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Research on parallel braking control of distributed drive electric vehicles

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ABSTRACT

For distributed drive electric vehicles, according to the actual needs of the composite braking system of electric vehicles, the braking safety is the mainstay, and the energy recovery is carried out at the same time, and the distributed parallel braking control strategy is proposed. The strategy adopts a hierarchical control structure, with the upper control aiming at brake safety and the lower control aiming at brake energy recovery. The designed parallel brake control policy takes into account the distribution of braking force in the front and rear axles, as well as constraints such as braking strength, battery SOC value, and motor. Finally, a simulation analysis is carried out to verify the braking efficiency and energy recovery effect.

Keywords: distributed electric vehicles; parallel braking; braking energy recovery

INTRODUCTION

There are three ways to brake the motor, namely reverse braking, energy consumption braking, and regenerative braking. The compound braking system uses an electric motor braking method as regenerative braking. Regenerative braking torque comes from the motor, through the motor in the braking, from the motor mode to the generator mode, through the inertia of the vehicle to drive the rotor rotation of the motor to produce a reversal torque, the direction of this torque and the direction of the speed opposite, so that the shaft produces a mechanical braking torque to slow down the vehicle, while a part of the kinetic energy into electrical energy recovery to charge the battery.

The compound braking system is divided into two ways: series braking and parallel braking according to the combination of motor braking and hydraulic braking. The tandem composite braking system is to change the original hydraulic brake mechanism, increase the wire control system, control the hydraulic braking system, so that it can realize electronic control, cooperate with the motor braking of the drive wheel, and carry out compound braking in different working environments.

Hydraulic and motor brakes work together when braking. This kind of composite braking system has high energy recovery efficiency, but the control and structure are complex, the control accuracy required is relatively high, and the cost of transformation is high. The parallel composite braking system is based on the original hydraulic braking structure to increase the electrical power torque on the drive wheel, and superimpose the electrical mechanism power on the hydraulic braking force. Although the effect of energy recovery is general, this composite braking system does not need to be modified by the original hydraulic braking system, which is relatively simple and easy to achieve [1-3].

For distributed two-wheel drive electric vehicles, Zhang Kangkang and others designed two parallel braking strategies, and compared with the tandem strategy, the simulation of the tandem strategy recovery rate is higher than the parallel connection, but it is difficult to use in engineering practice, the current parallel braking strategy is mostly used for centralized drive or distributed two-wheel drive electric vehicles, for four-wheel drive electric vehicle research is relatively small, and the parallel braking strategy is more and parallel braking strategy for simulation comparative analysis, the lack of experimental comparison, cannot verify the reliability of simulation analysis results [4].

In this paper, according to the actual vehicle structure, battery SOC value, speed, motor and battery, etc., this paper designs a parallel composite braking system according to the actual vehicle structure, battery SOC value, vehicle speed, motor and battery, and at the same time establishes a simulation model in Amesim and other related software, conducts joint simulation, and verifies the braking performance and energy recovery results of the composite brake control system.

COMPOSITE BRAKE SYSTEM STRUCTURE SCHEME DESIGN

Parallel composite braking system uses the traditional hydraulic brake system and motor brake system to work together, the mechanical power of the hydraulic brake system comes from the traditional hydraulic brake, and the four-wheel hub motors are respectively installed with a set of hydraulic brakes. The hydraulic braking system includes brake pedals, brake master cylinder disc brakes, and brake discs. This is shown in Figure 1.

