

Analysis on Improvement of Vehicle Handling Stability and Path Tracking Capacity with Person-Vehicle Closed Ring System based on Chassis Integrated Control

Huazhong Wang

Jiangxi University of Technology, College of Automotive Engineering, Nanchang, 330098, China

Keywords: chassis integrated control; handling stability; path tracking

Abstract. the research status of chassis integrated control technology is summarized first, and then on this basis, the person-vehicle closed ring system design based on chassis integrated control is proposed, subsequently, simulation verification is conducted for the effect of the system in improving the vehicle handling stability and path tracking capacity. The result shows that the system proposed in this paper can further improve the vehicle handling stability and path tracking capacity, with certain promotion and use value.

Overview to research status of chassis integrated control technology

In automobile manufacturing field, the motion control of vehicles is one of the main research topics of the automobile dynamics. The so-called motion control specifically refers to the effective control of various directions to further improve the safety and handling stability of the vehicle in road driving. With the continuous deepening of researchers' understanding to the automobile dynamics, the major automobile manufacturers both at home and abroad have more and more emphasized the integrated control, and the integrated control has become an important branch in the research field of automobile dynamics. Relevant researchers have pointed out that automobile will be developed toward the direction of safety, independent orientation and driving comfort, and the wire control technology and integrated control system etc. will become the technical support to realize this objective.

The experts and scholars in the automobile industry researched the vehicle handling stability first from the level of rear wheel brake steering. With the continuous deepening of research, the four-wheel automobile has emerged accordingly, which further improved the vehicle handling stability, at the same time, some researchers find that when the slip angle of the vehicle body and lateral acceleration are small, and the tier cornering force and slip angle are in a linear relation, the vehicles of four-wheel steering can obtain a higher handling stability, such situation generally exists when the vehicle is in normal running state; in case of emergency to the vehicle, its lateral acceleration, body slip angle and heading angle are large, and at this time, the vehicle cannot obtain a good handling stability, this is because the lateral force carrying of the tier will gradually tend to be mature in this status, so that there is a nonlinear relation between the lateral force and slip angle of the tier. Only with four-wheel steering, it is unable to increase the lateral force of the vehicle itself, so the lateral handling stability of the whole vehicle cannot be improved. In order to solve this problem, some experts and scholars propose achieve the purpose of controlling the slip angle of vehicles by virtue of the characteristic that linear scope of the tier longitudinal force is more than the linear scope of lateral force, and by adjusting the heading moment generated by the distribution of tier longitudinal forces on left and right of the vehicle, so as to increase the vehicle handling stability, and this control method is called heading moment control. On the basis of this control mode, German Bosch and Japanese Toyota have successively researched and developed relevant products, for example the ESP system of Bosch, which has been applied in many high-grade cars, becoming an important approach to improve the active safety of vehicles.

In recent years, with the continuous development of automobile electronic technology, the vehicle active chassis control signal is no longer transmitted via the machinery mechanism, and the signal can be directly transmitted via the electrical system, i.e. the wire technology. The emerging of this technology has replaced the traditional mechanical system, and various control information

required by the execution mechanism can be transmitted via the conductor, which further improves the response speed of automobile control and the safety and handling stability of vehicles driving in different work conditions have also been improved accordingly. For these two active control systems, mostly the control is targeted at some performance of the whole vehicle. The automobile is an integration, if only one aspect is considered, obviously it is insufficient; if many control system coexist, there also might be overlapping or disturbance in different systems. In order to solve problem of disturbance and mutual influence of many systems and fully mine the functional potential of the system, it is required to integrally control and match the system, so as to improve the comprehensive performance of the whole vehicle.

Analysis on design and simulation effect of person-vehicle closed ring system based on chassis integrated control

As early as in the 1950s, some automobile design and research personnel had a deep and specific research on the driver model, and applied the system control theory to deem the automobile driver as the control variable of the person-vehicle closed ring interaction system, and analyzed the characteristics of the whole vehicle on this basis. At that time, the proposal of driver model made it possible for the computer to simulate the person-vehicle interaction, which shortened the R&D cycle of vehicle and its control system to a certain extent and further reduced the pilot risk. Roughly, the person-vehicle closed interaction control system can be divided into two control circuits, one is internal ring control circuit and the other is external ring control circuit, the driver model belongs to the external ring controller of the control system, which is mainly responsible for optimizing and adjusting the vehicle driving path, and calculates the reference motion state of the vehicle. The chassis integrated controller belongs to the internal ring control, which calculates the ideal running state of the vehicle based on the vehicle reference driving state output by the driver model, and enhances the handling stability of the vehicle itself by controlling the longitudinal, lateral and heading states. A lot of experiments have shown that the person-vehicle close ring control system of internal and external rings cannot only detect the improvement of vehicle chassis integrated control to the handling stability, but can also detect its influence on the vehicle path tracking capacity. Therefore, the actual design effect of vehicle handling control system can be comprehensively verified.

