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Study on the Method of Closed Loop Control for Gas Engine

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Abstract

With the increasing number of vehicles, society and environmental problems become much more seriously. Aiming at the serious problems, CNG engine, which has better emission performance, has been paid much more attention. However, the CNG engine also has its own disadvantages, such as engine power deterioration, great influence of different mixture ratios of the gas and air on the optimum ignition time of the engine, and so on. Therefore, adaptive control for the air-fuel ratio and ignition timing should be properly adjusted with the consideration of the engine power, economy and emissions. There are two methods of controlling the ignition timing: mechanical and electronic control. In this paper, we develop an adoptive control method based on electronic control. According to the verification, the method can improve the efficiency of the CNG engine. It can be shown the validity of the adoptive method.

Keywords: *CNG engine, Adoptive control, ignition timing, torque, emission*

1. Introduction

With the increasing amount year by year, the vehicle brings great convenience to people, and it also brings a series of problems to the human society at the same time, especially in the aggravation of the air pollution and occupation of the limited oil resources [1-2]. Aiming at the serious problems, human beings have paid much attention and given lots of efforts. On one hand, the governments have made more and more fuel consumption regulations and emissions regulations [3]. On the other hands, research and development of alternative fuel engine [4-5] have also been committed. For the need of the contradiction between the shortage of oil resources in the world and the increasing demand of long-term stability and sustainable development and environmental protection, planning and development of internal combustion engine fueled with clean alternative fuels to replace petroleum based fuel has become an important research direction. Compressed natural gas (CNG) engine [6-9] has better emission performance and resources are abundant, therefore, the CNG engine has been paid high attention.

Combustion process of CNG engine determines the thermal efficiency and emission performance. Existing research shows that the combustion process of CNG engine [10] is often controlled by the boundary conditions of combustion, which can be optimized to effectively improve the combustion and emission problems [11-12]. Combustion boundary conditions include the gas supply characteristics, fuel supply characteristics and structural parameters [13-14]. Air supply conditions include inlet pressure, inlet temperature and exhaust gas recirculation (EGR) rate. Fuel supply conditions include physicochemical properties, fuel supply pressure, fuel starting injection pressure, supply time and supply rules [15]. The structural parameters include inlet, combustor and exhaust door status, *etc.*, [16-17].

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When the compressed natural gas is used as the fuel for the engine, ignition means must be used due to the high burning high ignition point [18]. Correspondingly, positive ignition system [19] must be equipped to ensure the normal order of each cylinder firing to keep the engine working reliable. Compared with the gasoline engine, natural gas for the engine has its particularity [20-23]:

(1) Deterioration of the engine power. The reason is that the natural gas intake in the pipe reduces the quantity of air.

(2) The natural gas engine is more suitable for lean burn.

(3) The optimum ignition time of the engine will change greatly with the different mixture ratios of the gas and air.

(4) Quality of natural gas will be with heterogeneity due to the origin, processing and using, *etc*.

Therefore, adaptive control for the air-fuel ratio and ignition timing should be properly adjusted with the consideration of the engine power, economy and emissions.

In accordance with the ignition timing system works, the ignition timing system can be classified into two categories: mechanical ignition timing system and electronic control of ignition timing system. The former uses a structure similar to the crankshaft gear box for ignition timing of gasoline car and the structure of the distributor, and the transmission relation between crankshaft rotation and the distributor is ensured by mechanical transmission mode to keep the spark plug working normally. The electronic control type uses a number of sensors instead of the distributor appliance to transmit the signal to the electronic control unit. The signal will be analyzed and then control the ignition time and ignition energy.

The ignition time is quite important to the CNG engine, so how to control this factor has a great sense to improve the efficiency of the engine. In this paper, we investigated the control strategy and the control method. The aim of the paper is to develop a new adoptive method for the ignition time control. The remainder of the paper is shown as the following: the control method is introduced in Section 2; the new adaptive control strategy is described in Section 3; the verification is shown in Section 4; and the Conclusion is shown in Section 5.

