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Research on Control Strategies for Improving the Minimum Turning Diameter in Pure Electric Vehicles

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Abstract: The minimum turning diameter is a direct reflection of a vehicle's agility. In research aimed at optimizing control to minimize the turning diameter, the key lies in understanding and adjusting various factors that impact vehicular steering performance. This paper focuses on front-wheel drive electric vehicles, with the primary research emphasis on identifying the optimal hydraulic brake distribution strategy under cornering conditions, targeting enhanced maneuverability. By adopting a control scheme that involves coordinated braking of non-driven wheels, particularly focusing on the outer wheel, simulation analysis reveals that implementing this control strategy can reduce the minimum turning diameter from 10.82 meters to 9.89 meters. Through real-vehicle functional testing, integrating this control strategy into an onebox braking system further demonstrates its effectiveness, decreasing the minimum turning diameter from 10.92 meters to 9.94 meters. The similarity between simulation and real-vehicle test results indicates that this control strategy significantly improves the vehicle's minimum turning diameter, thereby enhancing its maneuverability during turns while ensuring driving safety and handling stability.This finding highlights the potential of advanced braking coordination techniques, specifically targeting non-driven wheels during cornering maneuvers, to achieve tighter turning radii in electric vehicles without compromising safety or dynamic handling. This development holds significant promise for improving overall driving experience and efficiency in urban environments where tight maneuverability is often required.

1. Introduction

In terms of handling performance in passenger cars, the minimum turning diameter is an important parameter to measure the vehicle's maneuverability and passability, and its research has always occupied a core position. Especially in increasingly complex traffic environments and narrow city road conditions, the flexibility and handling performance of vehicles are particularly important[1]. The minimum turning diameter not only reflects the performance of the car under extreme steering conditions, but also directly affects the convenience and safety of the driver's operation. In recent years, with the rapid development of electric vehicle technology, front-wheel drive electric vehicles have received widespread attention due to their high efficiency and energy-saving characteristics[2]. However, how to optimize the vehicle's turning performance while ensuring energy efficiency has become an urgent problem to be solved[3]. Therefore, major OEMs are committed to exploring innovative control strategies and technical means to reduce the minimum turning diameter, in order to improve the passability performance of electric vehicles[4].

This study is based on current technical challenges and market demands, focusing on the optimization of the minimum turning diameter for front-wheel drive electric vehicles[5]. It will analyze in depth the key factors influencing the vehicle's turning performance, and propose a control strategy based on brake hydraulic distribution, aiming to effectively reduce the turning radius of the vehicle by precisely controlling the state of the non-driven wheels. In addition, the author will use simulation techniques and on-road testing methods to verify and optimize the proposed control strategy, providing scientific basis and practical guidance for the design and performance improvement of electric vehicles[6]. By combining theoretical analysis with experimental verification, this study aims to explore and optimize the control strategy for the minimum turning diameter of front-wheel drive electric vehicles, contributing to the improvement of vehicle passability, enhanced driving experience, and the advancement of electric vehicle technology.

2. Simulation plan for the minimum turning diameter

Based on vehicle dynamics design and relevant engineering experience, the factors influencing the minimum turning diameter of the vehicle can be determined. These mainly include the vehicle's wheelbase, steering gear ratio, and tire parameters. It also includes advanced features such as advanced turning assistance.

2.1. Vehicle parameter settings

The vehicle parameters are as shown in Table 1 below.

Table 1: Vehicle basic parameter table

basic parameter		Technical parameters
Vehicle parameter	Length (mm) ×Width (mm) × Height (mm)	4660×1900×1520
	Wheelbase (mm)	2880
	Steering gear ratio	15
Tire	Tire size (front/rear)	235/55 R18

Its settings in the CarSim model are as shown in Figure 1 below:

