Development and utilization of experimental device for gasoline engine fuel adjustment characteristics

Baoqing Deng¹, Yuchuan Jia, Zhuo Yang, Shuo Liu, Chengxi Cai and Lin Luo
Mechanical Engineering, Zhuhai College of Jilin University, Zhuhai 519041, China.
¹ Email:843723111@qq.com

Abstract. The fuel injection pulse of the electronically controlled injection gasoline engine is fully solidified in the ECU. In addition, the engine injection control uses negative feedback control. It is difficult to control the injection quantity of the engine without an external electronically controlled development system. Therefore, universities that do not have the ability to develop electronically controlled ECU have stopped or canceled gasoline fuel adjustment characteristics tests. In view of the current problem, based on the STM32 library function, this study developed an experimental device, which can dock well with the engine in use, and can easily input the injection pulse width without changing the original ECU of the engine, thereby controlling the mixture concentration of the engine and completing the fuel adjustment characteristic experiment easily. The fuel adjustment characteristics experiment was completed on the engine test bench, which verified that the developed experimental device has good practicality.

1. Introduction
Mixture concentration has an important impact on gasoline engine performance [1-3], which is the consensus of the internal combustion engine industry. Through the experiment of fuel adjustment characteristics, it can better reveal the influence of mixture concentration on engine power performance, economy and exhaust emissions [4-15]. It has an important role to understand the working principle of gasoline engine and the engine calibration professional to calibrate the engine properly for the internal combustion engine professional students. With the maturity and popularity of the electronic fuel injection, many colleges and universities have no longer tested fuel adjustment characteristics, and there is a tendency for fuel adjustment experiments to be ignored by internal-combustion engine majors. The reason is not that the experiment is not important, but that the existing products are not open ECU. The fuel injection MAP is completely solidified in the ECU, and now the engine fuel injection control uses negative feedback control [9]. It is difficult to control the fuel injection quantity of the engine without an external electronically controlled development system. However, there are very few universities and research institutes with ECU development capabilities. In addition to the professional manufacturers of electronically controlled injection systems and related development and research institutions, general universities and research institutions are unable to complete the experiment [15].

In view of the current status of the industry, it is necessary to develop a more versatile experimental device that can be easily linked with most of the existing engines on the market, without modifying the original ECU, to complete the gasoline fuel adjustment characteristics.
2. Selection of input and output connection modes

According to the investigation of the existing products in the market, there are mainly two types of nozzle interfaces in the vehicle, such as the square interface shown in Figure 1 and the oval interface shown in Figure 2.

Therefore, the input port of the system is connected in parallel with the above two ports for a variety of engines. In the experiment, the fuel injection line pencil of various engines can be directly selected without any modification. For the output port, each injector uses parallel connectors with the corresponding two ports. During the experiment, it is only necessary to use series connection of the experimental device and the fuel injection line to carry out the experiment. To facilitate the use of the instrument in the laboratory and the complete vehicle, the device uses 12VDC voltage.

![Figure 1. Square interface.](image1)
![Figure 2. Oval interface.](image2)

3. Hardware circuit design

In order to simplify the equipment, the device is only used experimentally under stable engine conditions, and the original engine ECU is directly used in the non-experimental state. Therefore, the system control logic is shown in Figure 3. There is a relay switching module. In the non-experimental state of the engine, the relay is in the normally closed state, and the engine is controlled by the original ECU. During the experiment, when the input has been ready, the relay is switched to the experimental state, and the injection pulse width is controlled by the experimental device. The test control system of the experimental device is composed of CPU, fuel injection timing and pulse width acquisition module of the engine ECU output to the first cylinder injector, driving module of injector, conversion relay driving module, infrared control module of fuel injection pulse width input, LCD display module and so on.

3.1. Main control unit CPU

The control unit CPU is the core of the entire control system. The control unit used in this experimental device is the MCU-STM32 of the Corex-M3 architecture. Its function and pin are shown in Figure 4.

