International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: #679

THE DRIVER-IN-THE-LOOP SIMULATION ON REGENERATIVE BRAKING CONTROL OF FOUR-WHEEL DRIVE HEVS

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ABSTRACT

Nowadays, the environmental problem is becoming more and more serious, attracting the attention of most people. Automobiles emission pollution has a great influence on environment, so the development of vehicles requires more efficient and cleaner. Regenerative braking is an effective method for hybrid electric vehicle (HEV) to improve fuel efficient. In this paper, firstly, the dynamics of the target vehicle was verified according to the selected parameters, including acceleration and climbing conditions. Then, a control strategy based on the parallel hybrid electric vehicle was proposed. Finally, in order to verify the control strategy's effectiveness and real-time performance, a driver-in-the-loop real-time simulation platform for HEVs was built up based on the Development to Production (D2P) product-level controller, which can reduce development costs and is easy to implement. The results show that the proposed regenerative brake control strategy has good real-time performance.

Keywords: Hybrid electric vehicle; control strategy; D2P;driver in the loop simulation;

NONMENCLATURE

Abbreviations	
HEV	Hybrid Electric Vehicle
D2P	Development to Production

1. INTRODUCTION

The problems of environmental pollution and energy crisis are becoming more and more serious. Environmental issues require the development of the vehicle must be toward to the direction of low pollution and high efficiency [1]. Including hybrid electric vehicle, pure electric vehicle, and fuel cell electric vehicle, when the vehicle is braking, compared to conventional cars, these types of electrified vehicles can be recharged by generators and stored in the batteries. Thereby, these types of electrified are an effective way for the vehicle to extend the mileage compared with traditional automobile [2].

Nowadays, regenerative braking technologies is widely used in electrified vehicles, in order to improve the efficiency of this technology, more and more scholar study about regenerative braking. J. HAN etc. proposed an adaptation regenerative brake torque optimization method using under-steer index to recover optimal braking energy for front wheel drive HEV, and by CARSIM software to verify the effects [3]. Maia etc. proposed a fuzzy logic model of regenerative braking to distribute the ratio of regenerative braking force [4]. Xu etc. proposed a braking system using only electric motors/generators as the actuators with a hierarchical control structure [5]. Kim etc. aimed at a four-wheel-drive hybrid electric vehicle using rear motor driving as the research object and proposed a stability enhancement control algorithm, using ADAMS and MATLAB Simulink simulations [6]. All of the above papers are off-line simulation. Using off-line simulation can short the development cycle and reduce costs. But it can't reflecte the real-time of the control strategy and ignore the driver's impact on the vehicle.

Regarding the issue above, in this article, in order to more accurately study the proposed effect of regenerative braking, we carried out the driver in the loop simulation for HEV using rear motor control. Compared with offline simulation, the driving in the loop real-time simulation can verify the real-time effect. Therefore, it is important to study in the loop simulation for this kind of model.

2. PAPER STRUCTURE

This paper is organized as follows: the analysis of vehicle dynamics is described in Section 2.1. The braking force distribution strategy and driver in the loop real time simulation system are proposed in Section 2.2. Simulation results and analysis are carried out in Section 2.3, and conclusions are given in Section 2.4.

2.1 ANALYSIS OF VEHICLE DYNAMICS

In this paper, the target model is different from the conventional parallel hybrid electric vehicle. The electric motor and the engine drive the front and rear wheels respectively, and the torque is coupled by the ground. This structure simplifies the torque coupling structure and that can achieve four-wheel drive under certain conditions.

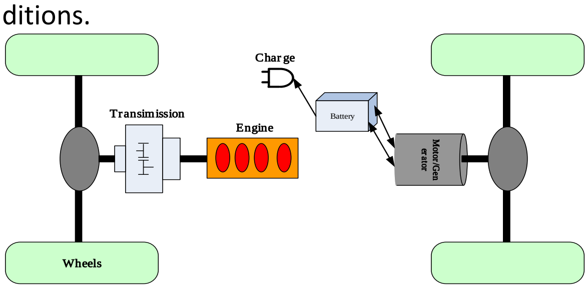

Fig 1 The structure of rear axle electric drive vehicle

Fig 1 shows the structure of a hybrid electric vehicle with rear axle electric drive vehicle that is proposed in this study. In this section, firstly, according to the driving equation of vehicle, the selected parameters of the vehicle were shown on the table 1. Then, in order to verify the selected parameters meeting the performance requirements of vehicle, we passed through simulation on the different road conditions in this paper. The results were shown in the Fig.2 and Fig.3.