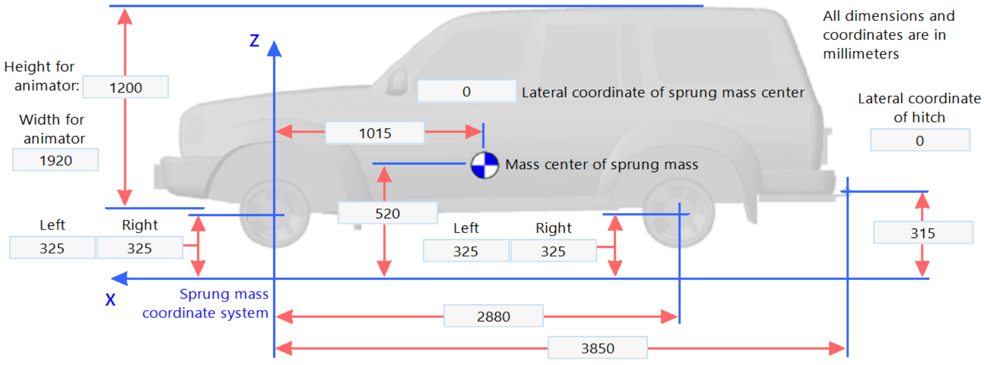

Figure 1: Schematic diagram of vehicle parameters in CarSim model

In CarSim, the steering gear ratio cannot be directly set. However, the rack travel for one full rotation of the steering wheel can be calculated using the transmission ratio. C Factor: Linear travel of the rack for one full rotation of the steering wheel. The conversion formula is as follows:

$$i = \frac{1}{\frac{\text{C factor}}{360} \times Steer\ Kinematics}$$

The C factor can be calculated as 53mm/rev using the formula provided, where *i* represents the transmission ratio and the *Steer Kinematics* represents the average value of tire slope[7]. The result is shown in Figure 2 below:

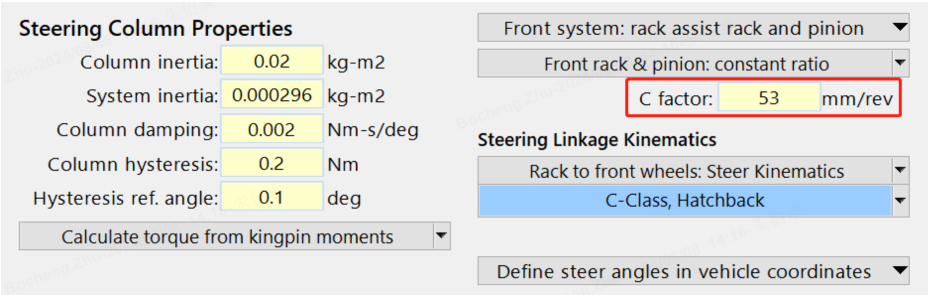

Figure 2: Schematic diagram of the linear travel of the rack for one full rotation of the steering wheel

2.2. Simulation scenario design

This study focuses on the minimum turning diameter of the vehicle. When setting up the simulation conditions, it is necessary to confirm the relevant parameters of the vehicle, which have been set up in the previous section. This section mainly deals with the simulation steps. According to the standard for this simulation, the vehicle speed is set to 5 km/h, and the steering wheel is turned to the left or right to the limit without touching the accelerator or brake pedal, and the diameter of the outermost tire track circle is recorded at this time. The above-mentioned is a conventional simulation scenario, while this study is based on a strategy involving improved braking.

2.3. Control scheme analysis

The strategy proposed in this paper is as follows: (1) When the vehicle turns left, the left rear wheel locks; (2) When the vehicle turns left, the left rear wheel locks and the left front wheel is slowed down. To verify the above two strategy schemes, the authors conducted a joint control simulation using Carsim and MATLAB/Simulink. The setup scheme is shown in Figure 3:

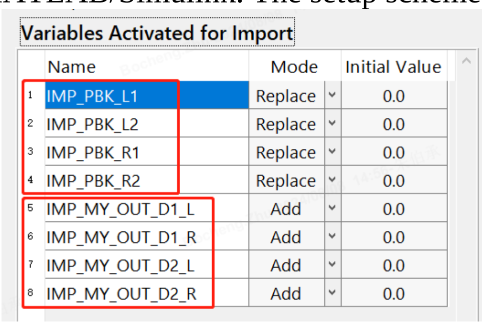

Figure 3: Simulink input parameters

In the figure, "IMP_PBK" represents the brake output hydraulic pressure, and "IMP_MY_OUT" represents the total driving torque of the tires. L1, L2, R1, and R2 represent the left front wheel, left rear wheel, right front wheel, and right rear wheel, respectively.

