Research on Regenerative Braking Force Control Strategy of Four-wheel Electric Vehicle Based on Auxiliary Braking

Dong Wang, Yonghui Zhang, Ling Wu, Yang Zhou, Ningqiang Wu, Xiaoliang Qiao, Xujuan Liu

School of Vehicle Engineering, Xi'an Aeronautical University, Xi' an, 710077, China

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Abstract: Since the birth of automobile, after more than 100 years of development, it has become an indispensable means of transportation in people's daily life. Electric vehicles have gone through key technological breakthroughs, prototype, prototype development, regional trial and small batch practical application, and are now close to commercial production. Compared with traditional vehicles, the most prominent advantage of electric vehicles is to achieve regenerative braking, that is, when electric vehicles brake or decelerate, the kinetic or potential energy of vehicles is stored in energy storage devices in the form of electric energy. Pure electric vehicles use power batteries as power sources, and their electric control systems are relatively simple and can basically work in high-efficiency intervals. From the perspective of battery technology, battery, as the power source of electric vehicles, has become the key to the development of electric vehicles. Based on the principle of auxiliary braking, this paper analyzes the typical regenerative braking system structure of 4WD electric vehicle and introduces the regenerative braking control strategy of 4WD electric vehicle.

1. Introduction

The rapid development of the automobile industry not only drives the development of society and economy, but also makes the connection between people more and more convenient, providing people with a lot of employment opportunities and improving people's quality of life and standard of living [1]. Electric vehicles have experienced breakthroughs in key technologies, the development of prototype and prototype vehicles, regional trials and small-scale practical applications, and are now close to commercial production [2]. In electric vehicles, regenerative braking can be realized by using the power generation function of the motor. The principle is to transmit the inertia energy of the car to the motor through the transmission system when braking, and the motor works in a power generation mode to charge the power battery. In the current research on electric vehicle technology, feedback braking has become an important technical means to reduce energy consumption and improve driving range [3]. If the braking method of a conventional car is used, energy will be converted into frictional heat and wasted. An electric vehicle with energy feedback can return the energy generated during the braking process to the battery pack to charge the battery pack. Although the fuel cell vehicle has a short charging time, its cost is high and it is difficult to lower it. The adaptability is poor and the technology is not mature enough [4]. The pure electric vehicle uses the power battery as the power source, and its electronic control system is relatively simple, and basically can work in the high efficiency range. From the perspective of battery technology, batteries as the power source of electric vehicles have become the key to the development of electric vehicles.

With the increase in the consumption of fossil energy around the world, the pollution of human living environment has increased, and the increase in car ownership in various countries has aggravated the energy and environmental issues. When the electric vehicle is braked, part of the kinetic energy can be stored, which can effectively extend the driving range of the pure electric vehicle. Since the electric mechanism power is limited, in many cases, the individual regenerative braking force cannot meet the braking demand, and the hydraulic pressure and the motor are required to provide the braking force to ensure the braking performance [5]. Compared with

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traditional vehicles, the most outstanding advantage of electric vehicles is that they can realize regenerative braking, that is, when the electric vehicle brakes or decelerates, the kinetic energy or potential energy of the vehicle is stored in the energy storage device in the form of electric energy [6]. Because the power density of the battery is relatively small, the energy of the battery that the electric vehicle can carry is limited, so the driving distance of the electric vehicle is relatively short [7]. After the introduction of regenerative braking in electric vehicles, the design and control of the braking system is quite different from that of conventional vehicles. It not only requires the electric vehicle to have good braking performance, but also can recover the braking energy to the maximum extent.

2. Analysis of Characteristics and Limiting Factors of Regenerative Braking

Limited by the battery charging power, the recovered power cannot exceed the current maximum battery charging power. When the braking intensity is large, the regenerative braking of the motor often cannot meet the braking requirements. The main process of regenerative braking is to transfer the inertia force of the car to the motor through the transmission system when the car is braking. The mechanical energy can be converted into electric energy by the motor. At this time, the motor works in the power generation state and continuously charges the battery. Regenerative braking of electric vehicles must cooperate with traditional friction braking to realize safe and effective deceleration braking. When the vehicle brakes or decelerates, the hydraulic oil in the oil tank is stored in the accumulator in the form of high-pressure oil through the action of the clutch and the hydraulic pump. Under the same working condition, the hydraulic regenerative braking energy recovery system scheme can provide more auxiliary power for electric vehicles than other regenerative braking energy recovery system schemes, and can also improve the energy utilization efficiency [8]. For a single-shaft driven electric vehicle, it is only necessary to consider whether the front and rear axles meet the brake safety stability and coordinate the regenerative braking and mechanical friction braking on the drive shaft in the distribution of the braking force.

