Research on regenerative braking system for linear control chassis platform

Guowei Gao¹, Xiaopeng Li¹ and Zheng Xu¹,²
¹School of Automobile and Transportation, Tianjin University of Technology and Education, Tianjin, 300350, China
²Donghexin Technology Co., Ltd., Tianjin 300350, China
¹email: 0721191007@tute.edu.cn

Abstract. The regenerative braking system of the electric vehicle with the linear control chassis plays an important role in improving the mileage of the vehicle, which mainly solves the problem of large electricity demand for the linear control chassis. After analyzing the structural characteristics of the linear control chassis, the constraints of regenerative braking and the existing regenerative braking control strategies, a new regenerative braking control strategy is proposed, and the control strategy is modified. The regenerative braking control strategy model is established by Simulink / Stateflow, and the braking effect and energy recovery efficiency are verified by changing the initial braking speed. The simulation results show that the strategy can well complete the braking task of the vehicle, and the braking energy recovery rate increases with the increase of the initial braking speed. Reasonable control strategy can effectively improve vehicle energy recovery efficiency.

1. Introduction
The linear control chassis platform uses four in-wheel motors to drive the car, and uses the linear control to brake the car. The entire chassis platform adopts the design of full electronic control, so the electricity demand is great [1]. Braking energy accounts for a large proportion of the total driving energy of the vehicle, especially in urban road conditions with frequent braking, which is even as high as 50%. Reasonable braking energy recovery strategy can increase the mileage of the vehicle by at least 20% - 30% [2].

Hu Wang [3] from Tianjin University of Science and Technology proposed a control method based on braking strength, and carried out experiments on NEDC conditions combined with fuzzy control model. Yajuan Yang of Hefei University of Technology [4] proposed the maximum energy recovery braking control strategy with the highest overall efficiency as the goal, and used the sequential quadratic programming method to optimize the charging power. Shixin Song [5] realized the control strategy of electric vehicle regenerative braking system by using a new type of electronically controlled hydraulic compound braking control mechanism. In this paper, a new braking force distribution control strategy is established based on the linear control chassis platform. The braking effect and energy recovery efficiency of the control strategy are verified by simulation analysis.
2. Generative braking system of linear control chassis platform

2.1 Platform structure characteristics
The line-controlled chassis platform is generated under the background of automobile electrification, intelligence and lightweight. The whole platform adopts the whole line-controlled technology (line-controlled drive, line-controlled drive and line-controlled steering) to drive the vehicle independently by four in-wheel motors, which cancels the complex transmission mechanism of traditional vehicles and has low energy loss. Moreover, each wheel can generate regenerative braking force and recover braking energy. The brake adopts the electronic mechanical brake system (EMB), completely cancels the hydraulic pipeline and vacuum booster and other components, and is replaced by sensors, motors and wires. The structure is simpler. Steering also uses the wire-controlled steering system, which can realize the independent steering of four wheels, reduce the turning radius of the vehicle, and is more conducive to parking and other scenes.

![Figure 1. Structure diagram of wire controlled chassis platform](image)

2.2 Constraint conditions of regenerative braking

2.2.1 Status of battery packs
When the state of charge (SOC) of the battery is greater than a certain limit or the temperature of the battery pack is greater than a certain limit, in order to ensure the normal performance of the power battery, we need to close the regenerative braking and not allow the braking energy recovered by the motor to charge the power battery when braking.

2.2.2 Speed characteristics of motor
In the process of power generation, the maximum regenerative braking torque generated by the motor changes with the change of speed. When the working speed of the motor is less than the rated speed, the motor outputs with constant torque. When the working speed of the motor is greater than the rated speed, the motor outputs at constant power, and the output torque of the motor is inversely proportional to the speed.

2.2.3 Power generation of motor
The generating power of the motor is proportional to the braking energy recovered. The total generating power of the hub motor can not exceed the product of the maximum charging voltage and the maximum charging current of the battery. That is the maximum charging power. Otherwise, the normal working
performance of the battery will be affected. [6].