The relevant parameters are synchronously set in Simulink, as shown in Figure 4:

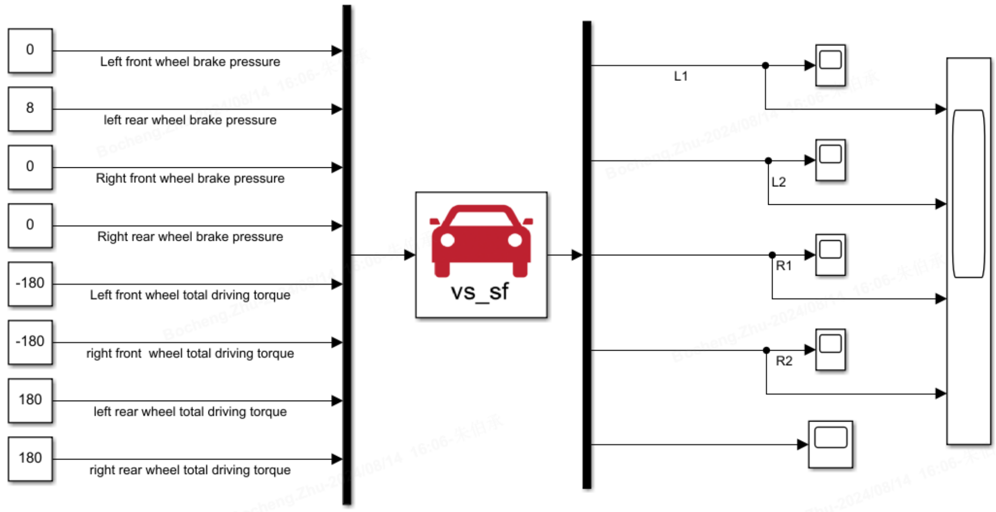

Figure 4: Simulink control model

After setting the relevant operating conditions, running the simulation in carsim can produce the vehicle's motion trajectory, with the starting point of the vehicle trajectory set at the center of the right front wheel.

When developing new features, the OEM will integrate multiple functions into specific software. In this study, the research team integrated the above function strategy into onebox, which is a traction control system and an automotive safety braking solution. In fact, it is the vehicle's underlying electronic control system. As shown in Figure 5 below, this is a schematic diagram of the onebox.

Figure 5: schematic diagram of onebox

3. Simulation analysis and real vehicle testing

3.1. Analysis of Results under Normal Driving Conditions

Based on the simulation results, we can obtain the trajectory circle as shown in Figure 6:

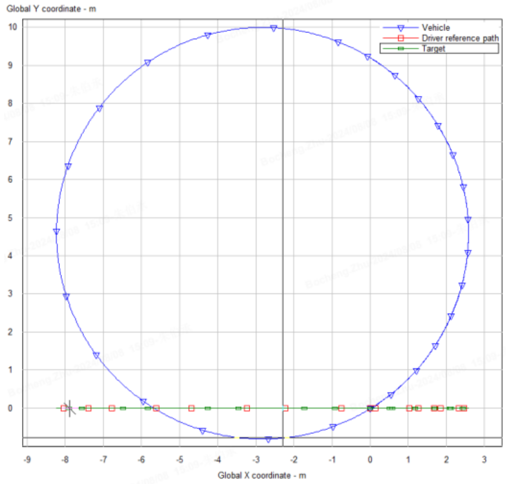

Figure 6: Simulation test trajectory diagram of minimum turning radius without control

According to the data shown in the figure, the turning diameter is 10.82 meters, which indicates a moderate level of performance compared to vehicles in the same class. However, there is still some room for improvement based on the current level.

According to the results of the real vehicle test, the following Figure 7 trajectory circles can be obtained.

Figure 7: Real Vehicle Test Trajectory Diagram of Minimum Turning Radius without Control

According to the measurement results, the turning diameter is 10.92m. This result is almost consistent with the simulation test results, indicating that the vehicle dynamic model is established with fairly accuracy. Accordingly, both test results are trustworthy.