When the motor speed is close to zero, the back electromotive force of the motor cannot meet the braking current requirement, and the battery will provide the braking current together with the motor back electromotive force. The sum of the currents is consumed together on the armature resistance of the motor until the motor stops. This state is the energy braking state. If the additional benefit from collaboration in multi-case optimization can be assigned among the participants, it is called payment-transferable multi-case optimization. On the contrary, it is called multi-case optimization that the payment cannot be transferred. Fig. 1 shows the scan speed modulation architecture of the power prediction model.

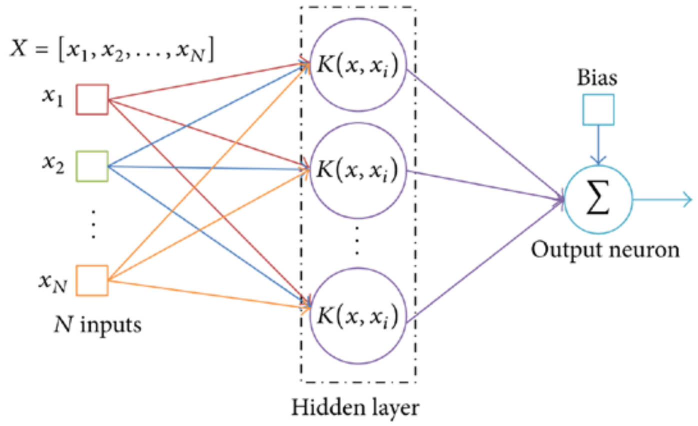

Fig. 1 Scanning speed modulation architecture of power prediction model

The structure of the electric vehicle regenerative braking system is related to the driving mode of the car. Only the wheel driven by the motor can realize the braking energy recovery. The two-axle car was chosen as the research object. Regardless of the elasticity and damping of the tire and the suspension, the whole vehicle was regarded as a rigid body, and the quality and force of the car were considered to be symmetrical with respect to the longitudinal axis. When the four-wheel drive electric vehicle starts or accelerates, the high-pressure oil in the accumulator is outputted by the hydraulic motor in the form of torque. The driving force of the motor and the motor output is coupled to the front axle of the four-wheel drive electric vehicle after being coupled by the power coupler. A pressure distribution unit is used in the friction brake system, which consists of a master cylinder pressure sensor and two electromagnetic actuators controlled by a brake controller. When the car is braking, the ground braking force will increase correspondingly when the braking force of the braking system increases, but there is a certain limit to the ground adhesion force. When the braking force of the braking system gradually increases to the ground adhesion force limit, the ground braking force will also reach its maximum value. The brake controller uses signals obtained from the motor controller, master cylinder pressure sensor and brake pedal sensor to control these solenoid valves, and sends a regenerative braking command to the motor controller. The distribution of braking force between the driving wheel and the driven wheel should be able to ensure that the vehicle is in a safe area, which is related to the driving stability of the vehicle.

3. Analysis of Regenerative Braking Control Strategy for Electric Vehicles

3.1 Distribution of Braking Force for Electric Vehicles

The vehicle brake control system is the central hub of electric vehicle braking, and regenerative braking control strategy is an important part of it, which solves the problem of how to distribute braking force. The brake controller uses signal numbers obtained from the motor controller, master cylinder pressure sensor and brake pedal sensor to control these solenoid valves. When the vehicle brakes or decelerates, the hydraulic oil in the oil tank is stored in the accumulator in the form of high-pressure oil through the action of the clutch and the hydraulic pump. For electric vehicles, the quality of control strategy has an important impact on stable braking and indirectly affects the efficiency of energy recovery. For this kind of electric vehicle driven by rear wheels, in order to improve the regenerative braking energy, the braking force on the rear wheels must be increased, which may lead to the deterioration of the stability of the vehicle during deceleration. When the car slows down or stops, it must be subjected to an external force opposite to the direction of motion. Often the external force of the opposite demand is relatively large, and the effects of air resistance and rolling resistance are relatively small, failing to meet the requirements of braking.

