DESIGNING HARDWARE-IN-THE-LOOP MODEL FOR TRACTION CONTROL SYSTEM ON THE VEHICLE

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Abstract – When the vehicle moves on a complicated road, the active wheels on both sides receive different values of torque from the engine transmission down due to the distribution law of the differential in the active axle. Traction control in automobiles is the process of controlling the transmission torque from the engine to the active wheels so that it is suitable for the grip state of the tire and the road surface to avoid the loss of engine torque. This study was implemented to design a hardware-in-the-loop model to control the traction of the automobile when moving in a straight line with different resistances on both sides of the active wheel, designing a traction controller with two sets of brake and engine torque controllers. Experimental results shown that the traction control process achieves the expected effect of the designed hardware-in-the-loop model.

Keywords: brake control, engine control, hardware-in-the-loop, traction control.

I. INTRODUCTION

Hardware-in-the-loop (HIL) is a type of real-time simulation model that uses hardware in a control loop. Use the HIL model to test the controller design. HIL simulation shows the controller response in real time for realistic virtual stimuli.

The HIL model shall include hardware and software, where the software simulates part of the model and/or some non-measurable parameters recorded in the hardware, and the hardware can be a complete system or system part. HIL simulation of a dynamic system is a closed loop in real-time. The measured sensors are recorded from the hardware model along with the simulation parameters that are input into the simulation input in the software. Output parameters of the simulation model in the software are included in the hardware control (Figure 1).

Fig. 1: Hardware-in-the-loop model

II. LITERATURE REVIEW

Currently, the HIL model is very commonly used, Jin et al. [1] presented a new traction control system in complex situations, by simulating nonlinear dynamics in automobiles, adjusting drive wheel speed by adjusting engine torque, and wheel brake pressure. This adjustment is based on the ant colony optimization analysis scaling controller. The results indicated that the algorithm exhibits high control accuracy and strong performance compared with the traditional proportional integral derivative controller. Kuntanapreeda [2] has studied the Super-Twisting Algorithm (STA) algorithm which is performed on a one-wheeled test model (Figure 2). This model simulates the longitudinal dynamics of the vehicle. The test model consists of a drum set, a wheelset, and a measurement or control unit. The measurement and control units include signal modulation circuits for speed sensors and computers. The computer has software installed with a 12-bit analog or digital interface board. All signals are supplied to the computer through the interface board. The control signal from the
computer is transmitted to the motor control unit to create a closed control loop. The control sampling interval is 20 ms. The controller is a combination of the STA control law and the non-linear observer. The control rule is designed based on the SMC control method (sliding-mode control), but the switching control part is replaced by an STA. The results show that the controller has successfully controlled the system to operate at the desired coefficient of slip, effectively handling the sudden change in the coefficient of grip between the tire and the road.

Wilkinson et al. [3] used the experimental HIL model and determined the braking time by testing the contribution of each component in the determined control system. This test provided quantification of endurance, compliance and other variations as well as hardware response time results for ABS activation and stopping distances.

In addition, there are many studies that have used the electro-hydraulic brake system model by the HIL model. The model is based on the dSPACE® module platform [4–7] with a piece of hardware responsible for data input/output, EHB control, and communication with the simulator in the IPG CarMaker® (Figure 3). The dSPACE® instrument converts signals from analog to digital and vice versa for real-time testing.

![Diagram of interface between hardware and software in HIL model](image)

Fig. 3: Diagram of interface between hardware and software in HIL model

Through the traction control models surveyed above, the authors have used many control methods from surveying and simulating results through specialized software to studies on traction control in the field. The combination of software simulation and the HIL model gives results consistent with the goal of traction control. In the current conditions of facilities in Vietnam, in order to experimentally study the traction controller on cars, the research team proposes to design and manufacture a HIL model for testing in accordance with current conditions.

III. RESEARCH METHODOLOGY

A. Design options and selection of elements in the model

The HIL model consists of two basic parts: hardware and software. Hardware includes the parts such as the entire mechanical structure, engine and transmission, ABS brake actuators, electromagnetic clutches (EDVS), sensors, and A/D signal converters. In the software, there are three parts includes the electric motor controller, brake controller, and signal to simulate the speed of the car. The HIL model diagram is shown in Figure 4. Here, the active wheels are placed on a freely rotating roller base. At the top of the roller shaft, there is a brake mechanism to change the resistance torque which can cause the wheel
speed on both sides to be different. The active shaft of the main transmission is driven by an electric motor (type Teco 5HP 3.7 Kw, 3 phase), with a motor speed controller, as the driving source for all the system. Tachometer sensors are located at the top of the drive shaft and on either side of the drive wheel.

Toyota 90919-05024 electromagnetic sensors are used to determine the speed of the two side wheels and the speed of the active shaft rotation. When the wheel turns one revolution, the sensor measures 44 sinusoidal pulses, these sinusoidal pulses are fed to the A/D signal converter (Figure 5) to be converted into square pulses thanks to the Maxim MAX9926 controller chip, before when inserted into the traction control unit (ECU).

