Research on Shifting Quality of Automobile Based on Hardware-In-the-Loop with dSPACE

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Abstract

Starting with the design of bench test based on Hardware -In-the-Loop, the principle has been analyzed, the dSPACE simulation system and CAN field were incorporated; a controlling tool has been created with ControlDesk during Matlab/Simulink environment to carry out the Hardware-In-the-Loop simulation analysis and research the quality parameters related to shifting, which can provide the base for improve the development of shifting quality in terms of engineering aspects.

Keywords: automobile, shifting quality, Hardware-In-the-Loop, Dspace

1. INTRODUCTION

dSPACE real-time simulation system is a semi-physical simulation work platform. It is based on the control environment of MATLAB, aimed at providing more accurate shifting control and analysis of automobile(Mlikiet al., 2016). Specifically, dSPACE real-time simulation system is a set of MATLAB/Simulink-based software and hardware work platform of control system development and semi-physical simulation, achieving the completely seamless connection with MATLAB/Simulink/RTW(Liu et al., 2016). dSPACE real-time system is characterized by strong real-time, high reliability, good expandability and other advantages(Cannistraro and Cannistraro, 2016). The processors in dSPACE hardware system have high-speed computing power, and are equipped with a wealth of I/O supports, so that users can combine them as required; the software environment has powerful functions and convenience in use, and contains the whole set of tools for the realization of automatic code generation / download and test / debugging(Zhu and Li, 2016; Rafiee and Sadeghiazad, 2016).

Hardware-In-the-Loop Simulation test platform (HILS) refers to the use of physical controllers and simulation models to compose a loop test system together, mainly for the simulation test of complex nonlinear mathematical model parts(Choudhury and Das, 2016). Hardware-In-the-Loop Simulation test system operates the simulation model with real-time processors to simulates the running status of controlled objects, and conducts the all-around system test for the tested ECU through the connection with I/O interfaces and the tested ECU.Hard-In-the-Loop system is widely favored by scholars due to its real-time online parameter modification in the simulation process and other characteristics(Baraszu and Cišanež, 2002). HILS has a visual interface, and it can directly achieve the self-adaptive control of parameters without frequently re-encoding the program(Mocanuet al.,2016).

There are lot of factors influencing the shifting quality of automobile, mainly involving the coordinated control of the engine, clutch and transmission(Nasser and Duwairi, 2016). In terms of the shifting quality of transmission system, domestic researches are mostly conducted on the basis of the oil reduction with pulse width modulation(Luo et al.,2016). However, most domestic enterprises cannot completely open the communication of engine electronic control unit, thus becoming a major obstacle of the study on shifting quality(Giovanetti et al.,2016).

In this paper, based on the advanced German auxiliary software dSPACE, the Hard-In-the-Loop test of the automobile shifting time is implemented relying on the main control equipment. The real-time code is generated through the conversion of control algorithm and the conversion of automobile transmission simulation model, and the ignition timing and fuel injection amount are changed directly online, in order to achieve the purpose of controlling the engine speed and torque, and further enable the research on the shifting quality of automobile transmission system.

2. OPERATING PRINCIPLE OF TESTING BENCH
The automobile transmission system studied in this paper is mainly composed of an internal combustion engine, electric motor and nickel-metal hydride battery, and its measurement and control part is dSPACE. The physical structure diagram of the testing bench system studied in this paper is as shown in Figure 1.

![Figure 1](image_url)

**Figure 1** Structure Diagram of Transmission Testing Bench System

Among them, the engine and motor act as the power input source of transmission system; nickel-metal hydride battery system provides the electric energy for the transmission system as the energy storage device; the braking system consists of hydraulic components and drum brake; the road load is simulated by means of the eddy current dynamometer in the experiment, and the transmission inertia of the automobile system is represented by virtue of flywheel. Taking into account the low precision of the dynamometer at low speeds, a speed raising box is designed specially for the compensation.

### 3. HARD-IN-THE-LOOP MEASUREMENT AND CONTROL SYSTEM

#### 3.1 Data Collection

In the experiment of this paper, the angular displacement and speed torque sensor is used to collect the experimental data in the system. Among them, the angular displacement sensor is responsible for collecting the data on position signal of accelerator pedal, signal generated from the clutch engagement and the position signal of shifting selection. The sensor can draw the value of corresponding volts with reference to the position change of the contact terminal, and then the values are input to the data collection system for processing after A/D conversion.