3.2. Analysis of Results with Control

3.2.1. Analysis of Braking the Inside Rear Wheel

This control strategy is based on braking the inside rear wheel, causing it to be in a slipping state. The schematic diagram of this strategy is shown in Figure 8:

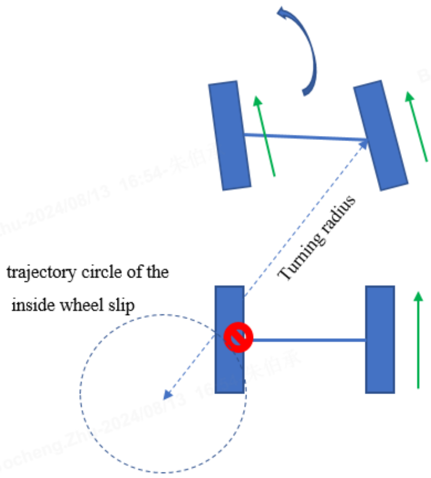

Figure 8: Schematic Diagram of Simulation Analysis of Braking the Inside Rear Wheel

Based on this strategy, a combined simulation control using Carsim and Simulink is performed, and the relevant results are shown in Figure 9 and 10:

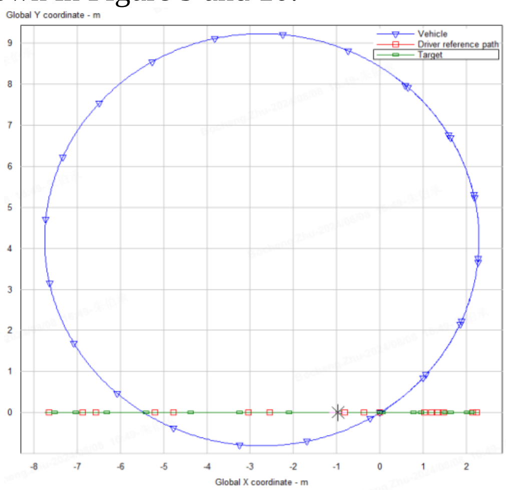

Figure 9: Trajectory with Simulation Analysis of Braking the Inside Rear Wheel and the Minimum Turning Diameter

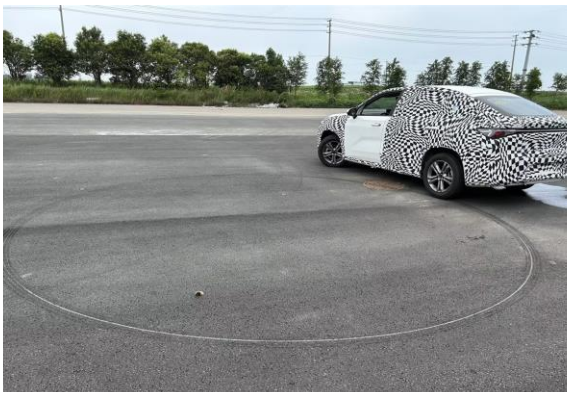

Figure 10: Trajectory with real vehicle testing of Braking the Inside Rear Wheel and the Minimum Turning Diameter

Based on the simulation diagram data, the turning diameter is 10.04m. Under uncontrolled conditions, the minimum turning diameter decreases by 0.78m. In terms of performance contribution, this control solution shows high feasibility. In vehicle tests, the measured turning diameter is 10.16m, with a reduction of 0.76m compared to uncontrolled conditions. The results closely match the simulation test results, confirming the effectiveness of the control.

3.2.2. Analysis of Braking the Inside Rear Wheel and Reducing the Speed of the Inside Front Wheel

This control strategy is based on braking the inside rear wheel and reducing the speed of the inside front wheel. The schematic diagram of this strategy is shown in Figure 11:

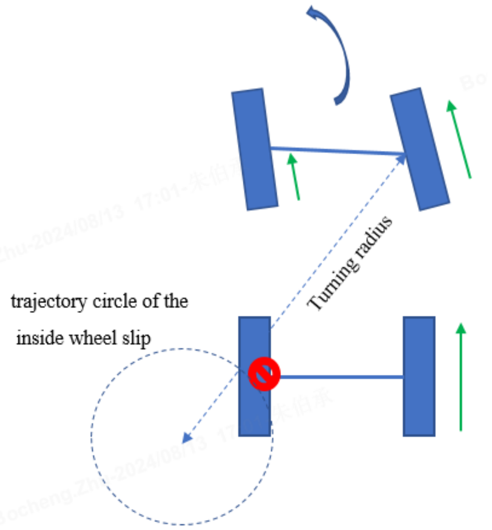

Figure 11: Schematic Diagram of Braking the Inside Rear Wheel and Reducing the Speed of the Inside Front Wheel

Based on this strategy, a continued combined simulation control using Carsim and Simulink is performed, and the relevant results are shown in Figure 12.In real vehicle testing, the trajectory diagram for the minimum turning diameter with braking of the inside rear wheel and reduced speed of the inside front wheel is illustrated in Figure 13:

