Research on ESC Hydraulic Control Unit Property and Pressure Estimation

Liu Wei, Ding Haitao*, and Guo Konghui

State Key Library of Automobile Dynamic Simulation, Jilin University,
Changchun 130025, China
dht_jlu@126.com

Abstract. Vehicle mounted Electronic Stability Control (ESC) requires exact estimation of wheel brake cylinder pressure. A model of pressure transfer property is established according to the structure of ESC Hydraulic Control Unit (HCU). The property model of HCU is established for pressure estimation algorithm. The property is acquired with the ESC hardware in loop (HiL) test bed, to calibrate the model parameters. The algorithm is then used in the closed loop control of HCU. The test is carried out to verify the effect of pressure estimation method. The test result demonstrates that the algorithm can supply stable pressure information to the ESC system.

Keywords: Electronic Stability Control, Hydraulic Control Unit, Pressure estimation.

1 Introduction

ESC system plays an important role on research of vehicle active safety. ESC logic distributes the braking force to control the gesture of vehicle, in order to improve the handling performance and safety of the vehicle. ESC has been widely used in vehicle electronic control. FMVSS126 which published in April 2007 is the first regulation in the world about ESC, it regulates that, since Sep 1st 2011, all car sold in US with the load below 4,536Kg（10,000pounds） must mount the ESC system [1].

HCU is the actuator of ESC, the ESC ECU acquires vehicle states information through sensor and CAN bus, then distributes braking force according to control logic. The HCU controls four wheel cylinders pressure according to independent up-keep-down instructions of four wheel cylinders. Hence, the research on HCU dynamic property provides the possibility to wheel cylinder pressure estimation, which saves the mounting of wheel pressure sensor, saves the costs of manufacturing and improves the stability of the vehicle [2].

HCU model is established with some simplifications to describe the property of hydraulic dynamic characteristic. The ESC HiL is used to acquire the property of HCU hydraulic system, which is analyzed for identification of HCU model parameters. The pressure estimation algorithm based on the HCU model is applied in

* Corresponding author.

Z. Du (Ed.): Intelligence Computation and Evolutionary Computation, AISC 180, pp. 625–631.
springerlink.com

the closed-loop control logic which is used for verification of pressure estimation algorithm [3].

2 ESC HiL Test-Bed and ESC HCU

2.1 ESC HiL Test-Bed

An ESC HiL test-bed is built for braking system research to avoid the complicate hydraulic system modeling. The states of hardware parts are measured by sensor and communicated with HOST PC and ECU on CAN bus.

The hardware of ESC HiL test-bed system includes braking system of vehicle with ESC HCU and pressure sensor mounted to measure pressure of main cylinder and wheel cylinder. The braking pedal is driven with braking-by-wire system to provide main cylinder pressure. The scheme of test-bed is demonstrated in Fig. 1.

In the braking-by-wire system, main cylinder is pushed with linear actuator which is driven by motor controlled by electronic brake pedal, to provide braking force. ESC ECU adjusts HCU to realize the required pressure of each wheel. The vehicle model is running in HOST PC to provide software environment for control logic. The monitor PC is used to modify and download control logic or pressure estimation algorithm into ESC ECU.

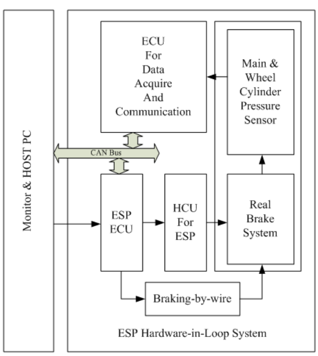

Fig. 1. The scheme for ESC HiL

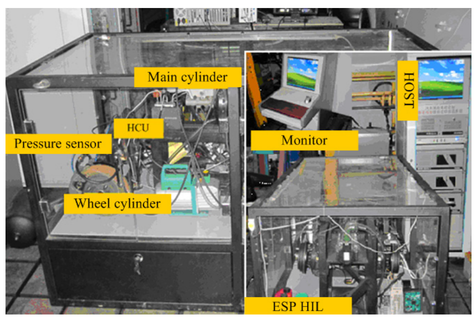

Fig. 2. Test bed for ESC HiL

Independent instructions of four wheels according to wheel cylinder required pressure is acquired with the calculation of veDYNA vehicle model running in simulink xpc-target, then communicated with ESC ECU on CAN bus, the ESC ECU executes to adjusts the wheel cylinder pressure and acquires the pressure sensor information which is send to HOST PC on CAN bus for analyzing.

