Research on charging safety and braking stability of pure electric vehicle regenerative braking

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Abstract: Pure electric vehicles play an important role in the rapid development of new energy vehicles due to their simple structure, zero emissions and high energy efficiency. With the implementation of the national electric vehicle strategy, the technology and products in the field of electric vehicles and their charging have developed rapidly, and the problems of charging safety and compatibility have become increasingly prominent. The structure of variable voltage charging of hub motor based on BMS and the working principle of variable voltage charging regenerative braking control method are introduced; Based on the theoretical model of variable voltage charging of hub motor, the control law of variable voltage charging regenerative braking of hub motor electric vehicle is explored. Firstly, the structure of electromechanical composite brake assembly of pure electric vehicle, the working principle of energy recovery and the main factors affecting the feedback effect of regenerative braking are analyzed in detail, and the distribution mode of electromechanical braking effort of regenerative braking system is studied. The solutions to the charging safety are given from the perspective of technology and management, and the safety issues that need to be studied are also put forward, so as to provide reference for the healthy development of electric vehicle industry.

1. Introduction

In recent years, with the successive introduction of new energy policies, the development momentum of electric vehicles is strong, and the demand for supporting construction of electric vehicle charging facilities is extremely urgent. Therefore, strategic research, layout planning and pilot projects for the construction of electric vehicle charging facilities are carried out as soon as possible. It is of great significance to realize energy substitution, optimize energy structure, and increase the proportion of clean energy [1]. At present, the world's major auto companies are committed to the development of new energy vehicles to achieve energy saving and emission reduction. The new energy vehicles that have been developed are mainly divided into pure electric vehicles, plug-in hybrid vehicles and fuel cell vehicles [2]. Electric vehicle charging piles are the premise for the development of electric vehicles. The charging pile generates a large amount of data during operation. These data types and attributes are diverse, which brings difficulties to the subsequent statistics and analysis of data [3]. In view of the current situation that it is difficult for power battery technology to make substantive breakthroughs in the short term, regenerative braking technology has become one of the research hot technologies of new energy vehicles [4].

The existing regenerative braking technology is realized by installing a bidirectional power control circuit between the motor and the power battery pack, and controlling the regenerative braking torque by adjusting the on-off time of the high-frequency power switch [5]. Before analyzing the charging safety of electric vehicles, it is necessary to classify their safety levels, so as to formulate safety measures according to the levels and ensure the reliability and rationality of charging safety of electric vehicles [6]. The key technologies for the development of pure electric vehicles mainly include the development of high-performance energy storage systems, the development of high-efficiency drive systems, the development of vehicle integrated control systems, and the regenerative regenerative braking technology. In regenerative braking, with the dynamic change of the braking intensity of the motor, the size of the charging current and the charging time to the battery both change. Therefore, in order to improve the regenerative

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regenerative braking rate while ensuring the safety and service life of the battery, it is of great significance to study the temperature rise control of the regenerative braking battery according to the actual cycle conditions, which is of great significance to the battery charging safety and regenerative braking [7]. According to the research task of the key project of the Natural Science Foundation, this subject takes the front-axle single-motor centralized drive pure electric vehicle developed by an enterprise as the research object, and takes the efficient energy recovery under braking safety and stability as the goal, focusing on the efficient energy recovery of regenerative braking, battery charging safety control and braking stability of the whole vehicle. As well as the cooperative control algorithm of electromechanical composite brake assembly composed of hydraulic braking and regenerative brake assembly, it is also the key research content of this subject.

2. Influencing factors of regenerative regenerative braking and braking effort distribution

2.1. Influencing factors of regenerative regenerative braking and braking effort distribution

During the regenerative braking of pure electric vehicles, the motor is in the power generation mode, which generates electromagnetic torque while realizing energy recovery, which is converted into wheel braking effort through the transmission system, that is, regenerative braking effort [8]. At the same time, the DC output can be sampled and detected, and sent to the controller for decision-making [9]. If the energy can be recovered, according to the analysis results and the corresponding regenerative braking distribution strategy, the braking controller calculates the required braking effort of the hydraulic brake assembly and the motor brake assembly and sends the control signal; If the energy cannot be recovered, the hydraulic brake assembly will complete the braking task independently [10]. The working principle of common DC charging pile is shown in Figure 1.