Table 1 Key parameters of target vehicle

Name	Value
Maximum engine power	40KW
Electric motor power	49KW
Battery capacity	45Ah
Vehicle loaded mass	1400kg
gearbox	3.52,2.04,1.40,1
air resistance coefficient	0.301
Windward area	2.05m^2
Number of batteries	25
rolling resistance coefficient	0.012
wheel radius	0.315m

Fig 2 shows the accelerated map of a hybrid electric vehicle with rear axle electric drive vehicle on the different adhering coefficient roads. When the car is driving in the road of good adhering conditions, such as

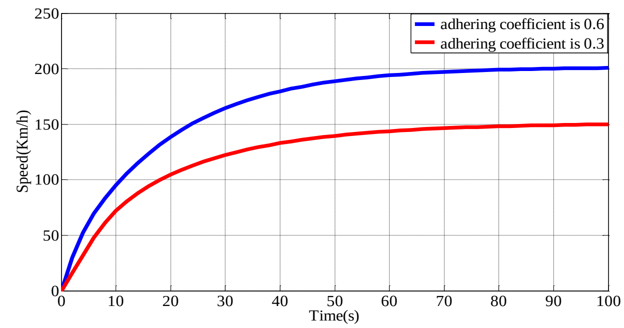

Fig 2 Accelerated map of rear axle electric drive vehicle

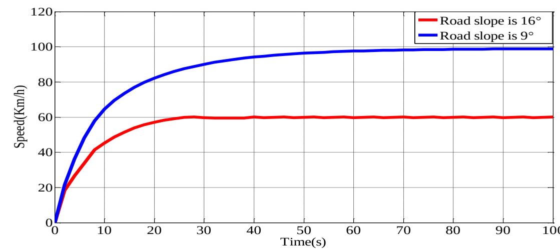

Fig 3 Climbing map of rear axle electric drive vehicle

the blue line shows in the Fig 2, we can see the vehicle has great acceleration and the maximum speed can up to 200km/h. Even though the road has not a good adhering condition, such as the red line as shown the adhering coefficient is only 0.3, the maximum speed also can up to 150km/h. So we can get conclusion that the selected parameters can meet the acceleration requirements of the vehicle.

Fig 3 shows the climbing map of the target vehicle in the different slope roads. When the road slope is equal to 9°, we can see the vehicle has great climbing ability and the maximum speed can up to 100km/h. When the road slope increases to 16°, the maximum speed can also up to 60km/h. So the matched parameters can satisfy the climbing requirements of the vehicle.

From what has been discussed above, we can get the conclusion that the target model can get better power when the road conditions are poor or the torque requirements are large. Therefore, the study of this type of vehicle is very necessary.

2.2 REGENERATIVE BRAKING CONTROL STRATEGY

In this paper, development of control strategy must ensure the braking safety as much as possible on the recovery of braking energy. The specific process is shown in Fig 4. When the vehicle is braking, the Electronic Control Unit (ECU) calculates the required braking force through the change of the brake pedal travel. Then, brake force distribution between front and rear axles is determined by the braking strength z. The braking force of the front wheels is supplied by mechanical brake system braking, and the braking force of the rear wheels is supplied by regenerative braking force and mechanical braking force. The size of the regenerative brake force is determined by many factors such as motor maximum braking power and maximum charge power of the battery.

