs. At present, there are 3 main ways to improve vehicle stability:

(1) Active Steering Technology
(2) Wheel Load Control Technology
(3) Braking/Driving Active Control Technology

Coupling of ESP and SAS in Yaw Stability Control. Semi-active suspension is in damping adjustment way around by changing the front axle and wheel load transfer which causes ranging from lateral force to form a stable and yawing moment of the vehicle and its control over the horizontal pendulum is indirect, and limited in their ability to control; And ESP to one side of the wheel is adopted to take the initiative to obtaining the vehicle braking stability of the yawing moment, its control over the horizontal pendulum is directly, which is the most effective. So on modern cars, researchers can see most of the semi-active suspension are used to improve ride comfort, comfort, and to the attitude control of the body, and ESP due to horizontal pendulum stability control is more effective, they will become the mainstream of the control. The control of the yawing stability exist complicated mutual influence and mutual restriction relation, the following on the in-depth analysis of coupling relationship between them. Through to the specific brake wheel, in order to get the vehicle stability of yawing moment is now the most commonly used method of ESP system, and there are many influence factors in ESP yawing moment, mainly including the following:

1. Changes of yawing moment caused by changes of braking force;
2. Changes of yawing moment caused by changes of automotive vertical load;

When μ<0.45, cross pendulum stability of vehicles completely relies on Yu ESP of control, half active hanging frame does not participate in the cross pendulum control, only take appropriate increased before and after hanging frame damping of way on body attitude for control, inhibit steering Shi of side pour, makes comfortable sex improve integrated control system requirements half active hanging frame and ESP on sensor information achieved shared, and vehicles on road status can for recognition, following to out road attached coefficient of estimates algorithm, road attached coefficient used side to acceleration for estimates that:

$$u_e = \frac{K_u \cdot \left|a_y\right|}{a_{y\max}}$$

Herein: ya is the lateral acceleration sensor output value ymaxa for the high-road conditions the car maximum lateral acceleration; k-μ to estimate constant general range. Cars the sideslip angle is reflected vehicle stability is an important parameter. When the vehicle sideslip angle is small, the car's yaw rate can be used to reflect the car's steering characteristics and reflect the driver's intentions; and when vehicle sideslip angle is large, the yaw rate no longer reflects the actual driving conditions. Therefore, and ESP integrated control for semi-active suspension systems must have the sideslip of vehicle stability control is another important criterion. Bad due to sideslip angle measurement on the real vehicle, therefore the use of estimation methods to get its value, this paper gives an algorithm-the direct integration method. According to the vehicle kinematic equation:

$$a_y = \left(\beta + \gamma\right) \cdot V_x$$

The lateral acceleration and yawing angular velocity can be measured directly by the sensor, while the vertical speed through the wheel and longitudinal acceleration estimation, formula for integral operation vehicle centroid side-slip Angle can be calculated out.

Analysis of ESP-SAS Integrated Control Simulation. Offline simulation for various kinds of control algorithm and control strategy in the realization of the real car provide a platform, to the real vehicle experiment made a likely scenario, through the simulation researchers can validate the control algorithm and control strategy is correct, and can be found in a timely manner or theory, some of the problems in our algorithm before cause huge losses and be able to solve them in a timely manner, and avoid some unnecessary trouble, thus the offline simulation of real vehicle test and hardware development has the very vital significance. Based on vehicle dynamics mathematical model of chapter 2 of this chapter, developed in Matlab/Simulink environment, through the graphical modeling method to establish the vehicle dynamics model of Simulink module, and use the light Iveco automobile related parameters, under the environment of Matlab/Simulink offline simulation, validation and ESP, SAS subsystem control algorithm based on linear distribution of the weight of the correctness of the ESP - SAS integrated control algorithm.

Simulation conditions: the initial speed V0 = 22 m/s, tire-road friction coefficientμ=0.9, road input level for A grade, the front wheel steering angle input as shown in Fig. 2, in 0.1 seconds peaked at 0.1 rad/s, and keep the value to the end of the simulation.

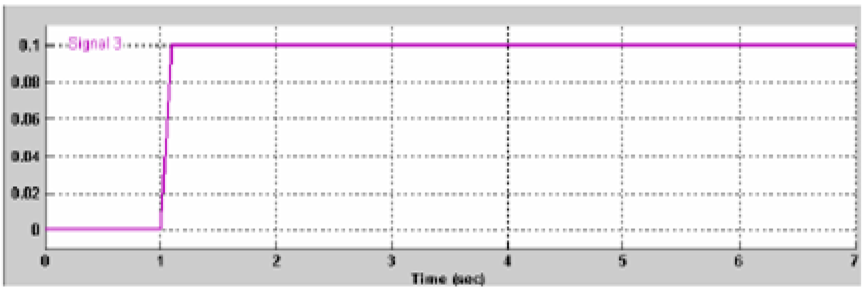


Fig. 2 Front Feet Input

Subsystem separately controls the effect comparison: SAS USES the front suspension damping incremental PID control, ESP the yawing angular velocity and centroid side-slip Angle joint PID control.

Conclusions

Semi-active suspension damping (SAS) based on the adjustable can also simultaneously affect the car's comfort and handling stability, high adhesion through different damping allocation strategy to have very good inhibitory effect over the vehicles small horizontal pendulum and the body roll, and electronic stability program (ESP) of a particular wheel is carried out through active braking, conduct very good control of the vehicle steering sideslip, avoid the happening of dangerous working conditions, but the ESP too much intervention will make the driver feel uncomfortable, but too much can make the car braking performance decline is very serious. To solve these problems, researchers can combine both of vehicle horizontal pendulum control, and deal with the coupling relationship between each other when they work together, and take reasonable comprehensive control strategy.

Acknowledgements

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