The signal output from the engine ECU to the injector is collected and processed by the signal collection circuit and input to the control unit. After processing, the collected injection pulse width and engine speed are displayed by LCD screen, which is convenient as the infrared controller to input the basic reference data of injection pulse width to the control unit. When the relay is switched to the experimental state controlled by the device, the injector executes the injection command issued by the experimental device. The LCD screen displays the out pulse width of the control device and the engine running speed signal.
3.2. Injection signal acquisition circuit
The injection signal acquisition circuit is shown in Figure 5. Due to the high voltage of the injection signal, it is easy to interfere with the signal from the main control unit. Therefore, optic-coupling parts should be used for isolation. The optic-coupling parts are mainly composed of LED, Phototransistor and current amplification. When the fuel injection signal is emitted, the emitting diode luminesces and the phototransistor is turned on. The 1 pin of the comparator rises to a high level, and which is output through the 3 pin of the comparator. When the injection signal is cut off, the diode in the optic-coupling parts does not emit light, and the phototransistor is cut off. The output signal from the 1 pin of the comparator is at the low level. In this circuit, D2 acts as a clamp protection. Using the 74LS04 inverter to make the waveform steep, eliminating the glitch on the pulse, the edge trembling of the acquired signal is weak to obtain the ideal pulse sequence.
3.3. Injector drive Circuit

The driving of engine injector can be divided into a voltage driving mode and a current drive scheme depending on the resistance of the injector itself [16, 17]. The voltage driving circuit is suitable for high-resistance type electronically controlled injectors and low-resistance type electronically controlled injectors. The advantage is that the circuit is simple and the heat is easily lost. The disadvantage is that the response speed is slow and the dynamic flow range is small, when the resistance value increases. The current drive scheme controls the fuel injection by the current in electromagnetic coils. The driving circuit applies a voltage to the injector. When the current increases until a peak is reached, needle valve opens. Then the current drops and remains at a lower value, providing the injection time. This method is suitable for low resistance injectors. Due to the complexity of the circuit, heat is not easily lost [16-20], and the circuit should fully consider heat dissipation.

The internal resistance of the injector used in the engine is 3 ohm, so the current drive scheme is adopted. The injection driving circuit is shown in Figure 6. The left input signal is a 5V driving signal from the control unit CPU. The signal is amplified by a PNP triode through a current limiting resistor R1 to drive the optic-coupling parts. R4, C1 and D1 form an inductive reverse current discharge circuit. Q1 is a MOS transistor that acts as a switch to control the injector. When the high level was outputted to MOS transistor by the input terminal to drive the injector, the PNP triode was turned off and the optic-coupling parts was cut off. When the low level was outputted to MOS transistor by the input terminal, the PNP triode and optic-coupling parts was turned on. The MOS transistor was cut off, and the injector was turned off.

3.4. Switching relay control circuit

The relay control circuit is shown in Figure 7. When the high level was inputted, the NPN triode was turned on, the relay coil was electrified, and normally open contacts were closed, thereby controlling the subsequent circuit to be turned on. When the low level was inputted, the relay coil was deenergized and the normally open contacts were broke. The resistor R1 acts as a current limiting function to reduce the power dissipation of the NPN triode. The NPN triode was cut off by the resistor R2. The function of diode D3 is to keep the current of the relay coil. When the relay was electrified or deenergized to generate a large back EMF, which was absorbed by the backward diode.
4. Software design of experimental device

4.1. ECU output injection signal acquisition program

The ECU sent an injection signal which was collected through TIM2-CH1. Set the high level signal outputted to the rising edge and record TIM2-CNT with setting the initial value to zero. Set the input capture device to the falling edge and record the value of TIM-CNT. Then, according to the set timer working frequency and the difference between the two values, the time of the injection signal is obtained. According to the number of injections collected within a certain period of time, the engine speed can be calculated. The acquisition procedure is completed in the interrupt function. The block diagram is shown in Figure 8.