2 The Control Method

2.1 The Traditional Control Method

At the first, the gasoline engine ignition control is almost mechanical. The main ideas are the centrifugal advance and vacuum advance to control the rotating speed of the engine and the load. Later, due to the development and application of computer technology, the engine control is also developed into the so-called classical control stage. In this kind of control system, most ignition timing control is the open loop. The control is processed by the pre stored tables in the microcomputer on-board or with some modification for the stored tables. The typical system is the Delco. It firstly obtain the basic data according to look-up table of rotational speed and load, and then the additional parameters, such as cooling water temperature, intake temperature, fuel property, state of transmission system, sensor signal, etc, will be taken into consideration to determine the appropriate timing value of ignition. However, the system should be calibrated in the dynamometer and road tests in advance.

This control method is more successful for the gasoline engine, but the open-loop control obviously will have deficiencies when it is used in the natural gas engine due to the unevenness of the natural gas, especially in the using process.

2.2 The Adaptive Control Strategy

Adaptive control has the ability to automatically adaption. When the characteristics or components parameters of system change or disturbance effect are violent, it can automatically measure the variation and change the system structure and parameters to enable the system to adapt the variation of the environment and keep the most optimal performance. Here, the first thing is to find what is the optimal performance, and the second, which is the most crucial point, is how to automatically identify that whether the current performance is optimum. Then, it can automatically determine the correction direction and finally correct automatically.

The basic control strategy of the adaptive system is adopted the fuel economy as the optimizing target and control and adjust the ignition timing. Measuring changes in engine speed will be used to determine the searching direction, which will be corrected automatically to achieve optimal performance. In the condition of certain fuel, the output torque represents the fuel economy. Measurement of torque changes has at least two methods: the direct method with the sensor or the indirect measurement of the variation of crankshaft speed. Both the two method has advantages.

3 The New Adaptive Control Strategy

3.1 The Control Strategy

Take the Figure 1 as the example.

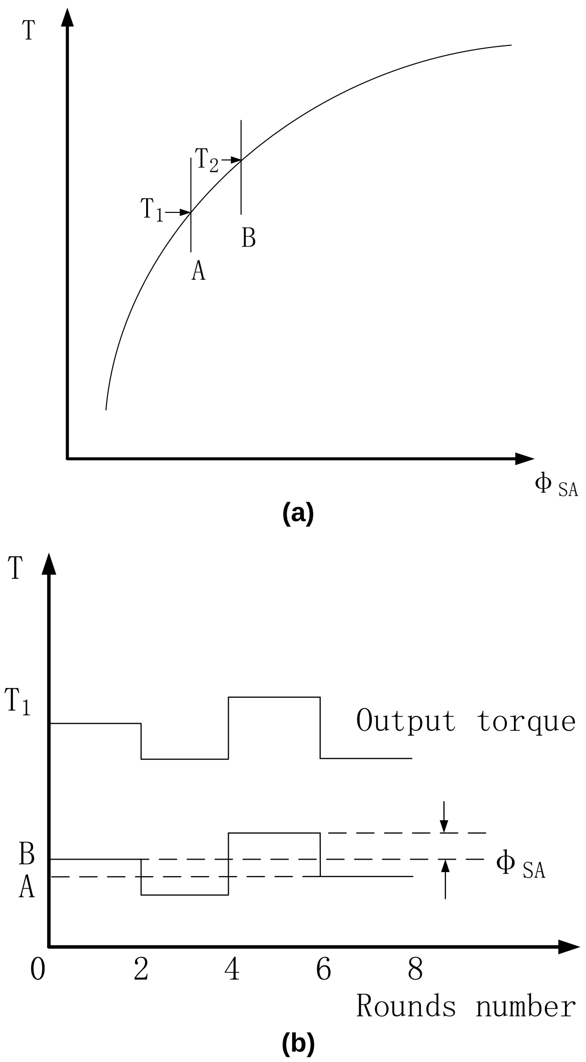

Figure 1. The Principle of the Polymer Solar Cell

When the engine is in a certain state and constant load, a positive method is adopted for the ignition time. For simplicity, assume that the increasing and reduction of the torque has the same condition, then the crank of the engine will produce an average angular acceleration of β . Then we have the following results:

$$\begin{cases} n_1 = n_0 + \frac{30}{\pi}\beta t_1 \\ n_2 = n_1 + \frac{30}{\pi}\beta t_2 \\ n_3 = n_2 + \frac{30}{\pi}\beta t_3 \\ n_4 = n_3 + \frac{30}{\pi}\beta t_4 \end{cases} \quad (1)$$