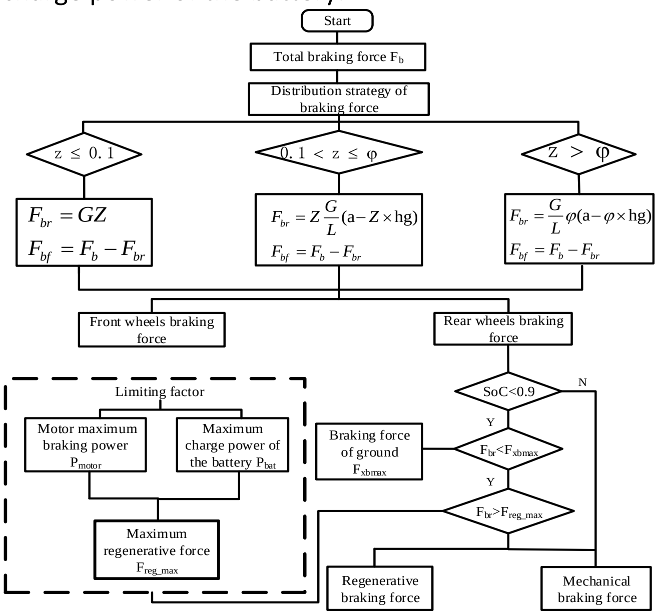

Fig 4 The flow chart of the regenerative braking strategy

In Fig 4, F_{br} denotes the maximum brake force in rear axle; G is vehicle gravity; a, b and L denote the front wheelbase, rear wheelbase and wheelbase, respectively; h_g is the height of vehicle body gravity center; Z represents the braking strength; ϕ represents the adhesion coefficient of road surface; F_{reg_max} denotes the regenerative brake force.

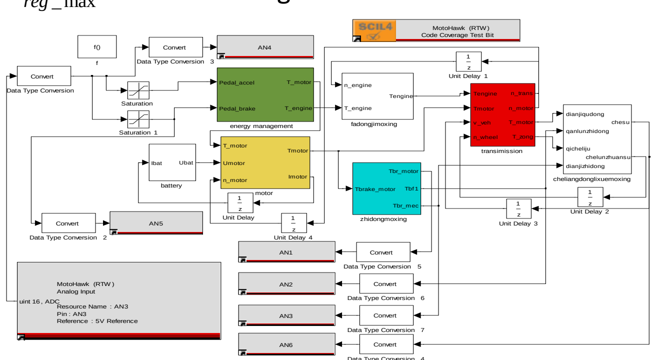

Fig 5 The real-time simulation model based on D2P

2.3 DRIVER IN THE LOOP SIMULATION PLATFORM

The driver-in-the-loop simulation can make real-time verification for the regenerative braking control strategy. Fig 5 shows the real-time simulation model based on D2P, this model has only one pedal as input, and is provided with seven monitoring modules.For further verifying the effects of the regenerative braking control strategy, a driver-in-the-loop simulation platform is required. In order to carry out ring tests in limited experimental conditions, the pedal signal is only used as an external input signal, whereas other components such as the engine, batteries, and electric, etc. are replaced with models. The platform of the driver-in-the-loop simulation system is shown in Fig.6. As the inputs of the system, the pedal is connected with D2P and the D2P system is connected with upper monitor by the CAN bus. The results of the real-time test are shown in the interface.

Fig 7 shows the input from the driver for the real-time experiment. The position of driver's acceleration pedal and brake pedal is quantized as a variable from 0 to 1 linearly. Pedal=0 represents the empty position of pedal while pedal=1 represents pushing the pedal to the bottom.

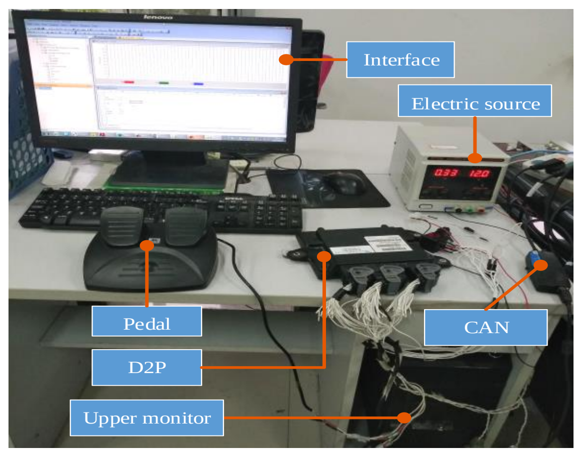

Fig 6 Driver-in-the-loop experiment platform

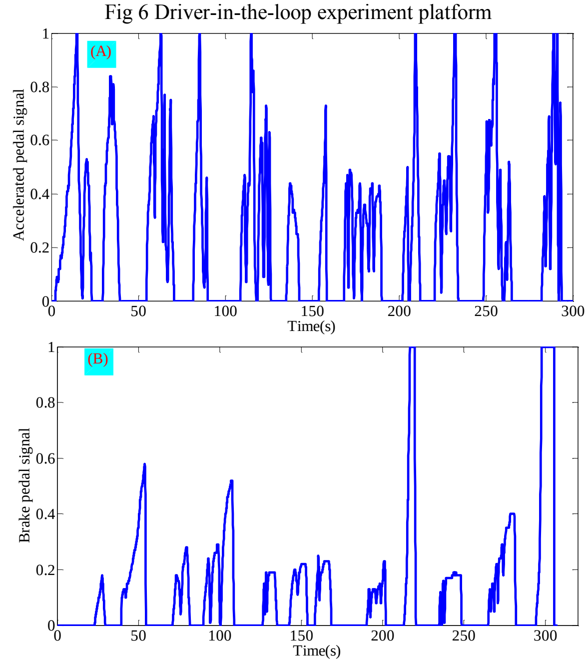

Fig 7 Driver operation signals: (A) Acceleration pedal; (B) Brake pedal.

