Design and Development of Brake Energy Recovery Test Bed for Electric Vehicle

Jinjun Zheng, Zhen Wang, Yumeng Wang, and Kun Ma

Abstract Aiming at the problem of brake energy recovery of electric vehicle (EV), a hardware in the loop (HIL) simulation test system based on MATLAB/Simulink is designed and built. The system uses real vehicle braking system and pedal simulation device, compiles control algorithm, uses real-time physical signals for real-time communication, and completes the semi physical simulation experiment. The results show that the test bed can realize the simulation of the brake energy recovery of electric vehicles, and the experiment can achieve the expected results.

Keywords Electric vehicle (EV) · Brake energy recovery · Hardware in the loop (HIL) · Experimental research

1 Introduction

In recent years, the EV industry has developed rapidly in China. In 2018, the sales volume of EV in China was 984,000 [1]. Braking energy recovery can improve energy utilization, reduce vehicle wear and braking heat, reduce noise, alleviate heat recession, optimize the braking performance of EV, and improve braking stability, which is one of the key technologies of EV control [2]. Braking energy recovery refers to the function that the driving motor works in the form of a generator during the deceleration or braking process of an EV, which converts part of the kinetic energy of the vehicle into electrical energy and stores it in a battery pack through the motor, and releases it again during the acceleration process of the vehicle to drive the vehicle [3]. The main work of this paper is to establish the simulation model, build the real vehicle brake system and brake pedal simulation device test bed, use the computer model signal and the actual physical signal of the test-bed for real-time communication, and complete the HIL simulation test.

J. Zheng (✉) · Z. Wang · Y. Wang · K. Ma
College of Automotive Engineering, Jilin University, Changchun, China
e-mail: zhengjj@jlu.edu.cn

J.-W. Chang et al. (eds.), *Frontier Computing*, Lecture Notes in Electrical Engineering 747, https://doi.org/10.1007/978-981-16-0115-6_91

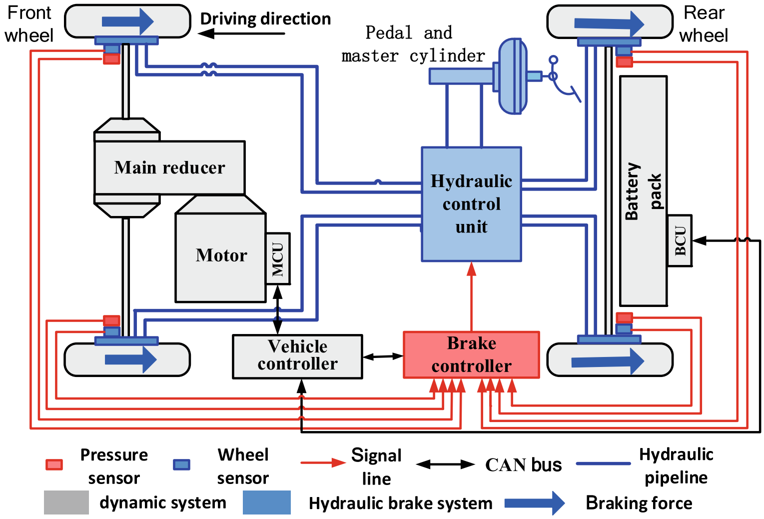


Fig. 1 Configuration scheme of electric vehicle braking system

2 Configuration Scheme of Braking Energy Recovery System

The target vehicle of this paper is a self-developed EV with motor front drive. In addition to the ESP standard brake function, there is signal exchange between the hydraulic brake system and the motor, which has the conventional hydraulic brake boosting function and the motor feedback brake torque coordination function. The system calculates the driver's braking demand according to the signal of the braking controller and then distributes the braking force according to the feedback braking force provided by the motor and the vehicle stability [4–8]. Its structure is shown in Fig. 1.

3 Design of HIL Test Bench

HIL technology establishes simulation model through software to replace the real vehicle and its related parts, accepts the physical signals of the real state for calculation, and sends out corresponding control instructions, which can shorten the product development cycle period, to meet the needs of testing and verification of vehicles and related products [9, 10]. The schematic diagram of HIL test bench for brake energy recovery of EV is shown in Fig. 2, which is composed of hardware and software.

