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Research Progress on Handling Stability of Four-Wheel Steering Vehicle

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Abstract*— The handling stability of the car is one of the important performance of the vehicle, which is related to the driving safety of the vehicle. Therefore, the handling stability of a vehicle has become an important indicator to measure the performance of a vehicle. This paper describes three aspects of four-wheel steering system structure, control strategy and development trend to provide some basis for the future development of four-wheel steering system.*

Keywords*— Four-wheel steering; Maneuvering stability; Control strategies; Development trends.*

I. Preface

With the improvement of living standards, people's requirements for cars are no longer limited to a means of transportation, but have become a pleasure to drive. With the continuous development of major cities, the rapid increase in the number of motor vehicles, urban roads are also becoming more and more congested, car parking, turning around are much more difficult than before. The phenomenon of changing lanes to overtake and changing lanes to avoid causing congestion ahead is increasing year by year. Front wheel steering system by turning the steering wheel, only drive the front wheels of the car for steering conditions, the rear wheels of the car does not have steering function. The front wheel steering system has certain disadvantages especially in the case of high-speed driving, the car's mass side deflection angle will increase due to the influence of the tire side deflection angle, reducing the car's traction ability and safety performance [1].

In order to solve the above problems, four-wheel steering system was born. Four-wheel steering control technology means that when the front wheels turn a certain angle, the rear wheels will turn a corresponding angle according to the angle of the front wheels and the speed of the car, and the participation of the rear wheels in steering can avoid problems such as long response time and poor tracking ability. When a four-wheel steering car is cornering at low speed, the rear wheel angle of the car is in reverse phase with the front wheel angle, which can reduce the turning radius of the car and improve the maneuvering flexibility. When the car is running at high speed, the rear wheels of the car are in the same phase with the front wheels, and the lateral eccentricity of the center of mass of the car becomes smaller at this time, and the maneuvering stability and safety are greatly improved [2].

II. Four-Wheel Steering System Structure

There are two main ways of steering the rear wheels of a four-wheel steering car: reverse-phase and in-phase. In the process of steering, the front and rear wheels turn in the same direction, which is the same direction steering, the steering wheel can quickly transfer the turning information to the rear wheels after turning, prompting the rear wheels to turn. And when running at high speed, the actual steering wheel angle is very small, the car's center of mass side eccentricity becomes small, which can improve the stability and safety of the vehicle at high speed; the vehicle in the process of steering the front and rear wheels turn in the opposite direction is the reverse position steering. When the vehicle is in the low-speed driving state, the turning angle is larger, and the rear wheels and the front wheels turn in the opposite direction, which can reduce the minimum turning radius of the vehicle and improve vehicle maneuverability [3].

At present, there are three main types of four-wheel steering systems: hydraulic, electric and mechanical four-wheel steering systems according to their structure [4], and each of these three systems has its own advantages and disadvantages.

(1) Mechanical four-wheel steering system

Most of the earliest four-wheel steering systems are mechanical. Mechanical four-wheel steering system controls the rear wheel turning angle by mechanical means. The driver turns the steering wheel and drives the tires to turn through a certain mechanical mechanism. This system has a simple structure and high reliability, but for the control of complex mechanisms, the accuracy is not high. A representative one is the Prelude developed by Honda, which controls the steering of the rear wheels through a mechanical structure connecting the steering wheel and the rear axle of the car.

(2) Hydraulic four-wheel steering system

This system uses hydraulic actuators to achieve the control of the rear wheel turning angle. It is a more mature and widely used four-wheel steering system with high reliability and low price, but the response time is long under high-speed conditions. Representative of the Mazda company.

(3) Electric four-wheel steering system

The system in the actual application process mainly has steering mechanism and electronic control unit two component institutions, is the use of sensors to measure

specific parameters of the vehicle to detect the vehicle movement state, and then the electronic control unit to calculate the rear wheel angle, with the steering booster to control the rear wheel angle, so that it turns through a certain angle. The system responds quickly and controls better, and gradually becomes the mainstream way of four-wheel steering system.

III. Four-Wheel Steering Control Strategy

Four-wheel steering control strategy is an important aspect to determine whether a vehicle can achieve four-wheel steering.

