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CONTROL PARAMETER ANALYSIS OF REGENERATIVE BRAKING FOR HYBRID ELECTRIC VEHICLE

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ABSTRACT

Energy and environmental protection have already become two principal themes of the development for the world in our times. The hybrid-electric vehicle (HEV) is considered as a new-type car with strong enforceability, which can deal with energy crisis, pressure of environmental protection and realize the sustainable development of the auto industry at present. This paper proposed that the control parameters of regenerative braking has influence on hybrid electric vehicle(HEV). Many experiment and simulation results show that reasonable selection of the control parameters of regenerative braking for the HEV can increase energy recovery, which is good for reducing fuel consumption and keeping SOC. It turns out that the control parameters of regenerative braking have great influence on fuel consumption and SOC. The HEV represents an important direction for auto-industrial development at the beginning of 21st century. Regenerative braking for the HEV is one of the reason for energy saving. The control parameters of regenerative braking for the HEV have an important influence on vehicle performance.

Keywords: *Hybrid Electric Vehicle, Regenerative Braking, Control Parameter, Parameter Optimizing*

1. INTRODUCTION

In the wake of the rapid development of the global automotive industry, the volume of production, sales and inventory of automobile has been increased year by year, and the automobile industry has become a pillar industry of the modern economy[1-3].

However, the vast majority of automobiles are based on fuel oil at present, which have increasingly growing demand on the oil resource and influence on the ecological environment. Therefore, in the premise of limited oil reserves, a number of international famous automobile manufacturers have been making great efforts to manage and organize their research and development (R&D) processes concerning fuel-efficient automobiles in order to maintain long-term stable development of the automotive industry. Tzeng and Chen [4] formulated multi objective functions using nonlinear programming techniques and produced various solutions to emit low CO emissions. Sugawara [5] developed an emission-optimized traffic assignment model that used average speed CO emission factors developed by the California Air Resources Board. Kale[6] designed three types of planar solid-state sensors for measuring NO2 in a gas mixture in the laboratory under controlled atmosphere between 573-723 K.In the meanwhile, due to the influence of emissions of carbon dioxide on the climate warming by automobile, as well as the negative influence of various harmful substances on the human ecological environment, including nitrogen oxides, carbon monoxide, unburned hydrocarbons, and particulate emissions, etc[7, 8]. Thus, a variety of countries have developed a series of stringent emission regulations requiring automobile manufacturers to strive to reduce vehicle emissions, exploiting pollution-free and ultra-low-pollution automobiles. Bannasch [9] proposed a set of design parameters to apply to the development of cold/hot chassis emission test facilities (C/H CETF).De Palma [10] described a model for car ownership and replacement, and use it to assess the impacts of two policies that have been widely used to regulate the automobile industry.

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Many famous automobile manufactures have shifted the focus of the study of the HEV since 1995 [11-13].The hybrid electric vehicles represent an important direction of the development of automobile industry in the early 21st century, while the regenerative braking of hybrid electric vehicle is one of essential reasons of its energy-saving, indeed[14-16].

2. THE FUNDAMENTAL PRINCIPLES OF REGENERATIVE BRAKING

Regenerative braking is also known as feedback braking. The braking of traditional automotive is to convert the vehicle's energy by the friction of the brake into un-recovered heat energy and then dissipate into the environment. The motor for a hybrid electric vehicle can be converted into the generator running state under certain conditions. Hence, the motor shall be operated in the generator state in braking, and charge the feedback current caused by braking into the energy storage device. Consequently, it is able to recover a part of the braking energy.

The energy that can be recovered by regenerative braking varies greatly in the different automobiles and different vehicle operating conditions. Due to frequent starting and braking in urban conditions, the electric vehicles in urban traffic can recover more energy.

Although there is certain loss of power in the process of regenerative braking, because of its huge energy recovery potential, so there is still a lot of potential to be tapped for the effective recovery of energy in the premise of no prejudice to the battery life. When the demand torque of the drive cycles is negative, i.e., in the event of braking, the braking torque shall be commonly shared by the regenerative braking torque and frictional braking torque:

$$T_{braking} = T_{reg\_braking} + T_{mech\_braking}$$

$T_{mech\_braking}$ —friction braking torque (N·m);

$T_{reg\_braking}$ —regenerative braking torque (N·m);

$T_{braking}$ —braking torque (N·m).