Maximum regenerative braking torque of four hub motors limited by maximum charging power

$$T_{\text{bat max}} = \frac{9550P_{\text{bat max}}}{n}$$

(1)

Considering the limit of maximum battery charging power, the maximum sum of regenerative torques generated by four hub motors is expressed as

$$T_{\text{reg}} = \min (4T_{m \text{ max}}, T_{\text{bat max}})$$

(2)

3. Control Strategy Design of Regenerative Braking System

At present, there are three commonly used regenerative braking control strategies. One is the optimal braking energy recovery control strategy, which is oriented to the braking torque required by the vehicle. The regenerative torque generated by the in-wheel motor is preferred, but the controller with high integration and intelligence is needed to cooperate with it. One is the ideal braking force distribution control strategy. The braking torque required for the front and rear axles is allocated according to the ideal braking force distribution curve, and the regenerative torque generated by the hub motor is preferred. However, with the change of vehicle load, the ideal braking force distribution curve is also changed, which increases the complexity of control and increases the cost. One is the control strategy of parallel energy recovery, which requires that the regenerative braking and the traditional braking work at the same time in the braking process. The proportion of the two work is adjusted according to the change of braking intensity. The control is simple, but the regenerative braking energy is not fully utilized, and the recovery rate is low. In this paper, a new control strategy is proposed to simplify the complexity of the regenerative braking system control. It can also make the driver feel the same as the traditional automobile braking, improve the stability of the braking and recover the braking energy as much as possible.

3.1 New Regenerative Control Strategy

If the braking force is small, the regenerative braking torque generated by the in-wheel motor is preferred. We assume that the regenerative braking torque generated by each in-wheel motor is the same (the braking force of each wheel is the same), and there is no difference. If the braking torque required by the vehicle is greater than the maximum braking torque generated by the hub motor, the motor provides the maximum regenerative braking force, and the rest of the braking force is provided by the mechanical braking force, and the mechanical braking force should be fully distributed according to the braking force distribution coefficient of the front and rear wheels.

The specific control strategy is: when the braking force required by the vehicle is less than the sum of the regenerative braking force generated by the four in-wheel motors, the vehicle is completely driven by the in-wheel motor, that is, the braking mode of the pure in-wheel motor. At this time, the braking force of the vehicle is equal, and the braking force distribution coefficient of the front and rear wheels is distributed according to 50:50. In this mode, the regenerative braking energy of the in-wheel motor is used to charge the battery and supplement the electric energy. When the braking force required by the vehicle is greater than the sum of the regenerative braking force generated by the four hub motors, the hub motor provides the maximum regenerative braking torque, and the remaining part is provided by the mechanical braking force. When the regenerative braking system is working, the distribution ratio of the front and rear wheels is 50:50. When the regenerative braking torque reaches the maximum, the distribution ratio of the front and rear wheels is 55:45.

3.2 Correction of Regenerative Braking Control Strategy

In the braking process, if the battery energy (SOC > 0.95) is high, the electric energy generated by the hub motor is not allowed to charge the battery to ensure that the battery does not overcharge. This part of the energy can be used by other devices that consume electric energy. This part of the torque is defined as load torque.
4. Simulation Verification and Result Analysis

Based on the control strategy of regenerative braking system designed above, the simulation model is established in MATLAB / SIMULINK software, as shown above.

![Simulation model of brake energy recovery system for wire controlled chassis platform](image)

Figure 2. Simulation model of brake energy recovery system for wire controlled chassis platform

The design parameters of the linear control chassis platform are as follows: the full load mass is 600 kg, the preparation mass is 200kg, the tire specification is 145/70R12, the battery capacity is 100Ah, the nominal voltage of the battery is 72V, the rated speed of the motor is 600r/min, the rated torque of the motor is 57Nm, and the rated power of the motor is 3.4kW.

4.1 Determining simulation indicators

In this paper, the braking energy recovery rate is set as the evaluation index of the simulation results [7]. We define the braking energy recovery rate as the ratio of vehicle energy recovery and total kinetic energy.

The total kinetic energy of the vehicle is expressed as

$$E_v = \frac{1}{2}mv^2$$

(3)

The energy recovered by vehicles can be obtained by integrating the battery charging power.

$$\int P_b dt$$

(4)

Then the braking energy recovery rate is expressed as

$$\eta_{reg} = \frac{E_b}{E_v}$$

(5)

4.2 Simulation Analysis of Different Initial Conditions

In order to make the simulation process more realistic, more reflect the most common braking conditions in the driving process, and also consider the real road congestion in China, this paper chooses the typical initial braking speed to simulate. The average speed of the car is about 20Km/h-30Km/h under the condition of urban congestion. The average speed of the car is 50Km/h-60Km/h under the condition of
good traffic congestion. The average speed of the car will not be less than 90Km/h on the highway. In this paper, 20Km/h, 60Km/h, 100Km/h are set as the initial vehicle speed for simulation analysis. After the simulation, in order to compare the simulation results under different initial braking speeds, we set the initial SOC value and braking strength of the battery as fixed values. In the simulation, the initial SOC value of the battery is set to 60%, and the braking strength is 0.4 to simulate the energy recovery of different initial speeds, which is more comparable.

