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Simulation Analysis of Fuzzy Control Strategy for Braking Energy Recovery of a Pure Electric Vehicle

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Abstract: *The pure electric vehicle studied in this paper takes the front drive as an example, uses the fuzzy control strategy to design the braking energy recovery strategy, sets three inputs as vehicle braking intensity, driving speed and battery state of charge, and the regenerative braking force ratio coefficient as the output. The braking force of the front and rear wheels is reasonably distributed, and the control strategy model is built in Matlab/simulink. The vehicle model was built in AVL Cruise, and the co-simulation was carried out to study the influence of this strategy on the energy utilization rate of vehicle braking.*

Keywords: *pure electric vehicle, braking energy recovery, regenerative braking force, fuzzy control*

1. Introduction

The automobile is one of the most important means of transportation in our daily life. The rapid development of the automobile industry not only facilitates our daily travel, but also promotes the rapid development of the social economy.

In the rapid development of the automobile industry, the number of cars is growing at the same time, the transportation of oil resources are also constantly rapid consumption, so the demand for oil resources is also soaring. With the increasing number of vehicles, the exhaust gas from cars is also increasing. The exhaust contains a large number of harmful substances, which will harm people's health and aggravate the impact of disaster weather such as haze[1].

Due to the gradual emergence of resource consumption and environmental pollution, China vigorously develops low carbon economy, and the development of the automobile industry is also gradually toward the direction[2]. In the era of environmental protection development, the emergence of pure electric vehicles has gradually attracted people's attention. It not only meets the requirements of environmental protection, but also reduces energy consumption. It is the preferred product[3].

At present, the energy storage technology of pure electric vehicle battery is in the stage of constant development and improvement, long charging time, short driving range, poor dynamics and so on have become important problems that electric vehicle need to overcome at this stage[4].

Because the vehicle will encounter all kinds of different conditions during the process of driving, or be affected by the environment and temperature and other aspects, these will affect the range of the car[5].In order to improve the driving range of pure electric vehicles, in addition to improving the capacity of the battery on its economy more in-depth research, braking energy recovery technology is also one of the important ways to improve the range of pure electric vehicles[6].

2. Theoretical analysis of vehicle braking process

2.1 Automobile braking force analysis

When the car is braking on the road, the force on the wheel is shown in Figure 1.

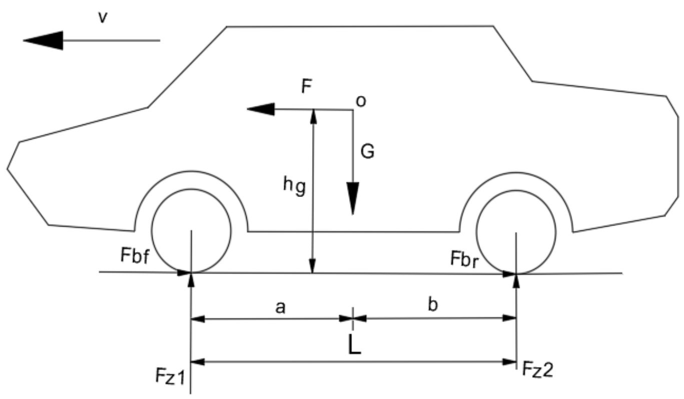

Figure 1: Braking force diagram of automobile

Fbf is the resistance required by the front wheel, N; Fbr is the resistance required by the rear wheel, N; FZ1 is the normal force on the front wheel, N; FZ2 is the normal force on the rear wheel, N; F is the current vehicle force, N; G is the gravity force on the vehicle, N; O is the vehicle's center of mass; hg is the height of vehicle centroid, m; L is the distance between the front and rear axles, m; a is the distance between the front axle and the vehicle's center of mass, m; b is the distance from the rear axle to the center of mass of the vehicle, m.