The development of the HEV is refitted from the chassis of internal – combustion engine vehicles. The motor can drive vehicles, and it can also charge after increasing the power source for the motor drives. The braking capability of motor of the hybrid electric vehicle is limited. When the separate electrical braking capacity cannot satisfy the requirements of the larger braking strength, the friction braking shall be applied simultaneously, i.e. composite braking method.

3. REGENERATIVE BRAKING CONTROL PARAMETERS

The regenerative braking control parameters consist of the regenerative braking scale coefficient and lowest regenerative braking speed. The regenerative braking scale coefficient is the ratio of the regenerative braking torque and the total braking torque, in the range 0 to 1, as shown in Figure 1. The limit value of lowest regenerative braking speed means that the regenerative braking no longer works under this vehicle speed. The braking force is provided entirely by the friction braking.

The regenerative braking strategy is shown in Figure 2. In the event of low braking intensity, the total braking torque is borne jointly by the regenerative braking and friction braking in line with a fixed proportion. In the event of high braking intensity, when the regenerative braking torque is saturated, the further increased braking torque shall be provided by the friction braking. With this control strategy, the structure of friction braking system and the control method of the frictional braking torque of the original vehicle may be substantially constant, while the regenerative braking torque of the motor shall be subject to simple proportional control according to the brake pedal input signal.

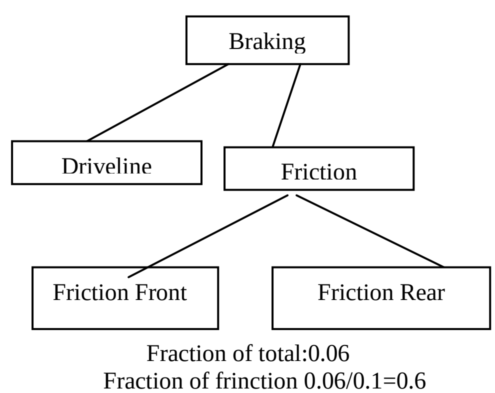

Figure 1. Proportion Between Regenerative Braking And Friction Braking

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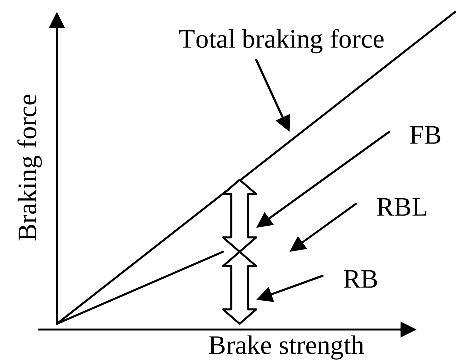

Figure 2. Sketch Map Of The Strategy For Regenerative Braking

The control strategy of regenerative braking can be briefly described as shown in Figure 3. It shows the relationship between the scale coefficient of the regenerative braking force in the total braking force and the vehicle velocity in the regenerative braking. Under a high vehicle velocity, it applies the constant proportion manner; in contrast, under a low vehicle velocity, the scale coefficient of regenerative braking will be dropped and until to zero.

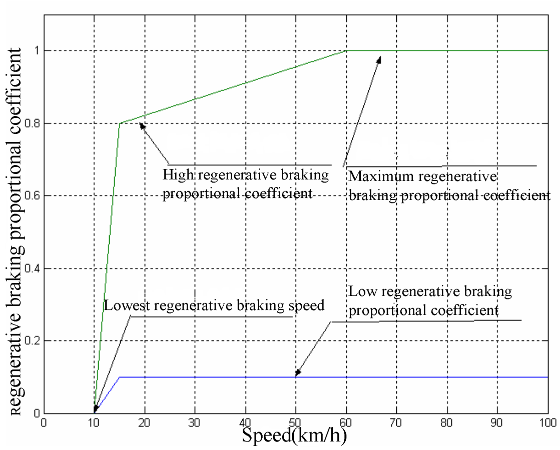

Figure 3. Sketch Map Of The Control Strategy For Regenerative Braking

The simulation results in the presence and absence of regenerative braking process are shown in Figure 4 and Figure 5. As can be seen from Figure, in the presence of regenerative braking, the battery will be available for more charging opportunities in the entire cycle, thus the SOC (State Of charge) will be maintained at a preferable level, and SOC will be 0.61 or more; however, SOC is around 0.57 in the absence of regenerative braking. Table 1 indicates the energy analysis in the presence or absence of regenerative braking. In the presence of regenerative braking under the UDDS, the fuel consumption is reduced by 11% and the power consumption is reduced by 19%. In the absence of regenerative braking under the UDDS, the fuel consumption is reduced by 3.3 % and the power consumption is reduced by 5 %.