If set the parameters t_1, t_2, t_3, t_4 are the round time in each 4 rounds respectively, then there will be the relation of $t = 60/\bar{n}$.

$$\begin{cases} t_1 = \frac{120}{n_0 + n_1} \\ t_2 = \frac{120}{n_1 + n_2} \\ t_3 = \frac{120}{n_2 + n_3} \\ t_4 = \frac{120}{n_3 + n_4} \end{cases} \quad (2)$$

The detail reasoning process can be learned in existing literatures [27], and we can get some useful conclusion.

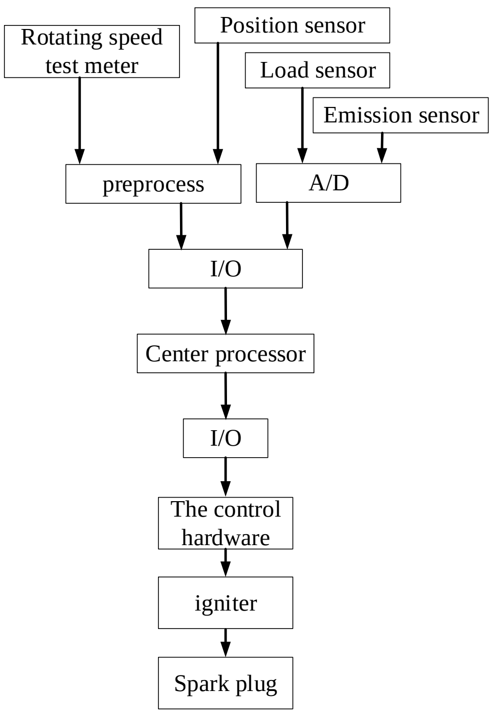

Figure 2. The Ignition System

Here, we will use two indexes as the main parameters: the maximum torque output and the harmful pollutants emission. In the paper we will mainly investigate these two indexes, and based on the maximum output torque, the emission of the engine has been studied.

3.2 Software Design for the Control

In the design process of the control software, characteristics of real-time, generality, flexibility and reliability have been taken into consideration according to the functional requirements of the control system. There are four modules in the software: starting, idling, acceleration, speed and optimizing control. These modules will be performed respectively according to the engine operating conditions. In each module, universal calculation process will be designed into sub-programs for public calls, such as the speed calculation, A/D conversion, and digital filter. In addition, a series of anti-interference measures are also adopted to ensure reliable operation of control system, such as to eliminate the influence of the engine fluctuation, to establish the digital filter for the elimination of the outside burst interference, system operation monitoring and reset, and hardware anti-jamming measures together, and so on.

4. Verification

4.1 The Test Method

This verification is based on light type natural gas engine with the port fuel injection, which is developed based on the diesel engine. It keeps the basic structure of the original machine unchanged, and keeps with the original machine parts commonality, such as crankshaft and connecting rod mechanism, cooling system and lubrication systems. The cylinder body and the cylinder cover have only partial improvement. The main parameters are shown in Table 1.

Table 1. The Main Parameters

parameters	value	parameters	value
cylinder diameter (mm)	106	Rated power (kW)	155
Stroke (mm)	125	Rated speed (r/ min)	2 300
The total displacement (L)	6.62	Rotating speed for maximum torque (r/min)	1 400
Ignition mode	ignition	Maximum torque (N/m)	700
Injection mode	Port fuel injection	The emission level	Euro III
Compression ratio	12.0		

The main equipment adopted in the experiment is shown in Table 2. Pressure sensor is installed on the first cylinder cover to measure the cylinder pressure. DELTER2613B angle gauge is installed on the belt pulley to judge the engine on the upper dead point signal and the trip signal, and the angle meter with an accuracy of 0.1°.