In order to have sufficient braking efficiency and stability in the braking process of automobiles, the United Nations Economic Commission for Europe has made regulations on braking force provided by the front and rear wheels of two-axle automobiles, and formulated the ECE braking regulations, which stipulate that the braking strength of vehicles with adhesion coefficient between 0.2 and 0.8 should meet $z \geq 0.1+0.85(\varphi-0.2)$. In the process of driving, the adhesion coefficient curve of the rear axle must be lower than that of the front axle[9].ECE brake regulation curve can be expressed as:

$$F_{bf} = \frac{G(z+0.07)(b+zh_g)}{0.85L} \tag{1}$$

$$F_{br} = zG - F_1 \tag{2}$$

The vehicle has the highest braking efficiency and the best stability when the front and rear wheels are locked at the same time during braking. In this ideal braking situation, the adhesion of the front and rear wheels of the vehicle is equal to the braking force of the front and rear wheels. At this time, the front and rear wheel braking force curve can be obtained, and this relationship curve is called the ideal braking force distribution curve[9]. It can be expressed as:

$$F_{bf} = \frac{zG(b+zh_g)}{L} \tag{3}$$

$$F_{br} = \frac{1}{2}[\frac{G}{h_g}\sqrt{b^2 + \frac{4h_gL}{G}F_{bf}} - (\frac{Gb}{h_g} + 2F_{bf})] \tag{4}$$

The braking of pure electric vehicles is divided into two kinds: electric braking and mechanical braking. When mechanical braking, friction between machinery will produce a lot of heat energy, which can not only be used effectively, but also make the temperature of the brake rise, accelerate the loss of the brake, thus reducing the braking performance.

Braking energy recovery technology is a pure electric vehicle in the process of electric braking, the vehicle will drive the motor due to inertia, the rotor will cut the magnetic induction line in the opposite direction of the motor, at this time the motor is converted into a generator, so that the rotor conductor produces reverse induced electromotive force and induced current[7].In this way, the motor can convert part of the kinetic energy into electric energy, which can not only consume kinetic energy at the same time, but also recover part of the energy, improving the utilization electric vehicle energy[8]. The schematic diagram of braking energy recovery is shown in Figure 2.

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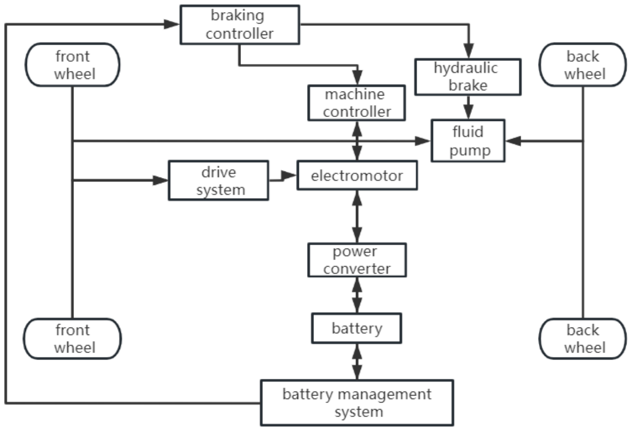

Figure 2: Schematic diagram of braking energy recovery

3. Design of fuzzy control for braking energy recovery

Fuzzy control is a kind of control technology based on fuzzy set theory, fuzzy language variables and fuzzy logic reasoning[10]. Fuzzy control can express all kinds of rules that cannot be accurately expressed in the complex control process according to experimental experience, rather than the strict mathematical model of the research object. It has good robustness, and the influence of interference and parameter change on the control effect is low[11] .

3.1 Design of fuzzy controller for braking energy recovery

In this paper, the front-drive vehicle is taken as the research object. The regenerative braking energy generated by the front wheel during braking comes from charging the battery, and the rear wheel adopts mechanical braking.A fuzzy controller is established with the braking intensity z, vehicle speed v, SOC as input, and the regenerative braking force distribution coefficient A as output. Figure 3 shows the fuzzy control structure of braking force distribution.