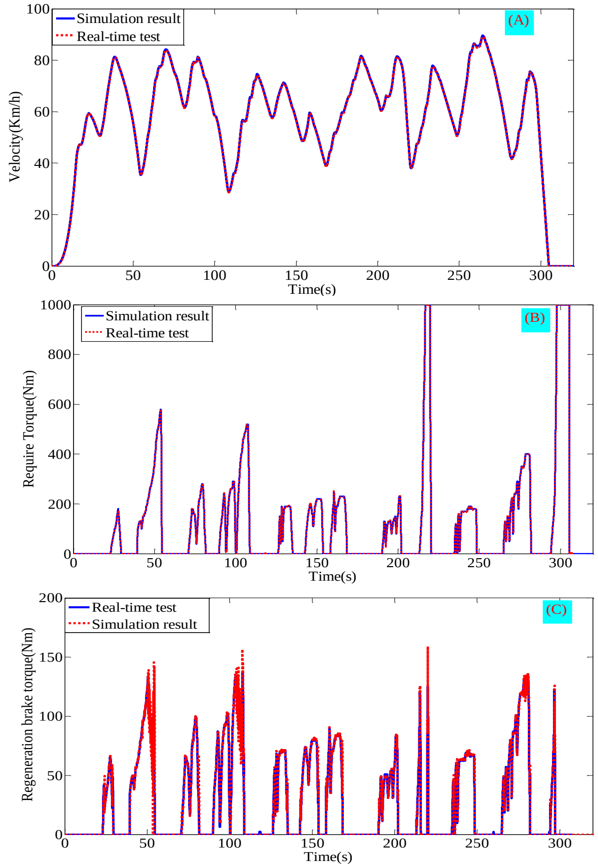

Fig 8 Comparison results of driver in-the-loop real-time test and offline simulation: (A) Velocity; (B) Require torque; (C) Regeneration brake torque;

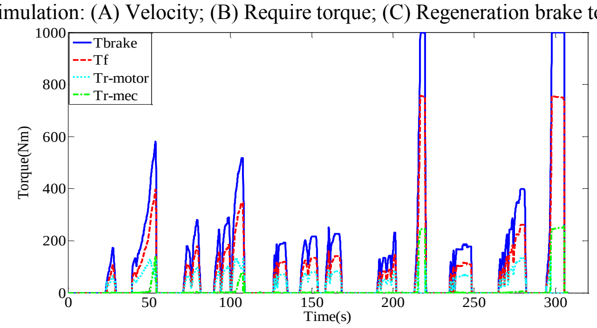

Fig 9 The real-time test results of brake torque

The calculation step of the simulation time is less than or equal to the execution cycle of the controller algorithm and can be exact division by the controller algorithm. In this paper, the execution cycle of the controller used in the real-time control is 50ms, and the step size is set up 10ms in the offline simulation .The comparison results of driver in-the-loop real-time test and offline simulation are shown in the Fig 8. First, the driver's inputs signals are recorded in the upper monitor by the mototune software. And then these data as the inputs are used in the offline simulation system. Finally, we draw the results of real-time test and offline simulation on the same picture. It can be seen that the results of the real-time test system and offline simulation results are very consistent. Fig. 9 shows the regenerative braking force distribution in a real-time test progress, we can see that the proposed strategy has very good real-time performance.

2.4 conclusion

In this paper, firstly, the dynamics of the target vehicle was verified according to the selected parameters, including acceleration and climbing conditions. Then, a control strategy based on the parallel hybrid electric vehicle was proposed. Finally, in order to verify the control strategy's effectiveness and real-time performance, a driver-in-the-loop real-time simulation platform for HEVs was built up based on the Development to Production (D2P) product-level controller, which can reduce development costs and is easy to implementation. In order to test the real-time operation possibilities of the control strategy of brake force distribution, a driver in-the loop experiment platform was established and the results shows that the proposed regenerative brake control strategy has good real-time performance.

ACKNOWLEDGEMENT

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