Research on Vehicle Driving Stability Based on Dynamics Co-simulation

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Abstract: Automobile braking system is an important guarantee for automobile driving safety, and improving automobile braking performance is an important task in automobile development. ESP system can effectively reduce the accident rate and improve driving safety. This paper systematically introduces the development of vehicle stability control technology from four aspects: dynamic modeling, state observation, control strategy and industrialization. It mainly introduces the state observation and control strategy.

1. Introduction

According to investigations, related studies have shown that car sideslip is one of the important causes of traffic accidents, and the braking force adjustment of the wheels and the control of the engine output torque can effectively restrain the car’s sideslip motion and improve the car’s lateral stability. The electronic stability program ESP is based on ABS and TCS, adding an angular velocity sensor for lateral swing when the car is turning, and controlling the driving force and braking force of the inner and outer wheels, front and rear wheels through the ECU, to ensure the lateral dynamics and stability of the car. The ESP system will detect the driver's driving intention and the actual driving situation of the vehicle at a certain frequency. If it finds an emergency, it responds quickly, adjusts the brake pressure of each wheel through hydraulic regulators, and intervenes in the engine and transmission system if possible. ESP can reduce the risk of vehicle sideslip, thereby reducing the occurrence of accidents.

In 2005, the ESP system equipment rate of Chinese new cars was 4%, and the European new car equipment rate was 40%. In 2006, the ESP equipment rate of new cars produced in Europe reached 50%, and China reached 5%. ESP is spreading to general commercial vehicles and heavy trucks, and many commercial vehicle manufacturers and heavy truck manufacturers are launching models with ESP systems [1]. As people's requirements for vehicle safety gradually increase, it is believed that ESP will become the standard equipment of vehicles just like the ABS system. At present, the ESP market and technology are mainly owned by several international automotive electronic product suppliers. If domestic automotive manufacturers need to be equipped with ESP systems, they need to request the aforementioned companies, which is extremely expensive. This is also the main reason why the assembly rate of ESP in my country is low. Therefore, research on ESP-related technologies to overcome the theories and key technologies of ESP design will improve the independent development capabilities of my country’s auto parts industry and break foreign monopoly on this technology. It is of great
significance to shorten the gap with developed countries.

2. Research object
As far as the current domestic research is concerned, the domestic research on vehicle dynamics stability control started relatively late and is still in the early stage of research and development. Only a few scholars are engaged in the simulation research of control methods, and due to the lack of experimental conditions, the research is not very deep. ESP can reduce the risk of vehicle sideslip, thereby reducing the occurrence of accidents, significantly reducing major losses caused by various external bad road conditions and driver errors, and greatly improving the dynamic driving safety of vehicles. Therefore, it is widely used in my country. There is high research value at this stage, but the current results are not rich enough. The lack of professional experimental equipment and market demand has created great resistance to the further development of research. At present, the main direction of domestic research is focused on ABS, while ESP theory is becoming mature, and it can only be optimized specifically when breakthrough innovation is not possible. In this aspect of optimization, the cost of some experiments is too high, and independent research by universities cannot afford the high cost. At this time, a method of using software for simulation is proposed, which can complete some damping characteristic experiments to a certain extent and obtain research data at almost no cost. Due to the lack of hardware facilities of the experimental conditions and the lack of conditions for actual vehicle experiments, this article can build vehicle models and stability control systems for simulation experiments through MATLAB/Simulink. In order to strengthen the practicality of the theory, physical experiments can be carried out on partial simulations.

3. Research methods

3.1 Related theories

3.1.1 Vehicle dynamics theory
First understand the steady-state steering characteristics of the vehicle [2] (understeer, oversteer), and tire cornering characteristics, determine the main cause of vehicle instability, and determine the control parameters required for stability control; for vehicle dynamics. The establishment of the model lays a theoretical foundation.

3.1.2 The control principle of differential braking technology
Differential braking means that different braking forces are applied to different wheels according to the needs of the car during the movement of the car, so that the wheels on both sides form a braking difference, and a stable yaw moment is generated on the car body to offset the unstable movement of the car body to ensure the vehicle Stable driving.

3.2 Related methods

3.2.1 Kinetic modeling and analysis
In the research process of automobile stability control [3], building an accurate vehicle model is the key to system simulation. In the simulation stage, a high-precision dynamic model is needed to analyze the complex dynamic stability of the car. There are two main types of current modeling methods: physical modeling and mathematical modeling.

Physical modeling is intended to construct an equivalent model that is as close as possible to the physical characteristics of the actual vehicle model. Because of its high accuracy, physical modeling can be closer to the actual state of the vehicle. It is an effective modeling method. The data calculated by the method is more convincing. ADAMS is the representative software for multi-rigid body dynamic modeling. However, because the physical models of some parts are more complicated, such as bolt connections, it takes a long time to build vehicle models and is not universal. Factors restrict the
development of physical modeling.