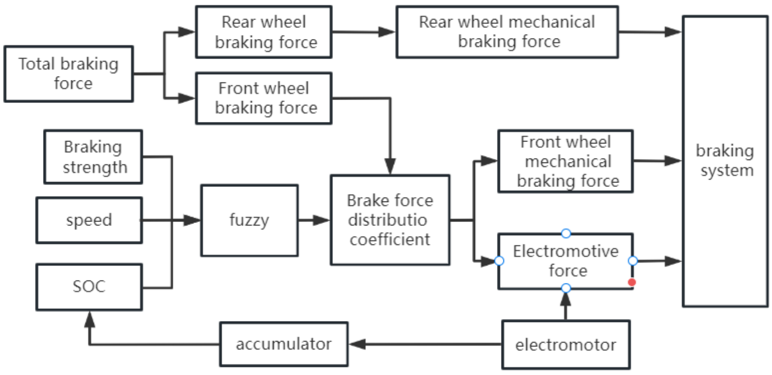

Figure 3: Fuzzy control structure diagram of braking force distribution

3.2 Design fuzzy rules

In the braking force distribution of front and rear wheels, the main braking strength is motor braking in hours, and mechanical braking in high braking strength. The range of braking strength z is specified as [0,1], and the fuzzy subset can be divided into low, medium and high (S, M, L) according to the different braking strength.

The vehicle speed v is one of the important factors affecting the braking energy recovery rate. When the speed is low, the braking energy recovery is small; When the vehicle speed is higher, the braking energy recovery is higher. The range of speed v is specified as [0,100], and its fuzzy subsets are divided into low, medium and high (S, M, L) according to different speeds.

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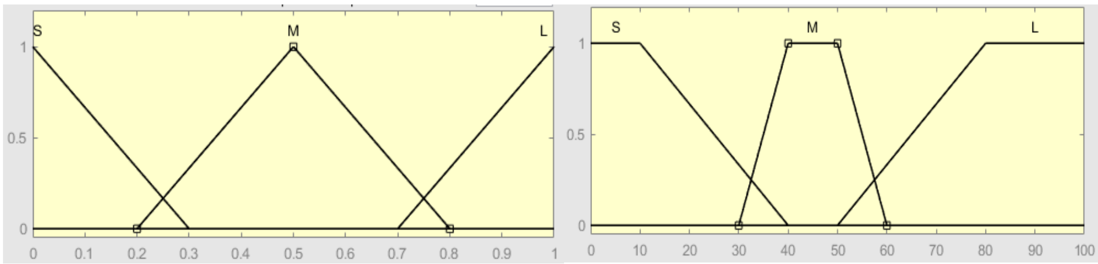
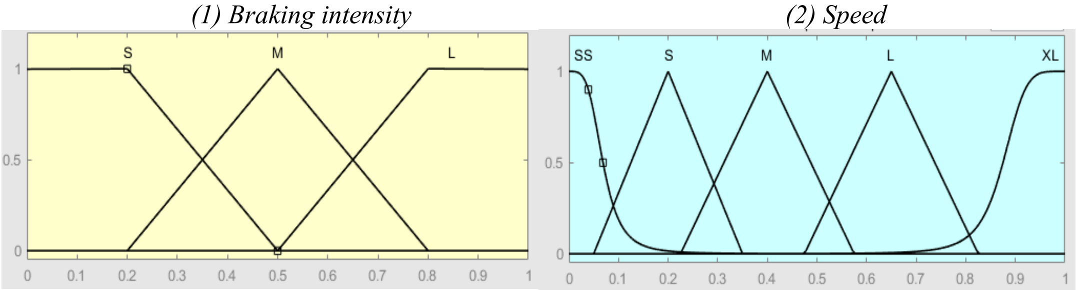
When the SOC of the power battery is higher than 80%, the battery should not be charged again. In order to protect the battery, the proportion of braking energy recovery should be reduced. The range of SOC of the battery is specified as [0,1], and the fuzzy subsets are divided into low, medium and high (S, M, L) according to the different current charges.

The range of braking force distribution coefficient a is specified as [0,1], and its fuzzy subset is divided into extra low, low, medium, high, and extra high (SS, S, M, L,XL).



(1) Braking intensity *(2) Speed*



(3) Battery SOC *(4) Brake force distribution coefficient*

Figure 4: Membership function graph of input and output

Figure 4 shows the membership function curves of braking strength z, vehicle speed v, battery SOC and regenerative braking force distribution coefficient a.