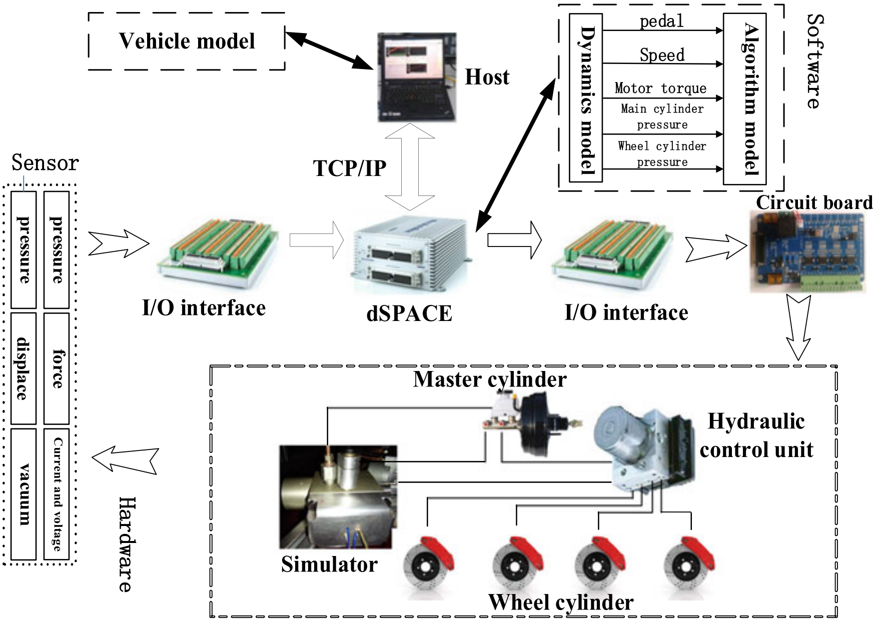


Fig. 2 Schematic diagram of brake energy recovery test bench

3.1 Hardware System

3.1.1 Braking System

In the test bed price, the real brake system can truly reflect the response characteristics of the EV brake system.

3.1.2 dSPACE Real-Time Simulation System

dSPACE used in this paper mainly includes processor board DS1401, I/O interface boards DS1505 and DS1507. The HIL test bench is shown in Fig. 3.

3.1.3 Sensor

The sensors used in this paper mainly include pressure sensor, displacement sensor, force sensor, and voltage and current sensor. See Table 1 for details.

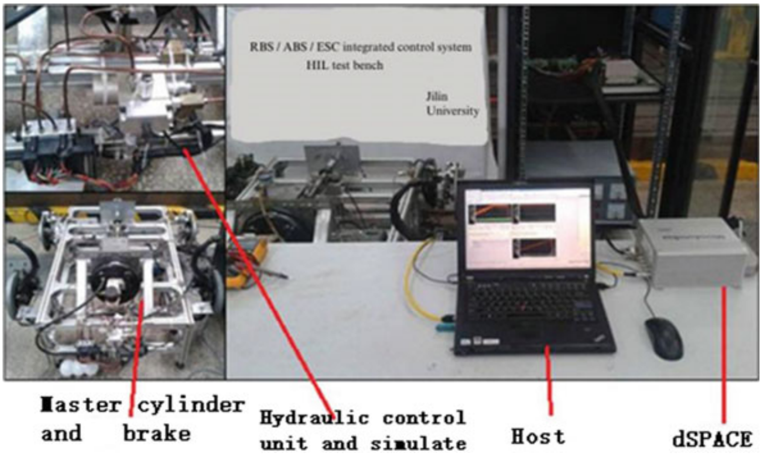


Fig. 3 Physical figure of HIL test bench

Table 1 Sensors selected for the test bench

Number	Name	Manufacturer/model	output signal
1	Pressure sensor	Keller/PA-21PRO	4–20 mA
2	Displacement sensor	Melexis/MLX90293	PWM
3	Vacuum sensor	HELM/HM27	4–20 mA
4	Voltage and current sensor	LEM/LF1005	1–5 V; 4–20 mA