Mathematical modeling can describe the laws of motion, energy transfer, and signal transfer in the vehicle system in the form of mathematical expressions. It is a brief expression that can accurately reflect the internal characteristics of the vehicle system. With the development of computers, The established mathematical model can be solved by computer and the accuracy of the solution is continuously improved, which improves the work efficiency of engineering designers. The development cycle is shortened, and it has become a convenient, convenient and flexible modeling method to solve practical engineering problems. As the representative software of mathematical modeling, Matlab/Simulink has huge advantages in establishing mathematical models. However, for a complex nonlinear system such as a vehicle system, it is very difficult and unnecessary to express the internal characteristics with mathematical formulas. Therefore, simplified models are often used when building mathematical models for vehicle systems. The two modeling methods have their own characteristics. The specific selection should be based on the specific object of the study and the accuracy that needs to be met. The basic requirement of vehicle modeling is to be able to control sufficiently accurately and conveniently. ADAMS is based on physical model modeling to more reflect the dynamic performance of the vehicle, but ADAMS is very troublesome to design the control system due to the imperfect system toolbox in the design of the controller. And Matlab has a corresponding control toolbox, which can control the vehicle stability system.

3.2.2 Stability control state observation

To realize the control of the vehicle's running state, it is necessary to obtain the key parameters that characterize the vehicle's running state in real time [4]. Some of the parameters can be measured by sensing, such as wheel speed, yaw rate, etc. but most of the parameters cannot be measured directly, or the sensor is too expensive to be used in automobiles, so it needs to be obtained by observation. The most important ones are the center of mass slip angle and the road adhesion coefficient.

Based on the referenced literature [5], the current methods of centroid slip angle are mainly divided into two categories: kinematics-based methods and dynamics-based estimation methods. The kinematic estimation method is mainly based on the direct integration method of lateral acceleration and yaw rate sensor signals (referred to as the kinematic estimation method) to estimate the side slip angle of the center of mass, which is very good for changes in vehicle parameters, road attachment conditions and driving control methods Robustness. When the sensor signal is accurate, the estimation result has a high estimation accuracy for the change trend of the actual vehicle's center of mass slip angle regardless of whether it is in the linear or non-linear control area of the vehicle. The dynamic estimation method is currently the main method of mass center slip angle estimation. Compared with the optical sensor measurement or kinematic estimation method, the dynamic estimation method does not have high requirements on the sensor. It is an estimation method based on a low-cost sensor configuration scheme. The basic principle of the dynamic method is to estimate the side slip angle of the center of mass through the observer technology in modern control theory based on the vehicle dynamics model and tires. Therefore, the use of different vehicle or tire models will have an important impact on the estimation results. In summary, the current common methods for estimating the side slip angle of the center of mass are: integral calculation estimation, fuzzy logic state estimation, neural network state estimation, Kalman filtering and its state estimation.

As the basic state parameter of active safety control, road adhesion plays an important role in its accurate and timely identification. Taking ABS as an example, the optimal value of slip rate differs due to changes in road adhesion. As shown in Figure 1 under different roads, the change of road adhesion coefficient with slip rate can be represented by $\mu$-slip curve.
As shown in the figure, the best slip rate of different road adhesion coefficients corresponds to the peak value of the utilization adhesion coefficient. Therefore, the best braking force applied by the stability control system ESP during braking force distribution is different. Only under the premise of relatively accurate coefficient recognition can the control effect of ESP be guaranteed [6].

3.3 Theoretical steps
First of all, according to the dynamics theory, first analyze the stability of the automobile, understand the reasons of instability, propose methods to improve the stability, determine the control strategy with the yaw rate and the side slip angle of the center of mass as the control variables, design the motion controller and distribution Controller.

Then, build a seven-degree-of-freedom vehicle dynamics model and a tire model based on the "magic formula" in MATLAB/Simulink. Establish a two-degree-of-freedom vehicle reference model in MATLAB/Simulink (to characterize the driver’s driving intention) [7].

Then, the vehicle dynamics model, tire model and controller model are built on the MATLAB/Simulink platform, and the various modules are combined to complete the establishment of the stability control system [8]. Analyze and process the simulation results, and verify the effectiveness and practicability of the vehicle stability controller proposed by this research in accordance with the evaluation method of FMVSS126.

Finally, the simulation experiment is carried out in accordance with the regulations of FMVSS126 standard [9] for sine hysteresis experiment, and the vehicle lateral displacement and yaw rate are used as the evaluation of stability control to verify the effectiveness and practicability of the vehicle stability controller proposed by this research.

4. Conclusions
This article analyzes the braking stability of the vehicle accordingly. The use of ESP control improves the braking stability of the vehicle to a certain extent, and can overcome the lack of hardware facilities of the experimental conditions and the conditions of no actual vehicle experiment. Through MATLAB/Simulink Building a vehicle model and stability control system for simulation experiments strengthened the practicality of the theory. Contributed to the research of dynamic control of vehicle turning and braking stability.

The work content of this paper also has many areas that need to be improved and deepened. The following prospects are put forward for future work: First, the control value of the ESP control model
of vehicle turning braking established in this paper is the braking torque of each wheel, without considering the actual More in-depth research can be done on the hydraulic or pneumatic characteristics of the brake system. Second, in stability control, direct yaw moment control is used, and the braking force is not distributed to generate the corresponding yaw control moment. It is necessary to further study the braking force distribution to achieve a fully coordinated control of ESP and yaw moment. To achieve ideal braking and stability. Third, the joint simulation based on ADAMS and MATLAB/Simulink can better reflect the discrete characteristics of the actual structure and control of the vehicle, and has the characteristics of visual and intuitive. When the vehicle's center of mass slip angle estimation and braking torque distribution can meet the control requirements, Co-simulation can be well used for vehicle turning and braking stability control analysis.

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