There is often a contradiction between stable braking and energy recovery, because to increase the recovery energy, it is necessary to increase the braking force of the regenerative braking shaft, but this will inevitably cause the front and rear axles to gradually deviate from the ideal curve in the braking force distribution. In the case of meeting the charging power demand of a four-wheel drive electric vehicle, when the four-wheel drive electric vehicle is connected to the power grid in an uncontrolled manner. Because it does not participate in the regulation of the power grid, even if it is charged at night, it may cause its charging load to coincide with the night load of residential electricity. In addition, the fluctuation of the power load is aggravated, and a load peak occurs. Fig. 2 shows the charging status of four-wheel drive electric vehicles in a certain area in one day.

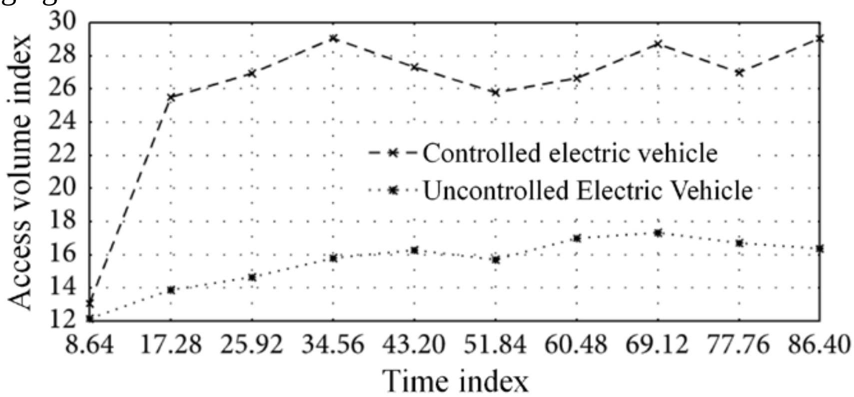

Fig. 2 Four-wheel drive electric vehicle charging access status

Since the power field does not need to consume fuel, the electric vehicle should first dispatch all the power. The goal of dynamic economic dispatching of the power field containing power system is to minimize the power generation cost of the traditional generator set. The objective function can be written as:

$$dR_t = \chi \cdot a(t) \cdot dt + \delta \cdot a(t) \cdot dw_t \quad (1)$$

Power balance constraints:

$$R_t^{\pi^*} = x + \int_0^t \xi \cdot a(R_s^{\pi^*}) \cdot ds + \int_0^t \zeta \cdot a(R_s^{\pi^*}) \cdot dw_s - U_t^{\pi^*} \quad (2)$$

Large-scale power cannot be absorbed locally and needs to be transported to the load center over long distances through the transmission grid. The expression of the optimization goal is not considered in the case of electricity operating costs:

$$M(t_0 + \Delta t) = R_0[1 + \frac{2\Delta RU}{Q_0 R_0^2}(t_0 + \Delta t)]^{0.5} \quad (3)$$

For most engineering problems, there are few analytical solutions due to the complexity of the geometry of the object or the non-linearity of certain features of the problem. Project quality control refers to the control of the progress level of each stage and the final completion time of the project during the project implementation process. The process duration is subject to a lognormal distribution. Fig. 3 shows the results of the key chain method planning.