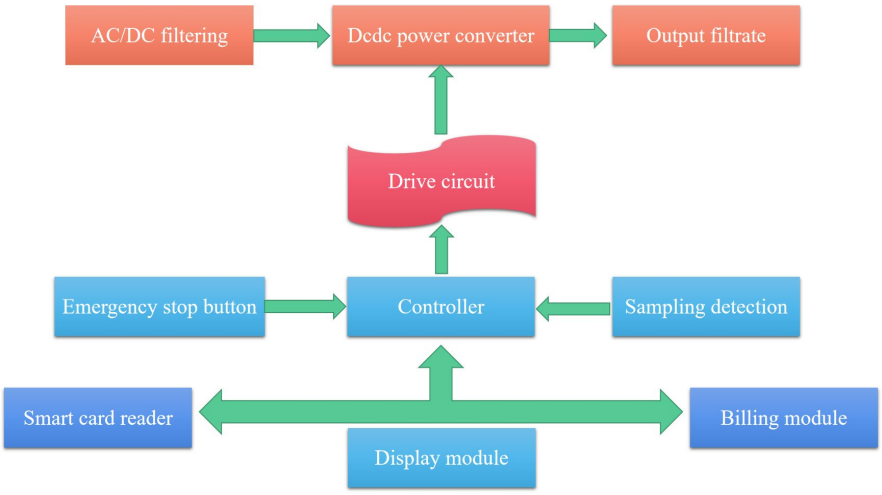

Figure 1 Working principle of common DC power piles

The energy storage devices in electric vehicles mainly include batteries, super capacitors, hydraulic accumulators and flywheel sets. For the application of electric vehicles, the specific energy restricts its driving range, which is the primary technical condition for the selection of electric vehicle energy storage devices. The battery has become the main energy storage device with high specific energy and mature technology. An important indicator of battery is SOC, that is, the ratio of remaining capacity to full load capacity. The control strategy of regenerative braking is the core of the regenerative brake assembly of electric vehicles. A reasonable regenerative braking control strategy can greatly improve the efficiency of energy recovery, while the electro-hydraulic hybrid regenerative braking control strategy of electric vehicle mainly solves the problem of determining the distribution share between motor regenerative braking effort and front and rear friction braking efforts. The reasonable and effective control strategy of electro-hydraulic compound regenerative braking has a very important influence on the energy recovery efficiency in the process of regenerative braking. When the vehicle is in high-intensity emergency braking, the

electric motor alone can't meet the braking requirements of electric vehicles. At this time, the traditional hydraulic brake is needed to cooperate to accomplish the braking task of the vehicle together. When the maximum regenerative braking effort in the current state of the motor is greater than the required braking effort of the front axle, the regenerative braking effort assumes all the required braking effort of the front axle. Hydraulic braking effort sharing.

2.2. Principle analysis of regenerative braking

In the structure of the motor brake assembly, the energy conversion device is the motor and the energy storage device is the storage battery. When the car is driven, like the traditional car, the electric car can realize the conversion of chemical energy to kinetic energy from the battery to the motor and then to the transmission system. When the car is braked, the traditional car uses the friction of the brake to convert the kinetic energy that needs to be reduced at the driving wheel into heat energy, and then the heat energy is dissipated to stop or slow down.Due to the functional inversion, electric vehicles can generate braking torque to absorb part or all of the kinetic energy that needs to be reduced on the drive wheels. The schematic diagram of the circuit principle of the regenerative brake assembly is shown in Figure 2. The circuit components include a motor M, an inductance L, a resistance R, two bipolar transistors V1 and V2, and a battery. as shown in picture 2.