Figure 6. Injector drive circuit.  
Figure 7. Relay circuit.  
Figure 8. Input capture program diagram.  
Figure 9. Injection driver flowchart.
4.2. **Fuel injection driver design**

When the experimental device is powered on, the device control program starts. After initialization, the acquisition circuit monitors the fuel injection signal of one cylinder in real time. When the upper edge is detected, the driving module circuit starts to work. If no infrared setting is made at this time, the driving module executes the injection pulse width of the engine ECU. Once the infrared input control is interrupted, the injection pulse width executes the injection pulse width of the infrared input to drive the circuit until the next input. The injection signal outputted by the optocoupler circuitry is connected to the IO port PC5 that triggers the interruption, and the four cylinders can be simultaneously injected. The injection driving process is as shown in Figure 9. Whether it is possible to control injector is determined by the relay switching position.

5. **The engine performance**

5.1. **Equipment**

A gasoline engine bench, FGA-4100 Exhaust Analyzer, ET2000 engine test and control system, 150W Eddy Current Dynamometer

The experimental device is connected in series between the engine injection line speed and the injector. The test board is shown in Figure 10.

![Figure 10. Fuel adjustment characteristic experimental device.](image)

5.2. **The experiment method**

Experimental preparation and engine preheating were completed under the original engine ECU operating state. After the experimental standard was reached, an engine fuel adjusting characteristic experiment was performed.

After the gasoline engine is running stably, the throttle opening and the engine speed remain unchanged, and the engine is operated in the ECU control mode. According to the current working pulse width of the engine, a starting pulse width is inputted to the device, and the working state of the relay is switched to the working state of the device. Changing the input value of the injection pulse width, when the excess air ratio indicated by the exhaust analyzer reaches the predicted value, the value is stable. And the indicators such as specific fuel consumption, torque and emissions are measured and recorded. Then adjust the injection pulse width and proceed to the next experiment.

After the experiment is completed, organize the data. The data points are connected by a smooth curve, and the power performance, exhaust emissions, and economy indicators are changed as the excess air ratio changes.

5.3. **Data analysis and processing**

In the first group, the engine speed was fixed at 2000r/min, and the load rate was 60%. By changing the injection pulse width, the excess air ratio will change with the increment of 0.05. The measured data is shown in Table 1, and the data curves are shown in Figures 11 and 12.
Table 1. Partial load fuel adjustment data.

| Speed (rpm) | Load (kW) | Oil temperature (°C) | Water temperature (°C) | Atmospheric pressure (100kPa) |
|-------------|-----------|-----------------------|------------------------|-------------------------------|
| 1000 | 0.65 | 78 | 16.5 | 389.3 | 0.99 | 8.5 | 0.5 | 0.1 | 0.0 |
| 1500 | 0.70 | 79 | 16.57 | 389.3 | 0.99 | 8.5 | 0.5 | 0.1 | 0.0 |
| 2000 | 0.75 | 79 | 16.57 | 389.3 | 0.99 | 8.5 | 0.5 | 0.1 | 0.0 |

Table 2. Full load fuel adjustment data.

| Speed (rpm) | Load (kW) | Oil temperature (°C) | Water temperature (°C) | Atmospheric pressure (100kPa) |
|-------------|-----------|-----------------------|------------------------|-------------------------------|
| 1000 | 0.65 | 78 | 16.5 | 389.3 | 0.99 | 8.5 | 0.5 | 0.1 | 0.0 |
| 1500 | 0.70 | 79 | 16.57 | 389.3 | 0.99 | 8.5 | 0.5 | 0.1 | 0.0 |
| 2000 | 0.75 | 79 | 16.57 | 389.3 | 0.99 | 8.5 | 0.5 | 0.1 | 0.0 |

Figure 11. Influence of excess air ratio on power performance and economy.

Figure 12. Effect of excess air ratio on emissions.
In the second, the engine speed was set to 3000 r/min and the load rate was 100%. By changing the injection pulse width, the excess air ratio will change with the increment of 0.05. The obtained data is shown in Table 2, and the data curve is shown in Figures 13 and 14.