4.2.1 Initial speed 20Km/h
When the initial vehicle speed is 20Km/h, the initial SOC of battery is 60% and the braking strength is 0.4, the simulation results of vehicle speed and braking distance are shown in the figure below.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{speed_curve_20kmh.png}
\caption{Speed change curve}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{braking_distance_20kmh.png}
\caption{Variation curve of braking distance}
\end{figure}

4.2.2 Initial speed 60Km/h
When the initial vehicle speed is 60Km/h, the initial SOC of battery is 60% and the braking strength is 0.4, the simulation results of vehicle speed and braking distance are shown in the figure below.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{speed_curve_60kmh.png}
\caption{Speed change curve}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{braking_distance_60kmh.png}
\caption{Variation curve of braking distance}
\end{figure}

4.2.3 Initial speed 100Km/h
When the initial vehicle speed is 100Km/h, the initial SOC of battery is 60%, and the braking strength is 0.4, the simulation results of vehicle speed and braking distance are shown in the following figure.
It can be seen from the following table that the braking energy recovery value and energy recovery rate corresponding to different initial braking speeds of vehicles are different, but they will increase with the increase of vehicle speed. When the initial vehicle speed is 20 Km / h, the energy recovery rate is only 4.5 %, but when the initial vehicle speed is 100 Km / h, the energy recovery rate can reach 13.81 %. The results show that the regenerative braking control strategy design is reasonable, the regenerative braking ability of the line controlled chassis vehicle can be effectively improved.

Table 1. Results of braking energy recovery at different initial speeds

| V (Km/h) | SOC (%) | E (J) | \( \eta_{\text{reg}} \) (%) |
|---------|--------|------|------------------|
| 20      | 0.03%  | 1823 | 4.5%             |
| 60      | 0.11%  | 20210| 5.6%             |
| 100     | 2.68%  | 138100| 13.81%         |

5. Conclusions
A new regenerative braking control strategy is proposed, which takes into account the problem of moving the center of gravity forward when the vehicle is braking. The braking force is distributed according to the corresponding proportion, and the limitation of battery SOC value on regenerative braking is considered.

The dynamic model of motor, battery and vehicle is established, and the simulation analysis is carried out. It is concluded that the control strategy designed in this paper can better complete the braking task and effectively improve the energy recovery rate. In the future research, the brake system model and the vehicle longitudinal dynamics model must be added for simulation in order to make the simulation results more practical.

Acknowledgments
This paper is one of the phased results of the joint fund project 《Design and development of electric KIT car》 (201902273015) of the Ministry of Education for Industry-University Cooperation and Education for Innovation and Entrepreneurship.

References
[1] Xie, B., Zhu, S., Li. J. (2018) Research on regenerative braking force control strategy of four-wheel drive electric vehicles. J. Electromechanical engineering, 35 (01): 83-88.
[2] Meng, X., Lu, Y., Wang, R., Zhang, L. (2019) Electric vehicle braking energy recovery technology. J. Auto Engineer, (02): 11-13 + 17.
[3] Wang, H. (2020) Energy recovery control method based on braking strength. J. Journal of Shenyang University of Technology, 42 (04): 417 – 422.
[4] Yang, Y., Zhao, H., Zhu, M. (2013) Research on maximum energy recovery regenerative braking control strategy for electric vehicles. J. Automotive engineering,35 (2): 105-110 + 132.
[5] Song, S., Wang, Q., Wang, D. (2015) Electric wheel vehicle regenerative braking system control strategy. J. Journal of Jilin University (Engineering Edition), 45 (2): 341-346.
[6] Rui, Y., Li, J., Shu, H. (2017) The regenerative braking system analysis of pure electric vehicles driven by in-wheel motors. J. Automobile industry research, (04): 17-21.
[7] Li, P. (2019) Research on regenerative braking control strategy of four-wheel motor drive vehicle. D. Chang’ an University.
[8] Tian, C. (2012) Research on regenerative braking control strategy of in-wheel motor drive electric vehicles. D. Beijing: School of Mechanical and Electronic Control Engineering, Beijing Jiaotong University, 2012.