(I) Construction of vehicle driver model based on field vector

Vehicles generally need to drive in various severe work conditions, therefore, in order to comprehensively verify the control effect of integrated control in various different work conditions, it is needed to construct a driver model so as to simulate the actual handling of the driver to the vehicle in different complicated conditions. The convergence field vector-based driver model was proposed by the British famous scholar Tim Gordon, which optimizes the driver's control behavior by reference to the actual driving condition of the vehicles, so as to form a person-vehicle closed ring integrated control system. This model provides the preview information needed by the driver during normal driving of automobile by reference to the field vector w_{drv} , the module of w_{drv} , i.e. the vehicle speed, is $v_{cg}^d = |w_{drv}|$, the direction of reference vector, i.e. the vehicle speed direction is $\psi^d = \arctan(w_y / w_x)$, while the tangential and normal components of w_{drv} are respectively:

$$d_t^d = e_t^d \cdot (w_{drv} \cdot \nabla) w_{drv} \quad (1)$$

$$a_n^d = e_n^d \cdot (w_{drv} \cdot \nabla) w_{drv} \quad (2)$$

In formulas (1) and (2), e_t^d and e_n^d respectively represent the tangential and normal unit vectors of the reference vector field. Generally, the longitudinal speed in the process of vehicle driving can be controlled by the acceleration a_x , and meanwhile, a_x can be transformed to be controlled by controlling the vehicle driving or braking torque, an its differential form is as follows:

$$a_0 = \frac{|w_{drv}| - v_{cg}}{\tau_1} \quad (3)$$

Formula (3) and the derivative of vehicle acceleration feedback component a_x can form the following formula:

$$a_x = \frac{a_0 - u}{\tau_2} \quad (4)$$

In formulas (3) and (4), τ_1 and τ_2 respectively represent the control design parameters. For research convenience, the ratio of lateral speed to the longitudinal speed can be negligible, and the longitudinal reference speed of the vehicle can be approximated to:

$$u_d^d = v_{cg}^d \quad (5)$$

In order to control the lateral dynamic behavior of the vehicle, the speed of the reference heading angle can be set as:

$$\gamma_0 = \frac{v_{cg} a_n^d}{|w_{drv}|^2} \quad (6)$$

Meanwhile, in consideration of the error of slip angle of the vehicle, the following formula can be used to express the heading angle:

$$\gamma_d^d = \gamma_0 - \frac{\psi + \beta - \psi^d}{\tau_3} \quad (7)$$

In the same way, the differential form of vehicle cornering can be obtained:

$$\dot{\delta}_f = k_{lat} (\gamma_d^d - \gamma) + k_{beta} \sigma(\beta \dot{\beta}) \dot{\beta} \quad (8)$$

In formulas (7) and (8), $\beta = v/u$, representing the slip angle of the vehicle; τ_3 , k_{lat} and k_{beta} are all the control design parameters; the first item in formula (8) represents the speed direction control, which can trace the reference direction of speed; the second item is the vehicle slip angle and the feedback value of its derivative, which can prevent a large slip of vehicle in the process of driving; $\sigma(\bullet)$ represents the switching control parameter of cornering control of the vehicle steering wheel. In order to make the actual driving speed of the vehicle trace other reference vector fields, its acceleration should meet $\bar{a}(t) = \bar{a}_r(\bar{r}(t))$. $\bar{a}_r(x)$ is an ideal reference vector field; similarly, the vector field of reference acceleration should also be limited by relevant restriction conditions, i.e.

$$|\bar{a}_r(x)| \equiv \sqrt{a_x^2 + a_y^2} \leq \mu(x) < \mu_0 \quad (9)$$

According to the actual handling characteristics of driver, the reference vector field designed does not need to trace the reference path, but it is only needed to meet certain convergence and boundary conditions. However, there might exist a certain preliminary tracing error between the actual driving speed of the vehicle and w_{drv} . Therefore, the driver preview information needed will change with the driving speed of vehicle, only in this way can the amplification of convergence vector field on the path tracing error can be further reduced. If θ_1 is used to express the preliminary tracing error of the vehicle relative to the reference path, in some specific conditions, influenced by the convergence of the vector field, the error will be increased, i.e. $\theta_1 > \theta_2$. Therefore, changing the relation between the preview distance and the vehicle driving speed can ensure the overall convergence of the tracing error, so when the driver handles the vehicle, it is needed to continuously modify the relation between the preview distance and vehicle driving speed, only in this way can the overall convergence of the tracing error be ensured.