Table 2. The Test Instruments

parameters	Model
The dynamometer	Eddy current dynamometer
Exhaust gas measuring instrument	HORIBA MEXA - 7000
Combustion analyzer	DEWETRON-2010
Air flow meter	Ultrasonic flowmeter
Natural gas flow meter	CMFC25M313NU CNG

We choose three tests rotating speed of 1450 r/min, 1750 r/min, 2050 r/min and load of 50%, and 100%. In the test process, the other parameters will keep constant except for the ignition timing. Adjustment of ignition timing is used to investigate the impact on the combustion and emission performance of CNG engine. The variations of the upper and lower limit for ignition timing of engine combustion cyclic are no more than 5%.

4.2 Analysis of the Results

Figure 3. The Ignition Advance Angles Optimized

Figure 4. Load Characteristic Curves of Natural Gas Engine (1450 r/min)

Figure 5. Load Characteristic Curves of Natural Gas Engine (1750 r/min)

Figure 6. Load Characteristic Curves of Natural Gas Engine (2050 r/min)

From Figure 4-6, we can see that the adoptive control method can improve the efficiency of the CNG engine.

Figure 7. Variation Curve of Output Torque with the Ignition Advance Angle (1450 r/min)

Figure 8. Variation Curve of Output Torque with the Ignition Advance Angle (1750 r/min)

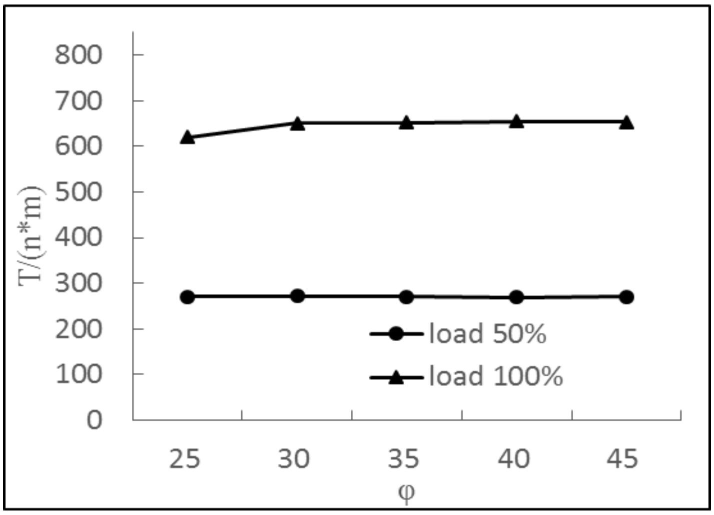

Figure 9. Variation Curve of Output Torque with the Ignition Advance Angle (2050 r/min)

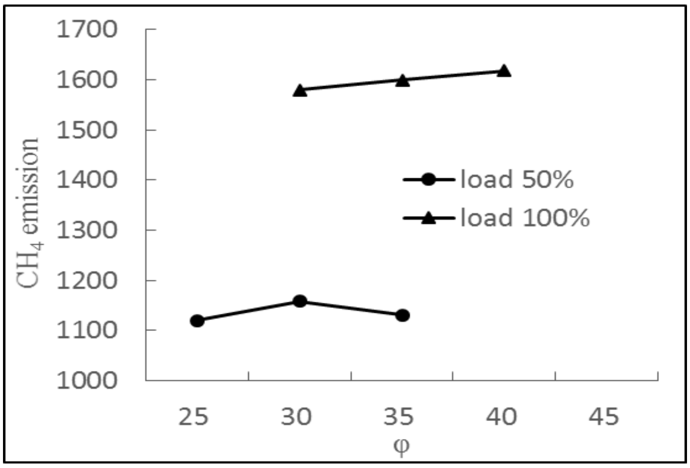

Figure 10. Variation Curve of CH_4 Emission with the Ignition Advance Angle (1450 r/min)