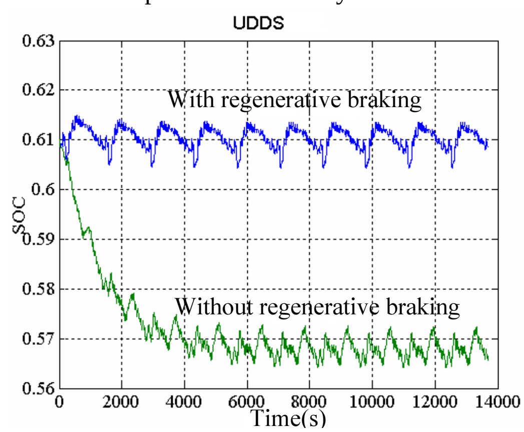

Figure 4. Contrast Of SOC With Or Without

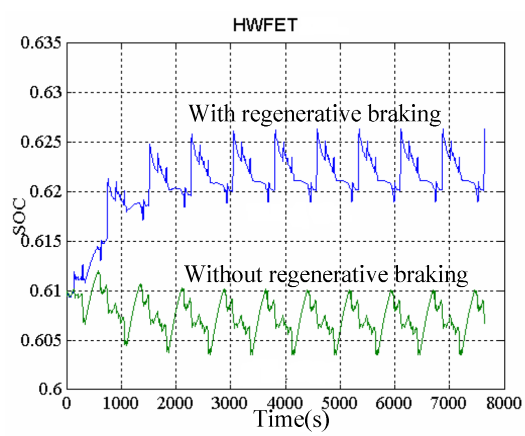

Figure 5. Contrast Of SOC With Or Without Regenerative Braking Under HWFET

Under a variety of drive cycles, the hybrid electric vehicle has significant energy saving effect in the presence of regenerative braking. In particular, with respect to the traffic conditions under frequent braking and relatively low braking strength, the energy-saving effect of regenerative braking is more significant (such as the UDDS).

As the regenerative braking provides more charging opportunity to the battery, therefore, the battery will maintain better charge state with regard to the cycle of more obvious regenerative braking effect.

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4. INFLUENCE ANALYSIS

The dynamic property of the hybrid electric vehicle is not affected by the regenerative braking control parameters. Its major influences are the fuel consumption and the SOC value of the hybrid electric vehicle. To simulate in line with the two kinds of control strategies in Figure 5, the simulation results for the comparison of different regenerative braking with different scale coefficients on fuel consumption.

4.1 The Influence Of Regenerative Braking Scale Coefficient On Hybrid Electric Vehicle

In the event of larger participation extent of the regenerative braking, the power generation torque of the motor will be greater, the batteries will have more in-depth charging opportunities, SOC will maintain good level, and the loss of mechanical braking power will be less, thus, the fuel consumption will be superior in case of higher regenerative braking proportion compared to that of the lower regenerative braking proportion. In addition, its fuel consumption is reduced by 10%, its power consumption is reduced by 1.6% and its energy recovery is increased by 93.4% under UDDS, while its fuel consumption is reduced by 2.6%, its power consumption is reduced by 19.9% and its energy recovery is increased by 95.7% under HWFET.

With respect to the simulation computation of Cyclic Test of the hybrid electric vehicle under the UDDS and HWFET, the influence of varied regenerative braking scale coefficients on the fuel consumption is shown in Figure 6 and Figure 7; while the influence of varied regenerative braking scale coefficients on the SOC is shown in Figure 8 and Figure 9. The simulation results show that, the fuel consumption decreases and SOC curve rises against the increase in the regenerative braking scale coefficient. Therefore, raising the regenerative braking scale coefficient is an important means to improve the recovery rate of regenerative braking energy. Thus, it shall apply a higher regenerative braking scale coefficient in terms of the influence on fuel consumption or SOC.