As mentioned before, the test-bed is able to acquire the property of ESC HCU during pressure increase process and decrease process, which is used to identify the parameters of HCU model. Fig. 2 shows the structure and components of ESC HiL test-bed.

2.2 The Structure of ESC HCU

ESC HCU which is able to control four wheel cylinders pressure independently is the actuator of ESC, it connects two main cylinder and four wheel cylinder with an ingenuity designed hydraulic system, which distributes braking force to wheel cylinder based on main cylinder pressure (the reflection of driving purpose) and control logic.[5][6]

The hydraulic system is designed with cross-pipe which means that FR/RL and FL/RR wheel cylinders separately share the same pressure establishing route of ESC HCU. The hydraulic system scheme is shown with one wheel cylinder route in Fig.3.

In valve group 1 for pressure establishing, the main valve is always ON, the overflow valve by-pass constrains the maximum pressure which can be established. Valve group 2 for pressure establishing is always OFF. Valve group 3 for pressure maintaining is always ON, the one-way valve ensures that cylinder pressure is less than main pipe route pressure. Valve 4 for pressure draining is always OFF.

The motor drives the piston pump to pump the brake fluid in the accumulator, in order to ensure pressure draining rapidly. At the same time, it pumps the brake fluid in main cylinder to establish pressure in main pipe route for ESC mode.

ESC HCU is the actuator of ESC, it adjusts the wheel cylinder pressure according to ABS logic, when ESC logic works it establishes the pressure in main pipe route for wheel cylinder to create braking force actively.

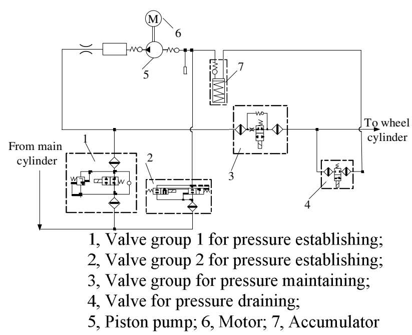

Fig. 3. The scheme of ESC HCU hydraulic system for one route

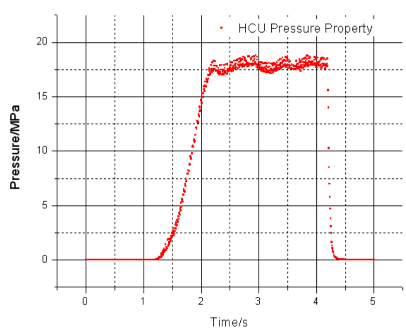

Fig. 4. The pressure property of ESC HCU

3 The Model of HCU Property

3.1 ESC HCU Model

According to the requirement of actuator in ESC system, ESC HCU is designed to be a hydraulic system with critical fabrication requirement, good response characteristic and stable dynamic characteristic. The HCU can be exactly modeled by reasonable test and calibration, the model is then used to describe the dynamic response of HCU, which is the base of cylinder pressure estimation [7].

The HCU property as shown in Fig. 4 includes: the delay of valve response, the transfer characteristic of hydraulic system, the pressure variation property of HCU in different pressure variation stage. The property is described by hydraulic dynamic model with parameters to be identified.

The modeling of HCU property is divided into two main processes, which are pressure increase process and pressure decrease process. The identification of HCU property also consists of two groups of parameters according to the HCU model.

We simplifying the system by neglecting the temperature impact of brake fluid viscosity, considering that brake fluid flow quantity is low during braking, the inner wall of hydraulic pipe is smooth. The model is established with the following process: ignoring pressure loss in pipes and parts, ignoring transient surge of brake fluid during valve changing, ignoring the elastic deformation of brake pipe and cylinder, ignoring the impact of temperature to brake fluid viscosity. These simplifications maintain the basic and main characteristic of HCU hydraulic system, at the same time, make the modeling process succinctly which ultimately simplifies the pressure estimation algorithm used in real time control logic.