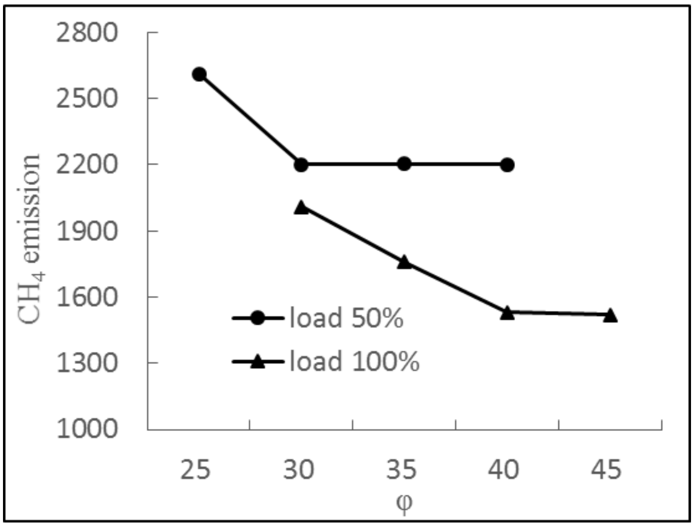

Figure 11. Variation Curve of CH_4 Emission with the Ignition Advance Angle (1750 r/min)

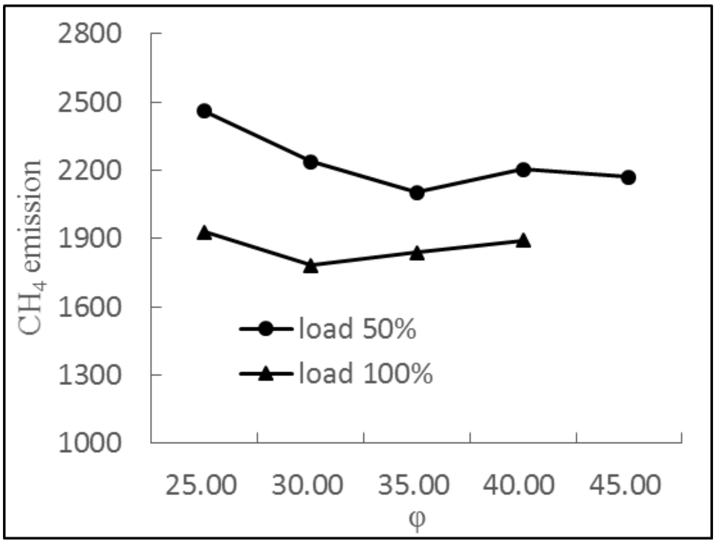

Figure 12. Variation Curve of CH_4 Emission with the Ignition Advance Angle (2050 r/min)

From the Figure 7-9, we can see that when the load is 100%, the torque will not be obviously changed. It meets the aim of the adoptive control method of outputting maximum torque with a certain quantity of the CNG. When the load is 50%, the torque is almost steady but with some fluctuation. This means that the adaptive control method can be used to adjust the ignition timing. Besides, the Figure 10-12 shows the CH_4 emission principle.

5. Conclusion

With the increasing amount year by year, the vehicle brings great convenience to people, and it also brings a series of problems to the human society, especially in the aggravation of the air pollution and occupation of the limited oil resources. So, the solutions to these problems become really serious tasks to the researchers. Research and development of alternative fuel engine have been paid much attention and CNG engine has been developed. Compared to the existing gasoline engine and diesel engine, the CNG engine has good emission performance. The CNG engine also has its own disadvantages, and there is also a lot of research work to improve the efficiency of the engine.

In this paper, we developed a new adoptive control method for the engine ignition timing, and it has been verified according to a modified diesel engine. The results show that the new adoptive method can improve the efficiency of the CNG engine, and the torque outputting can meet the aim of the control method. The control method can be seen efficient.

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