The brake actuator selected for use on this model is the one used on the Toyota Lexus GX470. Figure 6 shows the basic operation diagram of this ABS hydraulic actuator, with each channel there are two solenoid valves with two ON/OFF positions. When braking, the oil pump is activated and the inlet valve is opened and the outlet valve is closed to increase the brake fluid pressure in the wheel cylinder. Conversely, when you want to reduce the braking force, the outlet valve is opened and the inlet valve is closed. In the mid-pressure state, both valves are closed to keep the oil pressure at the wheel cylinder constant.

**B. Design communication block with the computer**

The computer interface has the function of transferring data between the computer and the hardware, collecting data from the hardware and controlling the actuator. This communication controller not only receives the drive shaft rotation speed signal but also receives the drive wheel rotation speed signal, then the ECU calculates and outputs the speed control voltage pulse signals to engine speed controls and hydraulic pump in the ABS brake actuator. During the control process, the ECU always receives signals from sensors, calculates and processes data according to pre-installed programs and transmits data to the computer to show experimental results such as wheel speed control, motor speed control, and brake control signals. The diagram of the functional blocks of the ECU is shown visually.
in Figure 7. The functions of the blocks in the traction control unit include:

- Voltage converter block: To power the whole system.
- Speed sensor block: This block uses a signal converter to convert the input speed signal of the driveshaft and wheels from the sine waveform to the square pulse form for input into the microcontroller.
- Motor control voltage block: Using a non-inverting amplifier circuit with a gain of about 3.03 times to reach 0-10 V to generate the desired control voltage, this signal is fed to the actuator motor control.
- Valve control block: Using Mosfet to control the solenoid valves in the brake actuator according to the increase, hold, and decrease modes according to the control rules of the ECU.
- Communication block with computer: Use FT232RL to connect hardware with Matlab/Simulink, hardware-in-the-loop (HIL) simulation to help transmit data between Matlab and Microprocessor.
- Microcontroller block: This block is the central microprocessor that helps to read data, control and communicate with the computer. The control program is loaded inside this microcontroller, when communicating with the computer, the microcontroller block will execute the required commands from Matlab/Simulink.

C. Traction control controller design

The traction control controller consists of two controllers: the brake torque controller on either side of the active wheel and the motor output shaft torque controller.

The brake controller

The brake controller is designed in the ECU whose input is the speed difference signal of the two wheels on either side, the output is a voltage signal pulse sent to the brake actuator to act on the valves according to the control rules of the ECU. When a wheel moving on a slippery road slips, its speed increases, the wheel on a good road cannot turn. As a result, engine power is lost due to friction between the road and the tire. To improve traction performance, the brake control unit is designed to apply braking torque to the skidding wheel to obtain the same speed as the two drive wheels. The controller is designed based on the PID (Proportional - Integral - Derivative) controller as shown in Figure 8. The control algorithm is represented by Equation (1).

\[ u_t = p(\omega_{ph} - \omega_{tr}) + i \int (\omega_{ph} - \omega_{tr}) dt + d(\omega_{ph} - \omega_{tr}) \] (1)

The motor controller

On the model using a three-phase AC motor, the motor torque control faces many difficulties. Actually control the motor torque by controlling the EDVS to change the motor speed, this making the motor torque change accordingly. The relationship between torque and speed depends on the characteristics of each type of motor. In this article, the researcher does not consider this dependence relationship but assumes that when the motor speed changes, the motor torque also changes and they have a linear relationship. Therefore, the motor controller is designed to apply a voltage pulse to the clutch from the EDVS.
to change the motor speed in accordance with the control rules of the ECU. When the slip of both active wheels is greater than the allowable slip coefficient \(\max(\lambda_{vr}, \lambda_{vh}) > 0\), the engine control unit will send a voltage pulse signal \((V_{S_t})\) to the EDVS to control reduces motor torque (speed) to reduce wheel slip. The motor controller diagram is shown in Figure 9, where \((\omega_{r_n})\) is the reference speed of the drive shaft, \((\omega_{b})\) is the speed of the drive shaft measured by the sensor, \((V_{S_t})\) is a voltage signal pulse that acts on the magnetic clutch to change the motor speed. The PID controller that controls the speed of the drive shaft is described as Equation (2).

\[
V_{S_t} = P(\omega_{r_n} - \omega_{b}) + I \int (\omega_{r_n} - \omega_{b})dt + D(\omega_{r_n} - \omega_{b})
\] (2)

Fig. 9: Diagram of the motor controller

The complete HIL model of the traction control system are shown in Figure 10.

Fig. 10: Installation position of parts on the HIL model

IV. RESULTS AND DISCUSSION

The traction control experiment on the HIL model is carried out in the following two cases: the first case controls the brakes for the same speed on both sides of the wheel within a predetermined threshold limit, and the second case builds upon the first case and combines motor control to maintain input speed.