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With the development of automotive technology and newer research on control strategies, the factors considered in four-wheel steering control strategies have gradually increased and the range has expanded from linear to nonlinear. Early four-wheel steering control strategies were relatively single and simple to consider, and as progress was made, the research on control strategies went from shallow to deep. Nowadays, four-wheel steering control strategies can be simply divided into four major categories: feedforward, feedback, integrated control type and intelligent control type with adaptive learning capability.

Sano S et al [5] derived the relationship between the proportionality coefficient with respect to the front wheel turning angle and vehicle speed, and experiments showed that vehicles based on this control strategy can reduce the value of the mass lateral deflection angle, improve the stability of the vehicle, and accelerate the response to lateral acceleration compared to front-wheel steering vehicles, but the disadvantage is that it reduces the steering gain.

Shibahata et al [6], on the other hand, achieved the control of the rear wheels by designing the rear wheel turning angle as a function between the front wheel turning angle and the vehicle speed, which enabled the control system to ensure that the vehicle's center-of-mass lateral eccentricity was essentially zero at a wide range of driving speeds, which could effectively improve the vehicle's handling stability, but its performance could not be guaranteed under complex or relatively extreme operating conditions and its reliability was poor.

Inoue et al [7] applied the feedforward plus feedback control method to the control of four-wheel steering system, in which the feedforward control completes the basic steering operation and the feedback control resists the external disturbance, which improves the car's handling stability and also enhances the car's ability to resist external disturbance.

Higuchi et al [8] designed a controller based on optimal control theory considering the nonlinear characteristics of the car, and the simulation results showed that the control strategy they designed was superior to the control strategy with transverse pendulum angular velocity feedback in the nonlinear region of the tire.

Kaoru Takanami et al [9] designed a four-wheel steering control strategy in which the front and rear wheel angles are a function of each other, and the rear wheel angle is a function of the front wheel angle, and the rear wheel angle varies with the front wheel angle.

Shiotsuka [10] designed a neural network adaptive controller, which can improve the adaptive capability of the four-wheel steering car and effectively improve the handling stability of the car, and can suppress the influence of external disturbances to a certain extent, and can improve the steering stability of the car without increasing the driver's driving burden.

Horiuchi et al [11] designed a controller based on H∞ control theory, which can track the reference transverse velocity to improve the steering stability of a four-wheel steering vehicle, and has good performance under various operating conditions and strong resistance to external disturbances.

Nagai et al [12] designed a nonlinear control strategy that can effectively improve the handling stability of the vehicle in the operating range where nonlinearity has a large influence, making the four-wheel steering vehicle more adaptable to the operating conditions.

Jarrah et al [13] designed a fuzzy logic robust controller with a linear quadratic regulator to obtain a robust integral control of the system, and the simulation confirmed that the controller designed by them can maintain the lateral eccentricity of the car near zero and ensure the good handling stability of the car even under the parameter changes and external disturbances.

Alfi et al [14] proposed a hybrid control method combining sliding film control and fuzzy control using fuzzy logic, and used Lyapunov stability theory to ensure the stability of the proposed control method. The simulation results showed that the control strategy designed by them could make the lateral eccentricity of the center of mass converge to zero and accelerate the transverse swing angular velocity response, which improved the driving stability of the car and maintained the stability of the car in the presence of external disturbances.

Hiraoka et al [15] designed a four-wheel steering vehicle path tracking controller based on the sliding film control theory and the simulation showed that the accuracy of its controller path tracking is better than that of the front-wheel steering vehicle path tracking controller, and the four-wheel steering vehicle has better stability in the path tracking process, and the control system can maintain good stability in the presence of external disturbances and changes in system parameters.

Hakima et al [16] designed a fuzzy controller for active control of rear wheel turning angle and the effectiveness of their designed controller was confirmed by simulation and the controller was able to remain effective and robust in the presence of parameter changes.

Saikia et al [17] used a two-layer controller to control the active steering and transverse sway moment of the vehicle to track the state values of the ideal model. The upper controller uses a sliding mode control algorithm to generate the front wheel steering angle and transverse swing moment, and the lower controller controls the wheels to generate the transverse swing moment for the upper controller. The simulation verifies that the designed two-layer controller works well, and the transverse swing angular velocity and the mass lateral deflection angle of the vehicle during steering track the ideal model values very well.