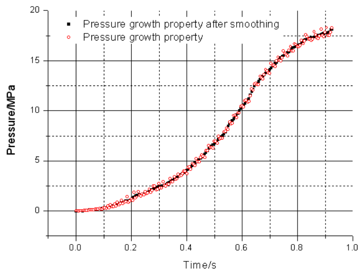

Fig. 5. The pressure increase property ESC HCU

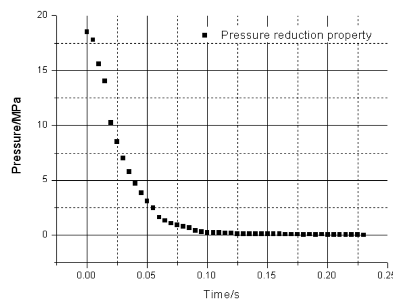

Fig. 6. The pressure decreaseproperty of ESC HCU

The pressure property after simplifying, Pm is pressure of main pipe route. Pw is pressure of wheel cylinder:

Pressure increase process:

$$\frac{dP_w}{dt} = \frac{1}{C_e R_e}(P_m - P_w)^{\phi} \tag{1}$$

- Ce: equivalent liquid capacity in pressure increase process;
- Re: equivalent liquid resistance in pressure increase process;
- Φ: throttling index in pressure increase process.

Pressure decrease process:

$$\frac{dP_w}{dt} = -\frac{1}{C_e R_e'}(P_w - P_r)^{\phi'} \tag{2}$$

- C'e: equivalent liquid capacity in pressure decrease process;
- R'e: equivalent liquid resistance in pressure decrease process;
- Φ': throttling index in pressure decrease process.

3.2 Parameters Identification of ESC HCU

The nonlinear relevant relationship between P_w and t is acquired by solving the states equations of the pressure increase and decrease processes. Through variable substitution, the nonlinear regression problem is then transferred to linear regression problem for system parameters identifying.

Pressure increase process:

$$(P_m - P_w(t))^{1-\phi} = (P_m - P_w(t_0))^{1-\phi} - \frac{1}{C_e R_e}(1-\phi)(t-t_0) \tag{3}$$

Pm = 18.32 is set by the overflow valve by-pass of valve group 1. According to the analysis of test data, we set Φ = 0.5 when correlation coefficient is 0.9963, identify the parameter $1/(C_e R_e)$ = 12.952 with least squares criterion. The inertial characteristic of brake system is also considered during modeling process.

Pressure decrease process:

$$(P_w(t) - P_\gamma)^{1-\phi'} = (P_w(t_0) - P_\gamma)^{1-\phi'} - \frac{1}{C_e R_e'}(1-\phi')(t-t_0) \tag{4}$$

Pγ is the pressure parameter of accumulator, we set Pγ = 0. According to the analysis of test data, we set Φ' = 0.9 when correlation coefficient is 0.9945, identify the parameter 1/(C'eR'e) = 43.14 with least squares criterion.

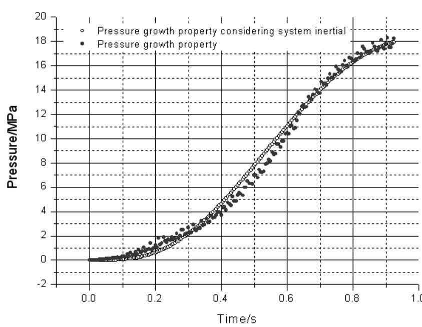

Fig. 7. The pressure increase property after parameter identifying

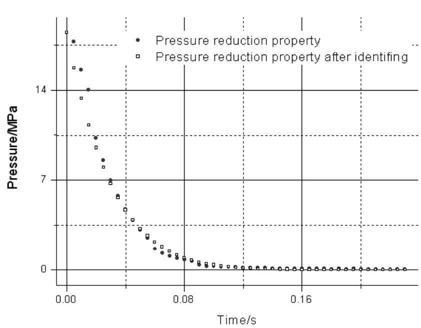

Fig. 8. The pressure decrease property after parameter identifing

After identification of parameters in each process, the complete HCU model is established for pressure estimation algorithm research.

4 Research on Pressure Estimation

4.1 Open-Loop Pressure Estimation

The performance of open-loop pressure estimation is guaranteed by the accuracy of HCU model. The algorithm for pressure estimation is also based on the HCU model. According to HCU property, the relationship between increment of cylinder pressure and cylinder pressure is acquired:

$$\Delta \mathrm{p} = \Delta \mathrm{p}(p_w) \tag{5}$$

In the control logic of HCU, the pressure of next control period is estimated by following discrete state function :

$$p_w(k+1) = p_w(k) + \Delta \mathrm{p}\big(p_w(k)\big) \tag{6}$$

4.2 The Closed-Loop Control Based on Pressure Estimation

The closed-loop control based on pressure estimation is achieved by the deference between estimated pressure and required pressure.