A. Case 1

The results of the speed control experiment on both sides of the wheel are shown in Figure 11, through three stages: the no-control phase, the control phase and the end phase. In the first stage, the wheel with high resistance rotates slower and vice versa. In this case, the right wheel has lower drag so it turns faster than the left wheel. For example, at 40s, the left wheel only reaches an oscillation speed of about 12.64 rpm, while the right wheel reaches 170 rpm, and the active axle speed is 273 rpm. This is consistent with the distribution law of the differential.

In the control phase (within a period of 80 - 180s), the ECU outputs a voltage pulse signal to the brake actuator that controls the valves to perform braking at the wheel with a higher rotational speed to keep the speed of both sides of the wheel is relatively equal. At time \(t = 100s\), the speed of the drive shaft is 154 rpm, the ECU outputs a voltage pulse signal to the ABS actuator to brake the right wheel, reducing its speed to 51.46 rpm, while the speed of the left wheel increases to 40.03 rpm.

The period ends (after 180s), the ECU does not control, the speed of the two wheels returns to a state consistent with the initial traction conditions of the wheels.

Figure 11 shows that when activating the controller, the input speed of the drive shaft is significantly reduced even though the voltage is constant, which can explain the responsiveness of the electromagnetic clutch at least. When braking the right wheel, the total resistance of both sides of the wheel will increase, but the overload capacity of the electromagnetic clutch is not good, leading to the clutch slipping, the speed of the main transmission shaft decreases. To increase the adaptability of the electromagnetic clutch, the second experiment presented below will incorporate engine control to maintain a stable speed on the drive shaft.

B. Case 2

Figure 12 shows how the speed of the engine and the two wheels on both sides vary according
to the condition of the drag and the control process of the two controllers in the system. In the first stage (time 50s-100s) the speed of the two wheels is different due to the different drag on both sides. When the engine speed controller is activated (time 100s-150s), the right wheel speed increases in proportion to the left wheel speed. Continue to create a barrier on the left wheel, causing the speed of the right wheel to skyrocket (for 150s-200s), the voltage supplied to the magnetic clutch fluctuates about 2 V, the engine speed ranges from 160-170 rpm, left wheel speed (32 rpm) is smaller than right wheel (44 rpm), this speed corresponds to the speed of two wheels in time from 100s to 150s.

Corresponding to the difference in left and right wheel speed, the impact pulses controlling the solenoid valves in the brake actuator will change according to the control law of the ECU as shown in Figure 13. During the periods from 100s to 150s and from 200s to 250s, the controllers are activated when increasing load on the left wheel causes the speed of the right wheel to increase, then the ECU outputs a voltage pulse signal to solenoid valves to increase braking torque on the left wheels to keep the two wheels relative to each other. The control signal pulse on the left wheel has a dense period due to the larger right wheel bumper, which shows that the brake controller is designed with high efficiency.

Figure 14 shows the results of motor speed control. In the first stage, the active shaft input speed is kept constant during this stage thanks to the motor speed controller. During the period from 100 to 150s, at the time of 100s when traction control is activated, the speed of the two wheels approaches each other (from about 120s). The speed on the main drive shaft has decreased, but not much. The motor control voltage rises and fluctuates between 2.5 V and 3 V. Between 150 and 200s, deactivate the traction control, because the right wheel resistance is less than the left wheel resistance, the speed of the right wheel increases and the left wheel decreases (Figure 12).

In the period from 200 to 250s, at 200s the traction control is activated again, and the speed of the two wheels is close to each other. At this stage, the ECU controls the brakes on both sides of the wheel similar to that in 100s – 150s to help stabilize the speed between the two wheels.

In Figure 11, we see that the engine speed setting value is 200 rpm. However, due to the response of the electromagnetic clutch, a speed difference of about 30 rpm is always maintained. During the period from 100s-120s, by turning on the brake control switch and creating a bumper on the left wheel, the control unit (ECU) outputs a signal to the ABS brake actuator to control the brake valves to stabilize the speed. The wheels, the engine speed drops quickly to about 53.5 rpm,
the speed difference is relatively high about 146 rpm, so the controller sends a voltage signal to the magnetic clutch with a value reached the limit (4V) to quickly stabilize the engine speed, but the speed of the main drive shaft is still reduced due to the limited torque transmission of the electromagnetic clutch.

Fig. 13: Graph of brake control impact pulse on both sides of the wheel

Fig. 14: Graph of motor speed control signal

V. CONCLUSION

In this paper, the author have researched, surveyed and designed the HIL model to test the traction control system in cars, based on the active demand of Toyota Lexus LX470. The research team designed, fabricated and assembled by themselves. The traction control unit is based on the principle of monitoring the coefficient of slip on both sides of the wheel compared to the specified slip, controlling traction on the car thanks to the operation results of the brake torque controller on both sides of the active wheel and engine torque controller. Experimental results show that the control ECU conforms to the law of traction distribution. When the resistance on one wheel increases, its speed decreases, the differential will distribute the speed to the other wheel. If it is greater than the allowable threshold, the ECU will send a signal to the actuator to control that wheel. It allows keeping the speed on both sides of the wheel commensurate with each other and consistent with the allowable threshold to keep a stable distribution of downforce on both sides of the wheel under different traction conditions.

REFERENCES