The speed torque sensor which corresponds to the angular displacement sensor is responsible for collecting the speed torque signal of the input and output terminal of transmission. The operating principle of speed torque sensor is as follows: quickly convert the target signal into two groups of AC signal through the structure auxiliary role of two groups of exciter alarm values, and make the AC signal have the same frequency and linear correlation between the phase difference and speed of measured shaft. The structure diagram is shown in Figure 2.

![Figure 2](image_url)

**Figure 2** Structure Diagram of Speed Torque Sensor

#### 3.2 Output of Control Signal

The control system in the experiment designed in the paper adopts the DS1103PPC controller board, and AutoBox integrated processor as the hardware and various I/O devices.
In the process of the output of control signal, first the target opening signal of accelerator pedal is converted and passed to the central processing unit of the engine, and finally the control of accelerator pedal is realized by the control unit.

In the control of shifting operation mechanism, the central controller inputs the signal by using the rotate speed of corresponding control board, and outputs the duty cycle signal to control the engagement speed and engagement position of the clutch; in terms of the motor control, dSPACE can output the torque signal via the motor controller, so as to realize the control of motor.

In order to improve the accuracy of the motor position sensor, the more advanced position sensor technology needs to be adopted, for example, the sensor itself has higher resolution, positional accuracy, transmission speed of data and anti-interference capability. The position sensors of simulation requires more advanced location settlement technology, such as rotating transformer, and controller should have the appropriate redress, compensation and anti-interference filter technique for the position accuracy.

In the control, the waveform output of motor drive shall be ensured. The control waveform and phase accuracy of motor drive are the direct factor affecting the low-speed performance of motor. The rigid anti-interference capability of the driving portion shall be enhanced, software algorithms in the control part shall be improved, and the control accuracy and response speed of the drive waveform shall be increased, so as to optimize the motor drive waveform.

The anti-interference performance of control system shall be improved. The sources of interference include electromagnetic, circuit, machine, fluctuation of load and many other aspects, which are all processed as the interference by the driver during the control. As a result, in order to improve the anti-interference capability, the following shall be achieved, advanced the electromagnetic compatibility of the driver, increase the stability and anti-interference performance of circuit, boost the hardware performance of driver, perfect the software algorithms, especially increase the performance of current loop, velocity loop and position loop and raise the control accuracy and response speed of the driver.

The hardware system adopts the modular and reconfigurable design idea, and has the individually designed power and control part. The hardware architecture in this paper is designed mainly through considering the engineering, modular and reconfigurable aspects. As a whole, the hardware is divided into two entities in the project, namely, the power part and control part. The whole hardware architecture is shown in Figure 3. The main reason for the separation is given to the purpose of product serialization. Through the separation of power and control part, only a universal reconfigurable control hardware needs to be designed as the upper plate in the whole product series, and the lower part with different power can be designed in accordance with varied power requirements, then the demands can be met.

![Figure 3 Hardware Composition Schematic Diagram](image-url)
4. MEASUREMENT AND CONTROL SYSTEM SOFTWARE DEVELOPMENT

4.1 Measurement and Control System based on CAN Communication

CAN (Controller Area Network) bus is the communication protocol of a series of multiple master buses developed by the German BOSCH Company to solve the data transmission between the control and test equipment in automobiles. CAN is an abbreviation of Controller Area Network (hereinafter referred to as CAN), and ISO international standardized serial communication protocol. In the automotive industry, for the requirements of safety, comfort, convenience, low pollution and low cost, a variety of electronic control systems have been developed. Since the data type used in the communication between these systems and the requirements for reliability are different, there are many cases that the data is constituted by a plurality of buses, and the number of harnesses also increases accordingly. To meet the needs of “reduction of the number of harness” and “high-speed communication of a lot of data through multiple LANs”, Bosch, a German electrical supplier, developed CAN communication protocol for automobiles in 1986. Thereafter, CAN was standardized through ISO11898 and ISO11519, and has become a standard protocol for automotive networks. The high-performance and reliability of CAN have been recognized, and CAN has been widely used in industrial automation, marine, medical equipment, industrial equipment and other aspects. Field bus is one of hotspots of the technological development of today’s automation field, and is honored as the computer local area network of automation field. It appears as a distributed control system, and provides strong technical support for the real-time and reliable data communication between the nodes.