In ESC HiL system, HOST PC calculates the value of required pressure for each wheel by the veDYNA vehicle model and ESC logic, and sends required pressure to ECU, which uses the open-loop pressure estimation algorithm to decide the control instructions of each wheel cylinder.

Signals of pressure sensors are acquired by ECU and sent to HOST PC on CAN bus for data analysis.

4.3 Test Result

Two typical types of pressure control processes are applied with the ESC HiL test-bed to test the pressure estimation algorithm. One is that required pressure is square signal, the other is that required pressure is step up and step down signal.

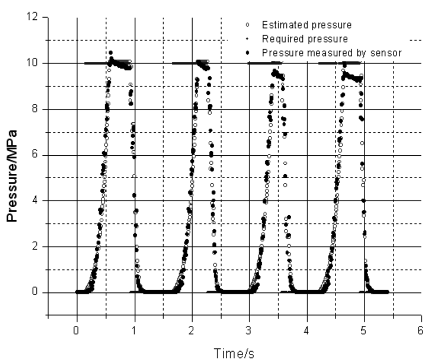

Fig. 9. The result when the required pressure is square signal

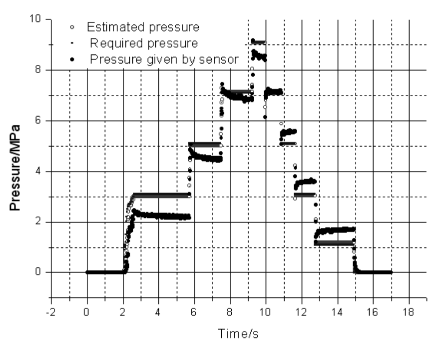

Fig. 10. The result when the required pressure is step signal

The required pressure is given by HOST PC, and is sent to ESC ECU, which controls the HCU with closed loop control based on pressure estimation. The wheel cylinder pressure created by HCU is measured by pressure sensor mounted in HiL. So the estimated pressure is acquired during the pressure control process, the required pressure is calculated by HOST PC, the wheel cylinder pressure measured by sensor is sent to ESC ECU. Through the CAN bus, the estimated pressure and pressure measured by sensor is also acquired by HOST PC for data analysis.

The maximum required pressure of square signal is 10MPa. As shown in Fig. 9, the estimated pressure follows the pressure given by sensor well, that means the closed-loop control logic based on open-loop pressure estimation algorithm describes the basic dynamic characteristic of hydraulic system.

In the step signal process, the required pressure increases step-by-step to maximum pressure , then decreases step-by-step to 0.The result is shown in Fig. 10.

5 Summary

According to the results which show the compare between estimated pressure and sensor tested pressure based on required pressure, the closed-loop pressure control logic based on the open-loop pressure estimation acquired by identifying the property of HCU is proved to be reliable, the open-loop pressure estimation provides the ESC with stable pressure state during the period when HCU works.

References

[1] Liu, W.: Research on Nonlinear State Estimation of Side-slip Angle for Vehicle Electronic Stability Program. CAE of Jilin University (2007)

[2] O'Dea, K.: Anti-Lock braking performance andhydraulic brake pressure estimation. SAE Paper 2005-01-1061

[3] Zhu, B.: Hydraulic brake pressure estimation for integrated chassis control. Journal of Jilin University (Engineering and Technology Edition) 39(sup. 1) (2009)

[4] Chen, C.-K., Dao, T.-K., Lo, M.-F.: A compensated-yaw-moment-based vehicle stability controller. In: Chinese Control and Decision Conference, CCDC 2008, July 2-4, pp. 892–897 (2008)

[5] Kusano, A., Kuno, T.: Hydraulic Brake System for Vehicles. Advics Co. Ltd., US Patent 6,709,072 (2004)

[6] Leppek, K.G., Hogan, M.A., Spadafora, P.J., Lee, A.J.: Antilock brake system with motor current controlof the pressure modulator. US Patent 5,102,207 (1990)

[7] Dawei, G.: Research on Hydraulic Modulator Modeling and Break Pressure Estimation for Vehicle Electronic Stability Program. CAE of Jilin University (2007)