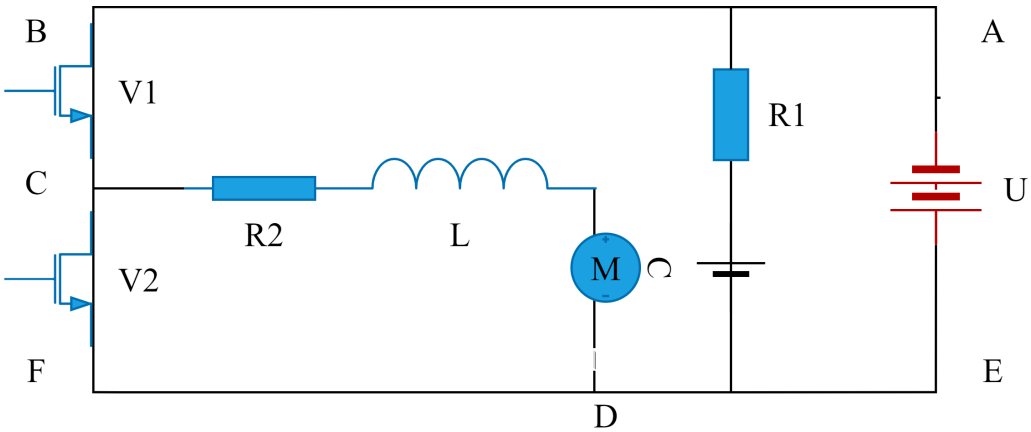

Figure 2 Schematic diagram of the regenerative brake assembly circuit

In the braking process of electric vehicles, the motor converts mechanical energy into electrical energy, which is an energy conversion device. Therefore, the motor performance is the key factor that directly affects the energy recovery. The greater the maximum braking effort that can be generated by the motor during braking, the higher the proportion of regenerative braking effort and the more energy recovered; The greater the generating power of the motor, the greater the charging power provided to the battery and the more energy recovered; In addition, motor efficiency and stator rotor resistance also have a great impact on regenerative regenerative braking. During the whole braking process, especially when the vehicle speed is high, the electric braking effort can't meet the demand of vehicle braking torque, so the hydraulic braking effort is needed to make up for the remaining braking effort. When the vehicle speed is low, the braking torque of the motor can basically meet the demand of the vehicle. It can be seen from the power generation efficiency diagram that the high-efficiency working range of the motor is mostly in the high-speed and low-torque area. However, since the output power of the motor is proportional to the charging current of the battery, and the charging efficiency and coulombic efficiency of the battery decrease with the increase of the charging current, the joint working efficiency of the battery motor may decrease when the charging current is large, that is, the output power of the motor is large. In the whole simulation process, the input variables of this module are the required speed and torque of the motor and the actual input power of the motor. The calculation of the power ratio sub-module and the thermodynamics sub-module obtains the output speed and torque of the motor.

3. Establishment of Simulation Model of Braking Control Strategy and Analysis of Simulation Results

3.1. Stability analysis of hydraulic regenerative braking for electric vehicles

In order to reduce the loss of steering ability caused by front wheel locking during braking and improve the adhesion efficiency, the actual braking effort distribution curve of front and rear wheels should be as close to the ideal braking effort distribution curve as possible. In order to meet the requirements of relevant ECE regulations and avoid the dangerous condition that the rear wheel locks before the front wheel, the actual braking effort distribution curve should always be below the ideal braking effort distribution curve, between curve 1 and curve 2. Among the factors that affect the charging safety of electric vehicles, there are many factors affecting the safety of insulation performance, which requires relevant electric vehicle designers to fully consider these factors affecting the insulation performance in the design process of electric vehicles. Improve the life of insulating materials and ensure better insulation performance of electric vehicles.

Electric vehicles are frequently used vehicles. In this case, the impact of external environmental factors on their charging safety increases. After long-term use, some parts of electric vehicles may be corroded or eroded, thus affecting the charging safety of electric vehicles. The common causes of instrument failure are divided into controller failure, circuit breaker failure, lightning arrester failure and contactor failure; Common communication failure causes are divided into BMS communication failure and TCU communication failure; Common mechanical failure causes are divided into charging gun failure and electronic lock failure. Under the condition of different speed and charging voltage of hub motor, the working characteristics of variable voltage charging of hub motor are tested by collecting parameters such as terminal voltage, line current and regenerative braking torque. At present, in the type test, the communication protocol conformance test is mainly to verify the communication compatibility, but the influence of various parameter settings in the communication protocol on the charging process has not been considered. In the case of hacker's active attack, the small probability event will immediately become the high probability event. By then, electric vehicles will probably be small bombs, and the consequences can be imagined. Displaying fault types through data feature mining and analyzing their causes can lay a foundation for the safe operation and maintenance of charging facilities, play a certain role in improving the stability and safety of charging facilities, and promote the development of electric vehicles.