Elhefnawy et al [18] proposed an advanced integrated control system that combines direct transverse moment control (DYC) and active front wheel steering system (AFS) to track the transverse angular velocity and center-of-mass lateral deflection angle of the reference model, and designed fuzzy logic controller to control the transverse moment and wheel

turning angle, which was simulated under J-curve and lane shift conditions, and the results showed that the designed integrated DYC and AFS control system showed significant improvement in vehicle stability in terms of vehicle lateral acceleration, lateral deflection angle, transverse angular velocity, and lateral camber angle.

Li B et al [19] proposed a vehicle stability control strategy combining direct transverse swing moment and active rear wheel steering, where the required transverse swing moment and rear wheel turning angle were generated by the upper sliding-mode controller, and the stability of the sliding-mode controller was demonstrated using Lyapunov functions, and the lower controller realized the distribution of the transverse swing moment, and open-loop and closed-loop simulations of the vehicle model were performed. The results show that the stability of the vehicle is improved and the effectiveness of the proposed bipolar control method is verified.

Zong Changfu et al [20] proposed three control strategies of front-wheel control, side-slip rate feedback, and side-slip rate and acceleration feedback, and compared front-wheel steering with conventional four-wheel steering through simulations and simulator tests, and the method was effective in improving vehicle handling stability.

Yin et al [21] designed a four-wheel steering vehicle control system based on μ integrated robust control method, and simulated and analyzed the control system, and the results showed that the four-wheel steering vehicle control system effectively improved the vehicle handling stability and the system robustness

Gu Zhengqi et al [22] designed a four-wheel steering control system based on the BP neural network model with reference to the adaptive control method, and a nonlinear three-degree-of-freedom vehicle model considering the side wind effect was used as the control object in the simulation, and the results showed that the transverse swing angular velocity and lateral acceleration response recovery time of the controlled four-wheel steering vehicle under the side wind effect were smaller than those of the uncontrolled vehicle, and the lateral displacement of the controlled four-wheel steering vehicle was much smaller than that of the uncontrolled vehicle, and the control system could ensure the stability of the vehicle under the side wind effect even under the vehicle parameter change conditions.

Ding Yanchao et al [23] designed a four-wheel steering path tracking control system based on optimal control theory, and the results showed that the designed control system has excellent path tracking performance, and the transverse swing angular velocity response of the car in the path tracking process approximates the reference value, and also reduces the mass lateral deflection angle of the car, so that the car has higher path tracking accuracy and better handling stability.

Wang Jing et al [24] designed a four-wheel steering control system with model tracking as the control strategy, combined feedforward and feedback, and designed an output feedback controller using constrained H∞ control theory, and the simulation results showed that their designed control system could track the reference center-of-mass lateral eccentricity and transverse swing angular velocity well, which effectively improved the handling stability of the car, and at the same time, the control system could resist the influence of external disturbances.

Tian J. et al [25] designed a four-wheel steering hierarchical control system to control a four-wheel steering vehicle by two controllers, the upper and lower layers, to achieve the tracking of the reference center-of-mass lateral eccentricity and the reference transverse swing angular velocity, and simulated the upper layer control system, the lower layer control system and the combined upper and lower layer control system respectively.

Mao Dingding et al [26] designed a four-wheel steering vehicle path tracking controller, and added the zero-mass lateral eccentricity control and dynamic tire lateral eccentricity boundary control methods into the path tracking algorithm, and the simulation results showed that the designed control system not only tracked the reference path with high accuracy, but also improved the driving stability of the vehicle in the path tracking process.

In summary, the four-wheel steering system does improve the driving stability of the car, and many control methods have been applied to the control of the four-wheel steering system, among which researchers have focused on different aspects, some mainly to improve the effectiveness of the control system in the nonlinear operating range of the car, while others mainly to improve the ability of the control system to resist external disturbances or to improve the adaptability of the control system.

IV. Development Trend

With the development of science and technology and the in-depth study of control theory, four-wheel steering vehicles will gradually appear in the public's view, which meets the needs of social progress and is the research direction of future vehicles. In the future research, four-wheel steering vehicles will focus on the following aspects.

(1) With the improvement of computer technology, various control theories will emerge, and how to realize the optimal control of four-wheel steering system is the key place of research.
(2) To continuously improve the performance of tires to adapt to the future development of automotive technology changes.
(3) The four-wheel steering system must take the closed-loop comprehensive evaluation as the starting point, and combine with other active safety technologies, in order to make the four-wheel steering technology practically applied to the engineering.

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