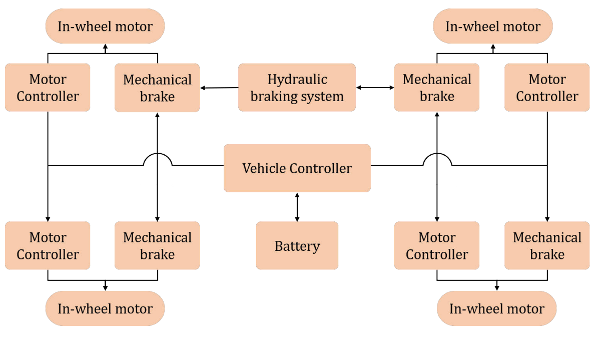

FIGURE 1: Composite braking system structure scheme

MODELING OF COMPOSITE BRAKING SYSTEMS

Control Policies

The compound brake control strategy adopted by this model is a control strategy that is improved on top of the braking method of traditional cars [5]. The upper controller uses a reasonable control algorithm to make the front and rear wheel braking force distribution conform to the ideal braking force distribution curve as much as possible for the stability of the braking system, and controls the slip rate of the vehicle during braking. The lower controller uses the brake energy recovery as the purpose to reasonably distribute the electrical torque and hydraulic braking force, and restricts the electrical mechanism power by the speed of the vehicle braking process, the characteristics of the motor itself, and the battery SOC. In the braking process, the electrical braking torque of the hub motor and the mechanical braking torque of the hydraulic braking system are jointly involved, and the energy recovery is carried out under the premise of mainly ensuring the stability of the brake.

First of all, the car according to the size of the brake pedal linkage displacement, the upper controller receives the brake pedal signal after judging the current braking intensity and total braking force, and the signal is assigned to the braking force distribution module; according to the real-time acquisition of the speed, wheel speed and other information calculated wheel slip rate judgment, the braking method will be used to transmit to the brake force distribution module, the brake force distribution module after receiving the signal, with braking stability as the control goal, the braking force required for each wheel is assigned to the corresponding wheel.

The lower-level controller distributes the electrical power with the goal of braking energy recovery. Although the more power distribution of the electrical mechanism, the better the effect on energy recovery, but due to the characteristics of the motor itself, the speed, the battery SOC and the limitation of charging power, the power of the electrical mechanism needs to be controlled.

Distribution of braking force

In order to ensure that the car brakes safely without dangerous working conditions, the vehicle should be allowed to avoid the situation of locking when braking, and the front and rear wheels should be held at the same time or only the front wheels should be held when the brakes are held [6-8]. According to the analysis of the braking force of the electric vehicle, the braking force distribution of the front and rear wheels can be obtained as follows:

$$\begin{cases} F_{\mu 1} = \dfrac{Mg(b+zh_g)}{L} \\ F_{\mu 2} = \dfrac{1}{2}\left[\dfrac{Mg}{h_g}\sqrt{b^2 + \dfrac{4h_g L}{Mg}F_{\mu 1}} - \left(\dfrac{Mgb}{h_g} + 2F_{\mu 1}\right)\right] \end{cases} \quad (1)$$

In the formula, h_g is the height of the car's center of mass from the ground; M is the body mass; b is the distance from the rear wheel to the center of mass; L is the distance between the front and rear axles of the car; $F_{\mu 1}$ and $F_{\mu 2}$ are the braking forces of the front and rear axles, respectively.

Taking the basic parameters of the vehicle into Equation (1), the ideal braking force distribution curve I curve of the front and rear axles can be obtained by calculation. In order to avoid the situation that the rear wheels lock first, when the electric vehicle brakes, the distribution curve of the front and rear braking forces should appear below the I curve. Therefore, the braking force curve equations of the front and rear wheels are shown in Equation (2).:

$$F_{\mu 1} - \frac{1}{2}\left[\frac{Mg}{h_g}\sqrt{b^2 + \frac{4h_g L}{Mg}} - \left(\frac{Mgb}{h_g} + 2F_{\mu 2}\right)\right] < 0 \quad (2)$$

When the vehicle brakes under different ground adhesion coefficients, the braking force distribution formula for front wheel locking is:

$$F_{\mu 2} - \frac{1}{2}\left[\frac{Mg}{h_g}\sqrt{b^2 + \frac{4h_g L}{Mg}} - \left(\frac{Mgb}{h_g} + 2F_{\mu 1}\right)\right] = 0 \quad (3)$$