3.2. Simulation results

The strategy calculates the optimal braking effort of the motor considering the vehicle braking safety and service safety by using the fuzzy controller with the input of the required braking strength, the battery SOC value and the driving speed. Then, the motor braking effort of the front axle is converted into the actual output braking effort of the motor through the formula, and corrected by using the vehicle speed and SOC influence factors. Cruise software provides an interface for joint simulation with MATLAB, allowing cruise model and control strategy model built based on simulik to call each other. Therefore, the integration and joint simulation of vehicle model and control strategy model can realize the power distribution and management of pure electric vehicles. There are four ways to combine CRUISE with Matlab: MATLAB-DLL, MATLAB-API, CRUISE-Interface and CRUISE-Interface CMC. The energy recovery effect of the regenerative braking control strategy model in this paper is evaluated by the regenerative braking rate ηb and the effective regenerative braking rate ηeb. The regenerative braking rate ηb is the ratio of the braking effort Ebat in recovered and stored to the battery in a braking condition test to the total braking effort Ebat in consumed by the brake without regenerative braking, expressed as:

$$E_{brake}=\frac{1}{2}m(v_1^2-v_2^2)-mgf\int_{t_1}^{t_2}vdt-\frac{C_DA}{21.15}\int_{t_1}^{t_2}v^3dt$$

Where, the recovered braking effort ebat I is calculated by integrating the instantaneous charging power Pb of the battery with the braking time; Ebat I is the maximum braking effort that can be

recovered in theory, representing the reduction of kinetic energy consumed when the vehicle decelerates from v 1 (T1 time) to V2 (T2 time) minus the energy consumption of rolling resistance and air resistance. In order to verify the effectiveness of the regenerative braking control strategy in this paper, it is necessary to select typical urban cycle conditions to simulate and analyze the control strategy model, and evaluate the energy recovery ability of the three regenerative braking control strategies in the actual driving conditions. In this paper, urban road cycle test conditions are selected: NEDC (New European road cycle condition) and FTP75 (American urban test cycle condition). The braking control strategy of the car look-up meter adopts the comparative model of regenerative braking control strategy in most studies, which belongs to the parallel fixed ratio distribution control strategy. According to the driving speed, motor braking and friction braking are distributed according to the fixed ratio. Results The representative state values, such as motor torque, battery charging and discharging current, battery SOC and so on, which can directly evaluate the energy recovery effect were selected by simulation. The motor torque can reflect the degree of motor participation in braking with different control strategies, and can reflect the amount of regenerative braking; the battery charging and discharging current and battery SOC value can reflect the driving energy consumption and energy recovery under different control strategies. Under the same driving conditions, the greater the braking torque of the motor, the more energy is recovered. In the negative torque region NEDC and FTP75, the motor torque of the non-energy recovery system is always zero. The motor braking torque of the control strategy in this paper is greater than that of the control strategy based on the look-up table at each braking time point. Under the urban cycle condition, the effectiveness of the fuzzy control regenerative braking strategy is verified based on the vehicle speed look-up table control strategy and the non energy recovery model. The results show that the strategy can effectively recover energy, and the energy recovery effect is also affected by the driving road conditions and braking frequency, and the constraints of motor constraints can be fully considered, so it has more advantages.

4. Conclusions

With the rapid development of electric vehicle industry, regenerative braking control strategy has become an important part in the research of regenerative braking technology. Under the condition of vehicle braking safety restriction, this paper aims at braking safety and maximizing energy recovery, and studies the regenerative braking control strategy of front-drive pure electric vehicle. With the continuous development and progress of new technologies such as high-power charging, wireless charging, and group charging, the elements of safety are constantly changing, so the research on charging safety is a long-term work. Through simulation and test methods, it is verified that the control algorithm for obtaining the charging voltage using the least squares fitting method has high control accuracy, and can be used for variable voltage charging regenerative braking control of in-wheel motor electric vehicles. Under different road driving conditions, the in-wheel motor electric vehicle adopting the anti-lock control strategy of the compound brake assembly can perform anti-lock control well, and the regenerative braking control strategy of variable voltage charging can accurately implement the regenerative braking behavior of the in-wheel motor.

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