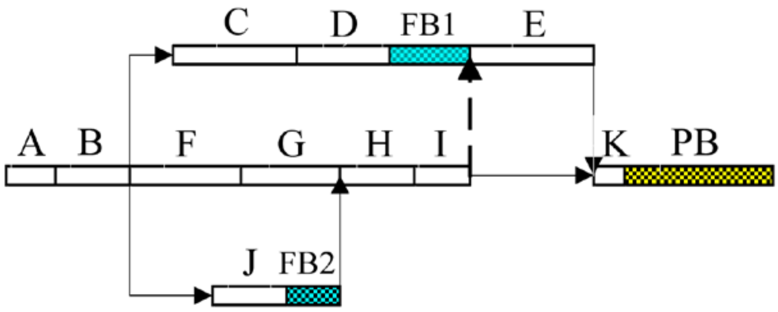

Figure 3 Key chain planning results

The braking force on the front wheel first reaches the limit condition of the ground adhesion. The front wheel first appears to be locked and dragged. As the braking force of the braking system continues to increase, the rear wheel gradually reaches the limit of adhesion and begins to lock and drag. Only when the car is braked at the maximum braking intensity will the steering wheel lose its steering ability and can effectively prevent the danger of rear axle slip. The purpose of car braking is not to lock the wheel, but to make the car get enough deceleration [9]. The most ideal braking situation for a car is to always ensure that the front and rear wheels are rolling. Various control strategies have emerged due to the different requirements for directional stability and energy recovery during braking. A reasonable control strategy should be able to solve the contradiction between car braking stability and braking energy recovery efficiency. Compared with other types of braking energy recovery systems, a significant advantage of the parallel type is that it does not need to make major changes to the original braking system, i.e. to keep the original braking mode of the non-drive shaft unchanged. Only motor braking is introduced on the drive shaft, so that the driving wheel can realize the combined action of mechanical braking and regenerative braking in the braking process. Since the main braking force of the vehicle in the braking state is not provided by the regenerative braking system, the braking energy that can be recovered is very limited.

3.2 Common Distribution Strategy of Regenerative Braking Force

The front wheel is the driving wheel, and the braking force of the front wheel is first provided by the regenerative braking force alone. When the regenerative braking force is insufficient, the remaining braking force is provided by mechanical friction braking force, and the braking force of the rear wheel is provided by friction braking. When the auto start accelerates or overtakes, the energy stored in the flywheel and the energy accumulator is released through the transmission device to provide driving force for the automobile, and the pressure of the system and the speed of the flywheel both drop at this time. When braking, other external forces are needed to meet the braking requirements. This external force is provided by the ground, and we usually call this force ground braking force [10]. The work done by the ground braking force is mainly divided into electric mechanism power work and friction braking force work, wherein the part of the work done by the front and rear hub electric mechanism power can be converted into electric energy for storage through the action of a motor. Since the inertial force moment generated by air resistance, rolling resistance and rotating mass has little effect on the car during the braking process of the car, it is ignored in the analysis of the force of the car. When using the imitation engine regenerative braking process, the regenerative braking strength depends on the degree of recovery of the accelerator pedal and the speed of the vehicle. With forced regenerative braking, regenerative braking is preferred when the braking strength is low. When considering the demanding braking force to distribute the ratio on the front and rear axles, it is necessary not only to balance the safety and stability of the brakes, but also to coordinate the working mode between the regenerative braking and the mechanical friction braking on the four wheels and the proportion of participation.

4. Conclusion

With the response to the energy conservation and emission reduction policies of all countries in the world, traditional fuel vehicles will gradually be replaced by low-energy, environmentally friendly and non-polluting new energy electric vehicles. However, due to the influence of many factors such as the energy storage system, the problem of short driving range for single-charge charging of electric vehicles has not been able to break through. Reasonable use of the motor for regenerative feedback braking power generation not only increases the driving range of the electric vehicle, improves the energy utilization rate, but also improves the braking performance of the vehicle, which has important practical significance. In this paper, the four-wheel drive electric vehicle is taken as the research object, and the key component accumulator in the hydraulic regenerative braking system is mathematically modeled, and the kinematics analysis of the four-wheel drive electric vehicle braking force is carried out. Although the adoption of regenerative braking force control mechanism is different for various types of vehicles, brake control ECU is used in different degrees. Controlling friction braking force and electric mechanism power not only ensures braking efficiency and its constancy, but also can recover energy to the highest extent. The hydraulic regenerative braking system and the motor system are coupled to drive the four-wheel drive electric vehicle, thus prolonging the driving range of the four-wheel drive electric vehicle after one-time charging.

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