Due to the constant change of input variables, the braking force distribution coefficient is also constantly changing. 27 fuzzy rules are formulated. The fuzzy rules are shown in Table 1, and the fuzzy surface is shown in Figure 5.

Table 1: Fuzzy rules

Z		S			M			L		
V		S	M	L	S	M	L	S	M	L
SOC	S	M	XL	XL	S	L	L	SS	SS	SS
	M	M	XL	XL	S	L	M	SS	SS	SS
	L	SS	SS	SS	SS	SS	SS	SS	SS	SS

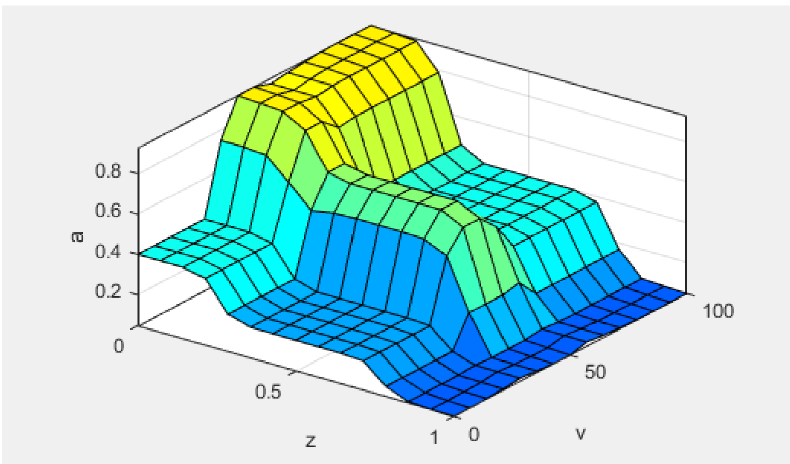


Figure 5: Fuzzy curved surface diagram

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4. Modeling and simulation

The above braking energy recovery strategy model is built in Matlab/simulink software, as shown in Figure 6. Figure 7 is the vehicle model built in AVL Cruise. The initial electric quantity of the vehicle is the same during simulation, and the initial value of the battery is set at 95% and the end value is set at 10%. The Matlab/simulink software and AVL Cruise software were used to simulate under NEDC cycle conditions, and the simulation driving time with or without braking energy recovery strategy was compared Figure 8 is the NEDC cycle diagram, and the curve of driving time and SOC of battery charge is shown in Figure 9.