At the same time, according to the braking requirements of the ECE braking regulations, when the braking intensity z is 0.2-0.8, the constraints of the vehicle are: $z \geq 0.1 + 0.85 * (\varphi - 0.2)$

The braking force of the front and rear wheels should meet the:

$$\begin{cases} F_{\mu 1} \leq \dfrac{Mgz(b+zh_g)}{L} \times \dfrac{z+0.7}{0.85} \\ F_{\mu 2} = Mgz - F_{\mu 1} \end{cases} \quad (4)$$

Through equation (4), the critical curve M curve of ECE braking regulation can be obtained simultaneously:

$$\frac{(F_{\mu 1}+F_{\mu 2})^2 h_g}{MgL} + \frac{(F_{\mu 1}+F_{\mu 2})(0.07h_g+b)}{L} + \frac{0.07Mgb}{L} - 0.85F_{\mu 1} = 0 \quad (5)$$

Parallel braking constraints

The proposed parallel braking strategy limits the braking power of the motor by considering the braking intensity of the vehicle, battery SOC, vehicle speed, battery charging power and other conditions.

vehicle braking strength

When the braking intensity of the vehicle is z>0.85, the continuous use of motor braking will cause safety risks. At this time, the motor does not participate in braking, and only traditional hydraulic braking is used.

When the vehicle braking intensity z<0.85, the motor braking and the hydraulic braking are superimposed

At this time, the braking strength constraint coefficient K_z is:

$$K_z = \begin{cases} 0 \mid z > 0.85 \\ 1 \mid z \leq 0.85 \end{cases} \quad (6)$$

Battery SOC

The current generated by the electric braking when the vehicle is braking needs to be recycled into the power battery. Therefore, whether energy recovery can be performed first depends on the SOC of the battery. In order to prevent the electric energy generated during the braking process from overcharging the battery, the motor braking force needs to be constrained. Therefore, the SOC value of the battery is set to 0.85 when the motor is braking, and the electric braking is stopped when the SOC value is greater than 0.85. The battery SOC influence factor K_{soc} is set as:

$$K_{soc} = \begin{cases} 0 \mid soc > 85\% \\ 20(0.85 - soc) \mid 80\% \leq soc \leq 85\% \\ 1 \mid 80\% > soc \end{cases} \quad (7)$$

Vehicle Speed

When the speed of the vehicle is less than 10km/h, the speed of the motor decreases. When the vehicle brakes, the inertia of the vehicle itself is small, and the back electromotive force cannot be generated higher than the battery voltage, so the regenerative braking ability disappears. Therefore, when the vehicle speed is lower than 10km/h, the motor brake is set to not participate in the braking process, and only hydraulic braking is performed. Set the vehicle speed influence factor K_v, the influence of vehicle speed on the click braking force is:

$$K_v = \begin{cases} 0 \mid v \le 10\text{km/h} \\ 1 \mid v > 10\text{km/h} \end{cases} \tag{8}$$

Charging Power

The rechargeable power generated by a single motor when the vehicle is braking is:

$$P_b = \eta_M \times \eta_i \times \eta_B \times P_{m\max} \tag{9}$$

In the formula, P_b is the instantaneous power during charging, η_M is the power generation efficiency of the motor, η_i is the inverter efficiency, η_B is the charging efficiency of the battery, and P_{mmax} is the maximum power generation efficiency of the battery.

The total power when all motors are electrically braked is:

$$P_{batt} = \sum P_b \tag{10}$$

The braking current generated by the motor braking is:

$$I = \frac{P_{batt}}{U} \tag{11}$$

The instantaneous power and charging current generated by charging during the motor braking process should not be greater than the maximum rated charging power and rated charging current of the battery to prevent damage to the battery. The charging power influencing factor K_p and the charging current influencing factor K_I are set as:

$$K_p = \begin{cases} 0 \mid P_{batt} > P_e \\ 1 \mid P_{batt} \le P_e \end{cases} \tag{12}$$

$$K_I = \begin{cases} 0 \mid I > I_e \\ 1 \mid I \le I_e \end{cases} \tag{12}$$

Among them, P_e is the rated charging power, and I_e is the rated charging current.