3.2 *Software System*

The software program of hardware in the loop test includes vehicle model, motor model, battery model, and control strategy model. At the beginning of the test, the model of vehicle, motor, battery, and other components in the host machine is downloaded to the target machine dSPACE. At this time, dSPACE participates in the test as a part of the hardware test ring. During the test, the sensor detects the changes of physical signals such as the pressure, displacement current, and voltage of each part of the hardware system and sends them to dSPACE I/O interface board. dSPACE is connected as a controller which receives the signal from the sensor and sends out the corresponding control command through the calculation of the program control strategy to complete the control of the hardware system of the test bed.

4 MATLAB/Simulink and AMEsim Joint Simulation

4.1 AMEsim Model

AMEsim software adopts the modeling method of energy port, which directly represents the physical topology of the system, freeing users from the tedious mathematical modeling and focusing on the design of the physical system itself [11].

4.2 MATLAB/Simulink Model

Simulink simulation model in this paper includes vehicle model, motor model, battery model, power distribution model, braking force coordination model, hydraulic braking system control model, and interface model [12]. The information of brake pipeline pressure and brake pedal displacement in the control strategy comes from AMEsim model, and the information of vehicle speed, deceleration, and motor battery voltage and current come from Simulink model. The hydraulic control signal of the braking system is transmitted to AMEsim through the interface module, and the control signal of the motor is directly transmitted to the motor model in Simulink. AMEsim model and Simulink model form a complete circuit of signal acquisition and control.

5 Simulation Analysis of Hardware in the Loop Experiment

The following brake conditions are used for the test: The vehicle speed is 100 km/h, and the brake pedal moves 40 mm. This working condition reflects the braking process under the condition of high vehicle speed and large brake pedal opening. The test results are shown in Fig. 4, and process 1 reflects the process of increasing brake pedal opening. In the middle is the braking steady-state process, and process 2 is the process of gradually withdrawing motor braking torque from braking.

Process 1: Due to the free travel of the brake pedal, when the pedal opening is small, the hydraulic brake system of the front and rear axle does not work, and the hydraulic brake torque is basically 0, and the motor applies the brake torque; with the increase of the brake pedal travel, the rear axle cylinder starts to build pressure, and the front axle cylinder still has no pressure, and the front wheel brake force is all provided by the motor brake force; with the brake pedal opening continuing with the increase, the empty stroke is completely eliminated. At this time, due to the limitation of the external characteristics of the motor, the motor braking capacity has reached the upper limit. When the braking force required by the current shaft is greater than the maximum braking force of the motor, the motor will generate the

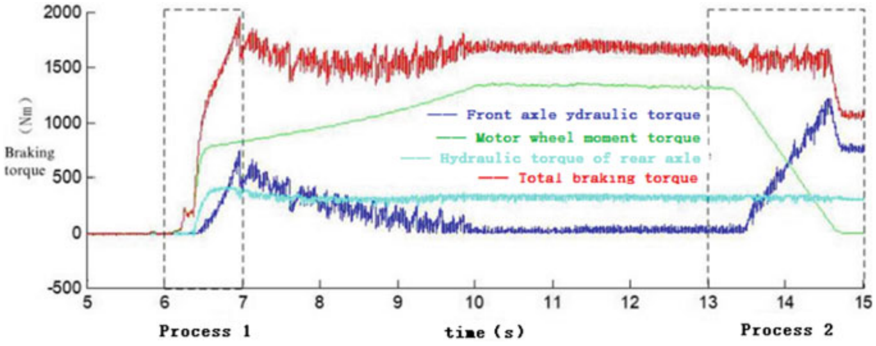


Fig. 4 Hydraulic motor and total braking torque

maximum braking torque. At the same time, the front axle cylinder starts to establish pressure to make up for the shortage of the motor braking force.