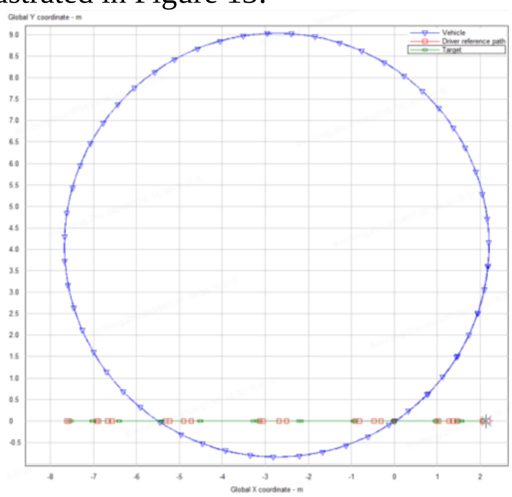

Figure 12: Trajectory with Braking the Inside Rear Wheel and Reducing the Speed of the Inside Front Wheel and the Minimum Turning Diameter

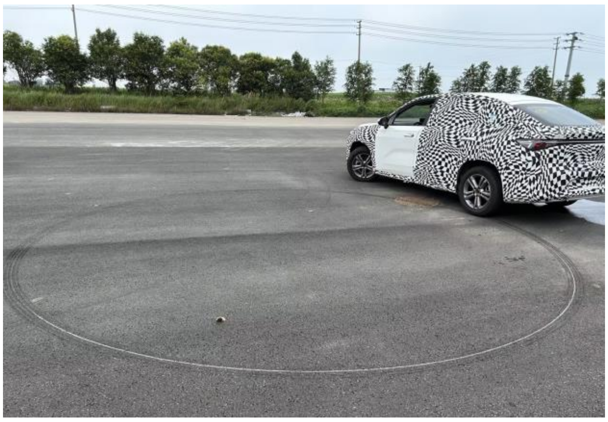

Figure 13: Trajectory with real vehicle testing of Braking the Inside Rear Wheel and Reducing the Speed of the Inside Front Wheel and the Minimum Turning Diameter

According to the simulation diagram data, the turning diameter is 9.89m. Under uncontrolled conditions, the minimum turning diameter decreases by 0.97m. In terms of performance contribution, this control solution shows high feasibility. In vehicle tests, the measured turning diameter is 9.94m, with a reduction of 0.98m compared to uncontrolled conditions. The results closely match the simulation test results, confirming the effectiveness of the control. Compared to the previous strategy, this control method exhibits better performance.

3.3. Comparative Analysis

Through the simulation analysis of different control strategies, the following results can be obtained. As shown in Table 2 below.

Table 2: Simulation Comparison Table

	Uncontrolled(m)	Control Strategy 1(m)	Control Strategy 2(m)
Simulation experiment.	10.82	10.04	9.89
Real vehicle test.	10.92	10.16	9.94
Measure of Variation	0.1	0.08	0.05

According to the above table, it can be observed that in the simulation experiments, strategy one reduces the minimum turning diameter by 0.78m with a contribution rate of 7.21% under no control condition, while strategy two reduces the minimum turning diameter by 0.97m with a contribution rate of 8.96% under no control condition. In actual vehicle tests, strategy one reduces the minimum turning diameter by 0.76m with a contribution rate of 7.01% under no control condition, while strategy two reduces the minimum turning diameter by 0.98m with a contribution rate of 8.97% under no control condition.

4. Conclusion

Aimed at improving the minimum turning diameter, this paper explores different braking strategies applied to the inside rear wheel and the inside front wheel. Through simulation analysis and real vehicle testing, it was found that locking the inside rear wheel and decelerating the inside front wheel yields the best results in terms of reducing the minimum turning diameter.The strategy proposed in this paper was first experimentally analyzed through simulations to draw conclusions. Subsequently, during actual vehicle tests, the onebox software integration method was employed to control wheel braking, thereby implementing the strategy. Based on the aforementioned analysis, the control strategy presented herein effectively enhances the minimum turning diameter of electric vehicles. This improvement ensures better maneuverability and passage ability when navigating narrow roads or making U-turns, providing reliable experimental analysis support for enhancing automotive chassis control performance.

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