To realize real-time data communication among multiple assembly control systems in the testing bench system, CAN communication can be used as the communication basis of the overall control system. It implements the communication coordination mainly based on the following basic rules:

1. Bus access: CAN controller can only start transmission when the bus is in the idle state.

2. Arbitration: if two or more CAN controller’s transmission simultaneously, the bus control terminal shall resolve by the arbitration methods during their transmission.

3. Encoding/decoding: the system automatically encodes for the start of frame, data field and the sequence position filling technology.

![Figure 4 Schematic Diagram of Data Collection Control System](image)

In the process of the establishment of testing bench, first the m file of the software control program will be directly nested into the Simulink environment of the simulation software, thus obtaining the dSPACE real-time simulation
system. Among them, the physical structure composition of the entire measurement and control system is shown in Figure 4 above.

4.2 Development of Measurement and Control Software

CANoe is a bus development environment launched by Vector Company from Germany, and with the full name of CAN open environment, it is mainly designed for the development of automobile bus. In the early stage, CANoe is for the modeling, simulation, testing and development of CAN communication network, and later, LIN, Ethernet, FlexRay, MOST and other networks are added for expansion. CANoe is the professional tool for the network and ECU development, testing and analysis, and supports the development process of the entire system from the demand analysis to system implementation. The rich function and configuration options of CANoe are widely used by network design engineers, development engineers and test engineer of OEM and suppliers. The CANoe simulation environment used in this paper is configured as Figure 5; and CANoe simulation node configuration is shown in Figure 6.

![Figure 5 The CANoe simulation environment](image)

![Figure 6 The CANoe simulation node configuration](image)

In the early stages of development, CANoe can be used to build simulation model, and evaluate the function of ECU on this basis. After the completion of the development of ECU, the simulation model can be used in the function analysis, test of the whole system, as well as the integration of the bus system and ECU, so that problems can be found and solved as soon as possible. The tables and texts of the assessment window can be used to evaluate the results.

Its main advantages are as follows:

1) Transmit the dynamic data to the system control program in an intuitive and convenient way through the virtual interface;

2) Enable the graphical management of the hardware, and the batch adjustment of experimental parameters and control study of associated data.
It has the universal compatibility for the programming language with the MATLAB software, and can directly program the M file to realize the development of ControlDesk. The distinguishing feature of this measurement and control software lies in online debugging function, and it can real-time regulate the experimental parameters with the help of software, and increase the excellent characteristics of self-adaption of the hardware-in-the-loop research.

5. SIMULATION ANALYSIS OF SHIFTING QUALITY

Taking into account the consistent focus of users on power upshift quality in the use of the vehicle, 3-4 shift is used as the research object in the simulation research of hardware-in-the-loop in this paper, and Delphi software developed is called. Thus, the simulation data generated after the processing is shown in Figure 7.

Along with the increase of the vehicle speed to a predetermined speed (as shown in Figure 7a), the clutch begin to separate and the system enters the upshift process. As can known from Figure 7b, after changing to a target shift (2.9s), the clutch begins engagement, and the speed difference of its drive and driven part decreases rapidly.

To shorten the power interruption time, in the downshift process, the motor works at the generator state, and outputs appropriate negative torque (-12 N.m) to the drive system to facilitate the engine speed drop to the speed at the engagement point. When the speed difference between the drive and driven disc of the clutch is gradually equal, the system is in the synchronized position, and the clutch accelerates engagement to complete the shifting process. Throughout the process, the output torque of the motor is shown in Figure 7d. As can be seen in Figure 7c, the shifting process occurs between 2s and 3s, in line with the practice that the motor outputs negative torque, which proves the validity of the shifting control strategy proposed in this paper.

![Figure 7 Uplift Parameter Diagram](image)

6. CONCLUSIONS

(1) During the production practice, dSPACE software system integrates with the processing board to compose the hardware-in-the-loop software; meanwhile, it can make use of the powerful function of MATLAB to integrate with RTI (Real-time Interface) to achieve the parameter setting of graphical management.
(2) The hardware-in-the-loop simulation system has convenient computer graphics interface to facilitate experimenters to adjust the parameter to control the vehicle drive system in the completion of various shifting parameter test; it has the anti-jamming capability against variable running environment of the automobile, conducive to the study on shifting quality of the drive system.

REFERENCES