Process 2, according to the control strategy, when the vehicle speed is low, the motor braking torque needs to exit. As the brake torque of the motor decreases, the front axle cylinder starts to be pressurized to meet the brake torque demand. In this process, the total brake torque remains stable, and the system can coordinate with the hydraulic brake torque and the motor brake torque.

During the test, the front axle cylinder pressure can follow the control strategy to set the target pressure better (Fig. 5); during the test, the braking process is smooth and stable, the braking deceleration is basically kept at -3.5 m/s^2, and the vehicle speed drops steadily (Fig. 6); during the braking process, the SOC of the battery increases by about 0.25%, and the braking energy recovery system plays the expected role (Fig. 7).

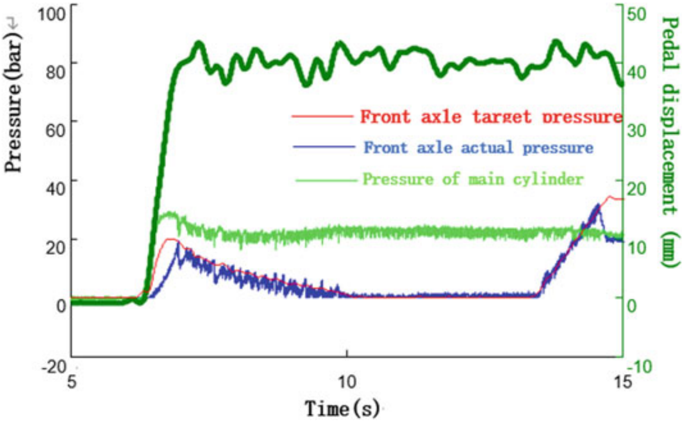


Fig. 5 Actual and target hydraulic brake pressure

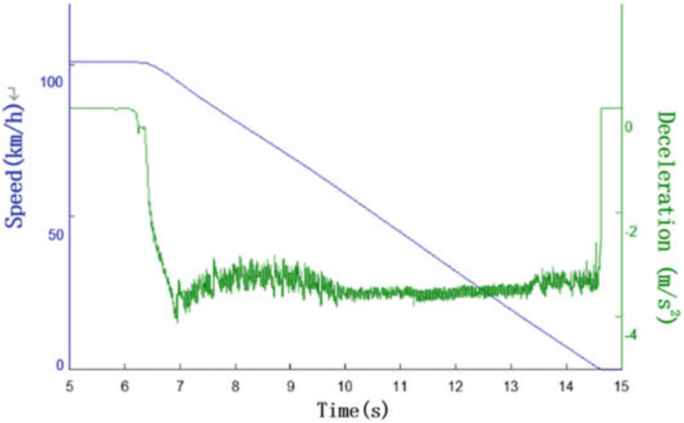
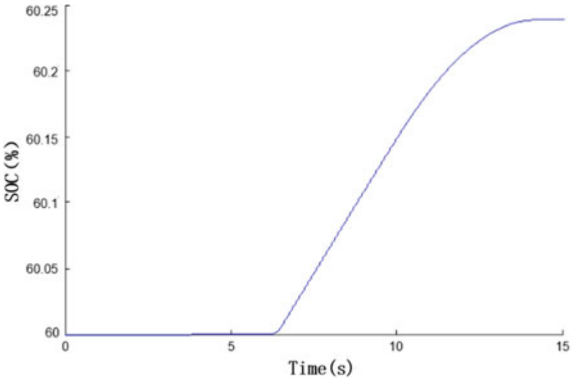


Fig. 6 Vehicle speed and deceleration

Fig. 7 SOC change of battery



6 Conclusion

This paper designs a HIL test bed hardware system of braking energy recovery system of EV. The test results show that the brake test bed can meet the requirements of control strategy and can realize the function of braking energy recovery, the speed changes smoothly, and the braking process has no obvious jitter. The test bed can simulate the actual braking condition of the electric vehicle in the laboratory. The experimental results are of great significance to the research and development of the brake energy recovery system structure and control strategy of the electric vehicle. The test bed meets the expected design requirements.

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