(II) Design of chassis robust integrated controller

The closed-ring robust model matching controller is a kind of chassis integrated controller which can further improve the lateral, longitudinal and heading running freedom of the vehicle, in other words, it can both strengthen the vehicle handling stability and improve the vehicle path tracing

ability. In the person-vehicle close ring control system, the driver model is an external ring controller, while the robust model is an internal ring controller, which is a H_∞ model matching controller based on the linear matrix inequation, i.e. R-MMC. The driver model can optimize the vehicle driving speed, acceleration, heading angular speed and steering angle of steering wheel according to the vehicle driving path an motion state. Meanwhile, H_∞ model matching controller can control the longitudinal driving or braking compensation force and rear wheel active steering angle etc. of the vehicle. The design of vehicle chassis integrated controller adopts the method based on linear inequation, which can realize the driving compensation force through the power or braking system of the vehicle, and the steering system can directly control the rotation of the rear wheel, while the heading control moment can be realized by adjusting the longitudinal sliding rate of the wheel.

(III) System simulation verification

In order to further verify the performance of the system proposed in this paper in improving of vehicle handling stability and the path tracking, it is decided to carry out single lane change, i.e. S curved path simulation test.

1. Single land change. The simulation test is conducted on the pavement with attachment coefficient of 0.8 and the design speed of integrated controller 20m/s. It is assumed that the driver does not participate in the control, but only controls via the controller, and meanwhile, the steering angle of the steering wheel and braking output are all fixed values, and the test is conducted after the vehicle drives at an initial speed of 30m/s, with single land change handling frequency 0.5Hz, and amplitude value 6° , at 2-4s, the vehicle acceleration is -0.2G. The result of simulation test shows that in the process of single lane change test, the driver model does not participate in the control, but R-MMC controller can effectively improve the handling stability of the vehicle, that is to say, in the condition of high-speed driving of the vehicle, the skip angle and heading angular velocity of the vehicle are within the allowable range of the stable threshold.

2. Path tracking capacity simulation. In order to further verify the improvement of system designed in this paper to the vehicle path tracking capacity, it is decided to carry out simulation experiment on S turning path, here the S turning path means the emergency steering operation and collision-prevention operation of the vehicle. In the simulation test, the initial speed of the vehicle is set to be 30m/s, and the turning radius is 50m. In order to make the result of simulation test more accurate, the initial position of the vehicle deviates 2.5m from the path central line. The result of simulation test shows that adopting the integrated controller to control the vehicle can improve its handling stability and path tracking capacity, with a good control effect.

Conclusion:

As stated above, a person-vehicle closed control system is designed based on the research achievements of the predecessors, which consists of driver model and robust model matching controller. Meanwhile, the effect of the system in improving the vehicle handling stability and path tracing capacity is verified through the method of simulation test, and the result of simulation test shows that the system proposed in this paper can further improve the vehicle handling stability and the path tracing capacity. Therefore, this system has certain promotion and use value, and when applied in vehicles, it can significantly reduce the driver's labor strength and is beneficial to improve the active safety of vehicles. In the future period, it is required to strengthen the research on vehicle chassis integrated control technology, and improve and perfect this technology continuously on the current basis, so that it can serve the automobile manufacturing service better, so as to promote the stable and sustainable development of automobile industry.

Acknowledgments

This paper is a scientific and technological project under the support of Provincial Department of Science and Technology, title name: Research on automobile active safety technology based on

chassis integrated control technology (project number: 20135BBG70010)

References

- [1] Wu Xing, Tang Dubing, *Limited Control Capacity Path Tracing Based on Speed and Acceleration Restriction* [J], Journal of Nanjing University of Aeronautics and Astronautics, 2012 (6)
- [2] Lou Peihuang, *Mixed Motion Control of Path Tracing and Servo Control of Automatic Guided Vehicle* [J] Journal of Machinery Engineering, 2011 (2)
- [3] Lyu Hongming, Chen Nan, *Handling Stability Simulation of Matlab/Simulink Four-wheel Steering Vehicle* [J] Journal of System Simulation, 2012 (9)
- [4] Jia Heming, Wang Jiapeng, Guo Jing, *Path Tracing Control of Intelligent Trolley Based on Adaptive Sliding Mode* [A], *Collected Papers of 2011 China Intelligent Automation Academic Meeting* [C]. 2011 (8).
- [5] Che Huajun, Chen Nan, Yin Guodong, *Stable Design Method of Vehicle Suspension based on Handling Stability* [J], *Automobile Engineering*, 2011 (6)
- [6] Yi Honghui, Xu Cangsu, *Vehicle Handling Stability Evaluation Method and its Application in Design of Vehicle Basic Structural Parameters* [J] *Machinery Design and Manufacturing*, 2012 (8)
- [7] Yang Rongshan, Yuan Zhongrong, Huang Xiangdong, *Optimal Research on Vehicle Handling Stability and Smoothness based on Approximation Model* [J], *Automobile Technology*, 2009 (7)
- [8] Li Jun, Yuan Shihua, Ju Dongmei, *Research on Test Method of Handling Stability of Special Vehicles based on Dynamics Simulation* [J] *Machinery Design and Manufacturing*, 2012 (10).