![Figure 13. Influence of excess air ratio on power performance and economy.](image1)

![Figure 14. Effect of excess air ratio on emissions.](image2)

Figures 11-14 show that the excess air ratio (mixture concentration) has a significant impact on the power performance, economy and exhaust emissions.

Therefore, in order to deeply understand the working principle of the engine and optimal matching, the experiment of fuel adjustment characteristics is very necessary. Therefore, the development of this experimental device has certain practical value.

6. Conclusions

This study developed a fuel conditioning characteristic experimental device that can be easily connected between the engine injection line speed and the nozzle. The device uses MCU-STM32 as the control unit, and designs the ECU injection signal acquisition circuit. Signal acquisition and injection drivers were designed using the stm32 library function. On the engine test bench, the fuel adjustment characteristics experiment was completed, which verified that the developed device is feasible.

This device has only developed current drive, only for low resistance four-cylinder and one engine. The next step will continue to develop high-impedance injector for more engines. Continue to
optimize circuits and procedures, improve the appearance of the instrument, form products as early as possible, and reduce costs.

Acknowledgement
Zhuhai Vehicle Engineering Dominant Discipline Funding.

References
[1] Zi K, Deng B Q 2014 Engine Principle M Beijing: Tsinghua University
[2] Guo K Y 2007 The carburetor of main adjustable jet CN 2876353
[3] Ant M C 1988 Carburetor performance adjustment test Automotive Technology 2 24-29
[4] Wang L B, Ge Y 2015 Explore automotive pollution and emissions technologies Journal of Jiaozuo University 3 72-74
[5] Liu J H, Wu S F, Li H Q, Su T X 2015 Analysis of emission factors of universal small gasoline engine Small internal combustion engine and vehicle technology 44(3) 79-83
[6] Zhao Y, Yang M 2012 Analysis of emission factors of universal small gasoline engine Electromechanical product development and innovation 25(5) 71-73
[7] Shi Z Z 1987 Review and prospect of the development of carburetor Internal combustion engine 6 37-40+43
[8] Wang S S 2002 Principle and maintenance of automotive electronic control system, Beijing Institute of Technology Press
[9] Liu Z M, Deng B Q, Chen Q H 2003 Application Research of Electronic Injection Ethanol Fuel in Spark Ignition Engine Automotive Engineering(zl), 9-13
[10] Li J B, Chen Y Y, Zhu Q 2016 Research on ECU calibration based on FSC racing car Communication World 7 227-229
[11] Soup S S, Xiao T J, Kong F 2017 Electronically controlled engine calibration system based on CAN bus[J] Computer measurement and control 15(11) 1519-1522
[12] Tan Z P 2014 Research on Engine Matching Calibration Based on FSC Racing Driving Condition Xi hua University
[13] Liu Y X 2013 Research and Design of Universal ECU Calibration System Based on CCP (Doctoral dissertation, Shanghai Jiaotong University)
[14] Huang G C 2013 GSX-R600 Engine Intake System Design and Bench Calibration Study (Doctoral dissertation, Changan University)
[15] Wang W, He X C, Zhou G M 2012 Current Status and Prospects of Optimization Calibration of Electronically Controlled Diesel Engines Internal combustion engine 1 3-6
[16] Hou L C 2015 Design of Control Circuit for Simulated Automotive Electronic Control Injector Based on 51 MCU Electronic Production (17) 95-95
[17] He F B 2010 Exploitation of Test Dais for Flow Characteristics and Test Analysis of Motocycle Electronic-Controlled Injectors (Doctoral dissertation, Henan University of Science and Technology)
[18] Xiong Y C 2015 Calibration Test of GSX-R60 Engine Based on MoTec System (Doctoral dissertation, Changan University)
[19] Chen N T, Gao H S 2016 Calibration Test of CBR600RR Engine Based on LinkG4+Storm Small internal combustion engine and vehicle technology 45(5) 27-33
[20] Du Z W 2004 Design and Implementation of Fuel Injection Vehicle Engine Control Circuit (Doctoral dissertation, Harbin Institute of Technology)