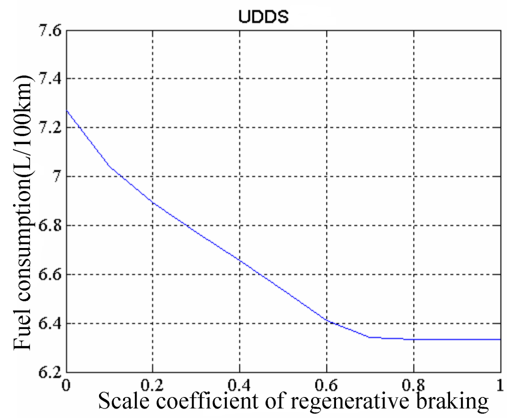

Figure 6. *Influence Of Scale Coefficient Of Regenerative Braking On Fuel Consumption Under UDDS*

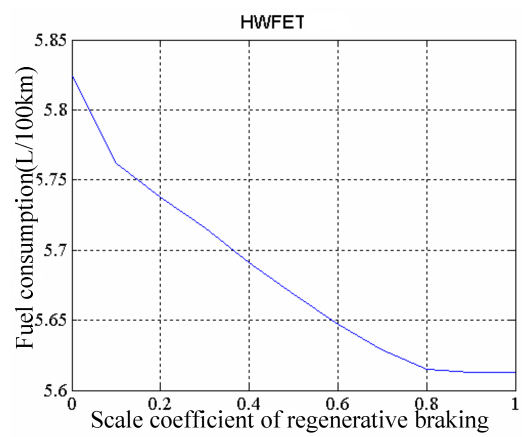

Figure 7. *Influence Of Scale Coefficient Of Regenerative Braking On Fuel Consumption Under HWFET*

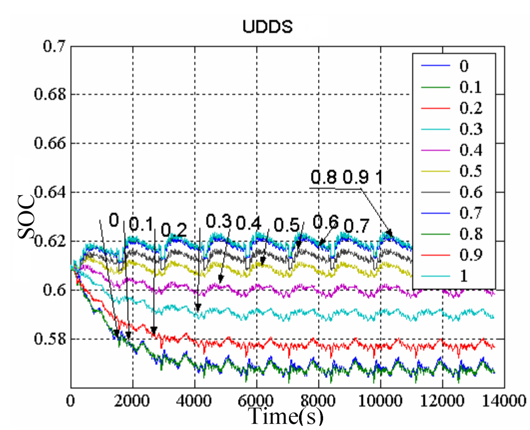

Figure 8. *Influence Of Scale Coefficient Of Regenerative Braking On SOC Under UDDS*

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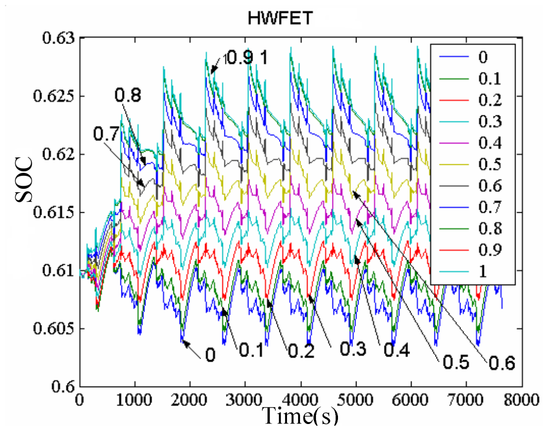

***Figure 9.** Influence Of Scale Coefficient Of Regenerative Braking On SOC Under HWFET*

4.2 The influence of lowest regenerative braking speed on the hybrid electric vehicle

The influence of the lowest regenerative braking speed on fuel consumption and SOC is shown in Figure 10 — 13, respectively. The simulation results show that, the limit of the lowest regenerative braking speed affects the regenerative braking effect, i.e., the lower the lowest regenerative braking speed limit, the greater the braking energy recovery rate. However, when the limit of the lowest regenerative braking speed is reduced to a certain extent (less than 10 km/h), the effect on the enhancement of the energy recovery rate will becomes less significant, and the influence on fuel consumption and the SOC is diminished. This is due to that the available braking power for recycling is already low in the event of low velocity; the recovery value of this part of energy seems faint.