Through the above analysis, it can be obtained that the actual maximum value of motor braking force is:

$$F_{m\max} = \frac{T_{m\max} * i_g * i_0 * \eta_T * K_v * K_P * K_I * K_{soc} * K_z}{r} \tag{13}$$

SIMULATION ANALYSIS

The simulation condition is a road with an adhesion coefficient of 0.7, braking at an initial speed of 36km/h, and the braking speed variation curve Figure 2, the braking acceleration curve Figure 3, the braking distance variation curve Figure 4, and the battery SOC are obtained. Change curve Figure 5.

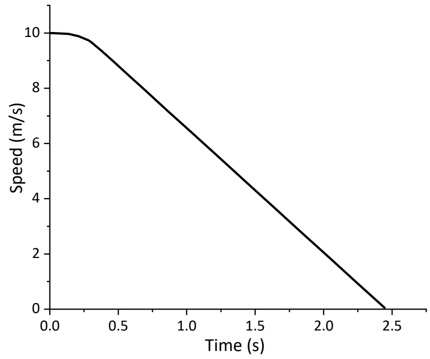

FIGURE 2: Braking speed variation curve

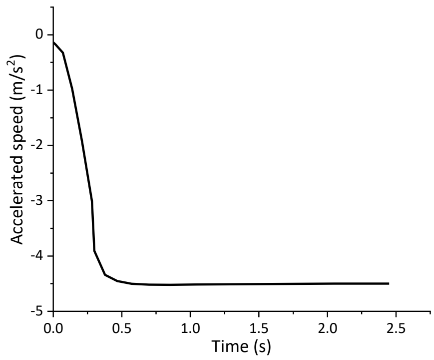

FIGURE 3: Braking acceleration curve

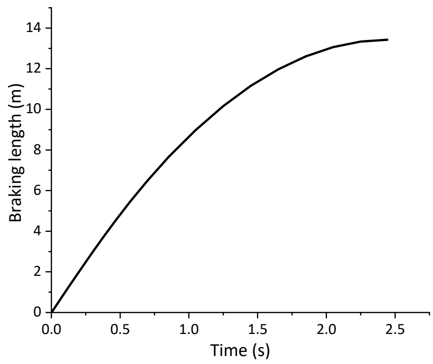

FIGURE 4: Braking distance variation curve

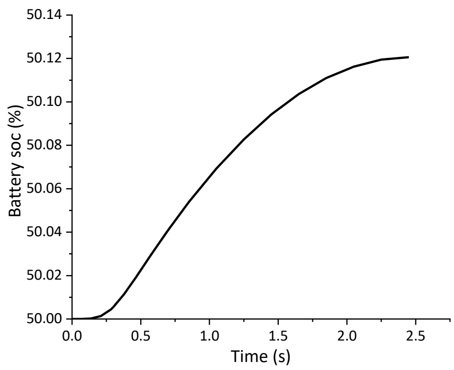

FIGURE 5: Battery SOC

When the car starts to brake at the initial speed of 36km/h, with the increase of the braking intensity, under the low braking intensity, the electric braking and the hydraulic braking are carried out at the same time, and the braking acceleration rapidly rises to 4.5m/s^2. The braking distance is about 12.5m. Since the motor participates in the braking process all the way, the battery keeps charging until 50.12%, and the SOC value keeps changing until the braking ends.

SUMMARY

Through the joint simulation of the built composite braking system control model, the speed change, braking distance, acceleration change and battery SOC value change curve of the vehicle under two different braking conditions are obtained. The parallel compound braking system can coordinate the motor braking and the hydraulic braking according to the braking conditions to achieve stable braking and good braking energy recovery.

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