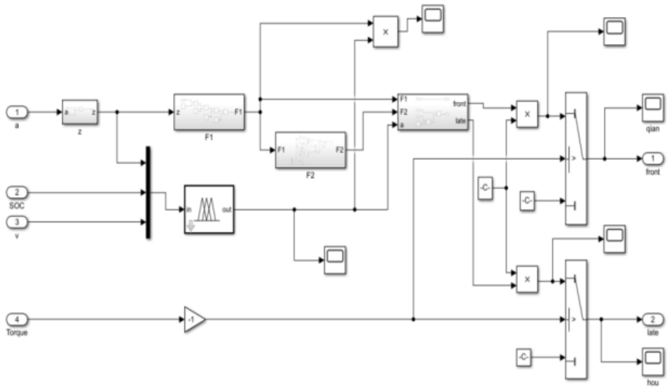


Figure 6: Braking energy recovery strategy model

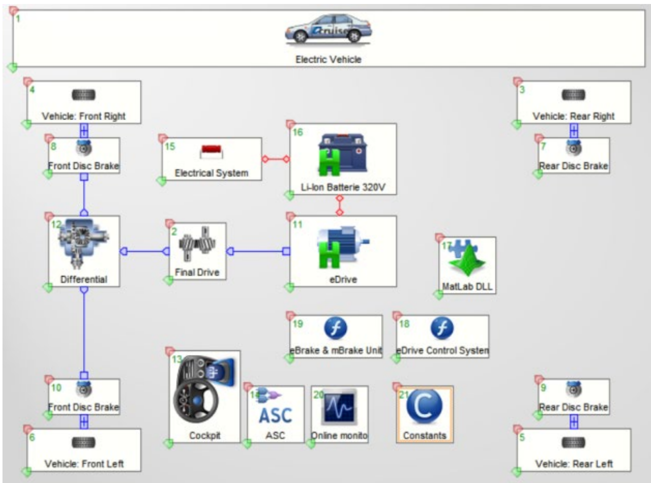


Figure 7: Vehicle model

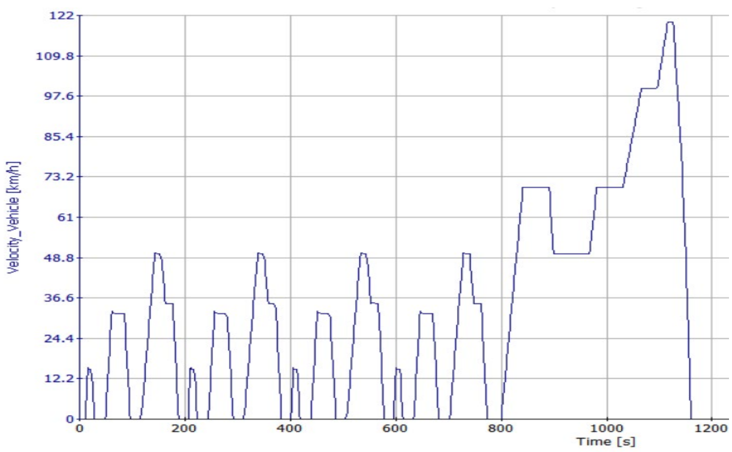
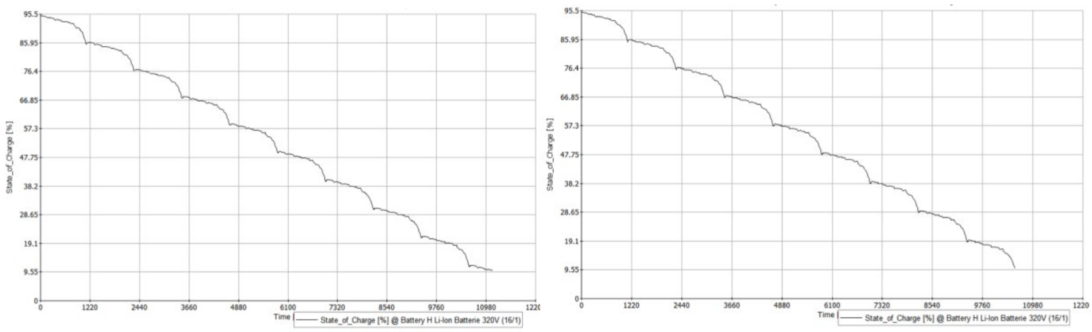


Figure 8: NEDC cycle condition



(a) With energy recovery strategy *(b) Without energy recovery strategy*

Figure 9: Curve of driving time and SOC variation

As shown in Figure 9, during the process from the initial state of the battery to the remaining 10% of SOC, the car can run for about 11,000 seconds when fuzzy control strategy is adopted, while it can only run for about 10,000 seconds when no control strategy is used.

To sum up, on the premise of ensuring sufficient braking efficiency and good stability in the braking process, the fuzzy control braking energy recovery strategy proposed in this paper can extend the driving time of the vehicle, thus improving the energy utilization rate of the vehicle.

5. Conclusion

In this paper, the braking energy recovery of pure electric vehicles is studied. The fuzzy controller takes the braking intensity, speed and battery charge as the input, and the regenerative braking force distribution coefficient as the output. The fuzzy control braking energy recovery strategy is designed to reasonably distribute the front and rear wheel electric mechanism power and mechanical braking force of pure electric vehicles. The control strategy model is built with Matlab/simulink software, and the vehicle model on AVL Cruise software is simulated and analyzed in NEDC condition. The results show that the fuzzy control braking energy recovery strategy designed in this paper can extend the driving time of the electric vehicle and improve the energy utilization rate of the vehicle.

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