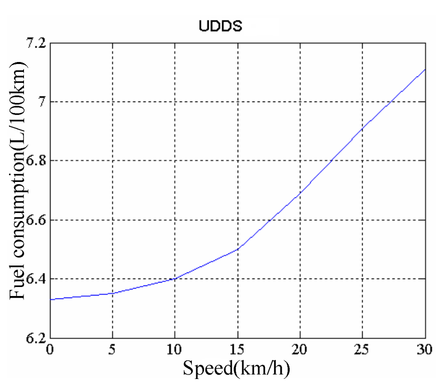

***Figure 10.** Influence Of The Lowest Braking Speed Of Regenerative Rraking On Fuel Consumption Under UDDS*

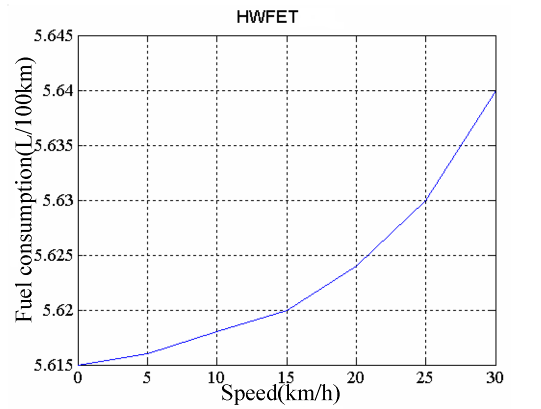

***Figure 11.** Influence Of The Lowest Braking Speed Of Regenerative Braking On SOC Under HWFET*

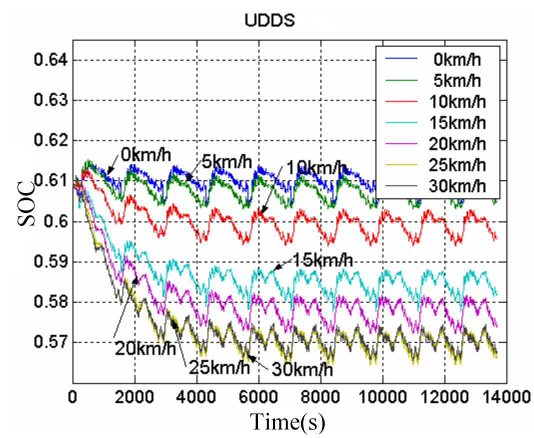

***Figure 12.** Influence Of The Lowest Braking Speed Of Regenerative Braking On SOC Under UDDS*

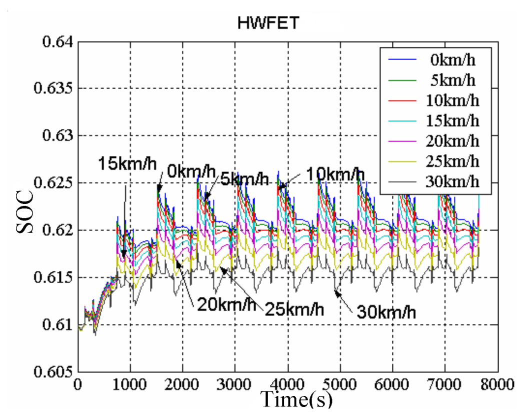

***Figure 13.** Influence Of The Lowest Braking Speed Of Regenerative Braking On SOC Under HWFET*

5. CONCLUSION

Under a variety of drive cycles, the hybrid electric vehicle has significant energy saving effect in the presence of regenerative braking. In

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particular, with respect to the traffic conditions under frequent braking and relatively low braking strength, the energy-saving effect of regenerative braking is more significant (such as the UDDS). As the regenerative braking provides more charging opportunity to the battery, therefore, the battery will maintain better charge state with regard to the cycle of more obvious regenerative braking effect.

The enhancement on the scale coefficient of regenerative braking is conductive to the fuel economy and SOC. The influence of lowest regenerative braking speed on fuel consumption and SOC: the limit of lowest regenerative braking speed makes a difference on the regenerative braking effect, i.e., the lower the lowest regenerative braking speed limit, the greater the braking energy recovery rate. However, when the limit of the lowest regenerative braking speed is reduced to a certain extent (less than 10 km/h), the effect on the enhancement of the energy recovery rate will becomes less significant, and the influence on fuel consumption and the SOC is diminished. This is due to that the available braking power for recycling is already low in the event of low velocity; the recovery value of this part of energy seems faint.

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