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Investigation on the Application of Radical Basis Function Neural Networks to Compressed Natural Gas Engine

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Abstract

Automobile exhaust emissions is one of the important pollution sources. How to reduce automobile emission is a hot topic in the research field. Research on the alternative fuel and alternative fuel engine has great potential application. CNG engine is more promising due to its less emission and relatively rich resource. Existing research on the combustion process of CNG engine realize that the performance is affected by the boundary conditions, and the ignition time is a key parameter in reducing the emission and improving the efficiency. In this paper, an adaptive control method, which is based on radial basis (RBF) network method, has been proposed for the optimal ignition advance angle. According to the training sample, the simulation results have great coincidence with the experiment results. According to the experiment, the necessity of the control method is proven, and the validity of the RBF neural network applied in the calculation of the ignition advance angle has been proven.

***Keywords**: CNG engine, radical basis function, neural network, ignition timing*

Introduction

The ecological problem has become one of the important problems which restrict the development of human society. In the pollution sources of the environment, automobile exhaust emissions is one of the important sources of pollution. At the same time, the vehicle's fuel is also facing the problem of oil shortage [1]. Under this condition, many fuel consumption and automobile emissions regulations have been enacted [2]. Meanwhile, research on the alternative fuel [3-4] and alternative fuel engines [5-6]. In various alternative fuel engines, compressed natural gas (CNG) engine [7-8] is much cleaner and the natural gas resource is relatively rich. Therefore, investigation on this kind of engine has great potential application.

Compared with the common engine, combustion process of CNG engine is different from the conventional gasoline engine. Existing research reveals that the combustion process of CNG engine [9] is determined by the combustion boundary conditions, which mean that proper control to it can help to solve the combustion and emission problems [10].

Factors affecting the combustion boundary conditions [11-12] are shown as following:

(1) Gas supply characteristics [13]. Air supply conditions include inlet pressure, inlet temperature and exhaust gas recirculation (EGR) rate.

(2) Fuel supply characteristics [14]. Fuel supply characteristics mainly include physicochemical properties, fuel supply pressure, fuel starting injection pressure, supply time and supply rules [15].

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(3) Structural parameters of the chamber [15]. The structural parameters include inlet status, combustor parameters, and exhaust device status, etc. [16].

When the engine works rely on the compressed natural gas combustion, its ignition time must fit for the high ignition point [17]. Generally, positive ignition system is usually adopted to provide the working order of each cylinder. Besides, the natural gas engine has its own characteristics [18-20]:

(1)Deterioration characteristics of the engine power [21]. This condition appeared mainly due to the mismatch between natural gas quantity and air quantity.

(2) Lean burn [22]. This kind of engine is usually suitable for lean burn.

(3) Different optimum ignition time with different mixture ratios of the gas and air [23].

(4) Quality of natural gas is different because of the different origin and processing.

Therefore, how to make the CNG engine working with high efficiency is quite important due to the inconsistency of the gas. Under this condition, the adaptive control [24-25] is an effective control strategy for the ignition time. The ignition time system includes two types of mechanical and electronic system. The former relies on the crankshaft gear box, and the electronic control type uses a series of sensors to transmit the signal to the electronic control unit.

It is important to control the ignition time to make the CNG engine working with a higher efficiency. In this paper, an adaptive control method based on the radical basis function neural networks for the ignition time has been proposed. The aim of the paper is to develop a new adoptive method for the ignition time control, and the remainder of the paper is shown as the following: the control method is introduced in Section 2; the verification is shown in Section 3; and the Conclusion is shown in Section 4.

2 The Control Method

2.1 Test System

Electronic control test system of high pressure injection with spark ignition CNG fuel engine is shown in Figure. 1. The gas is provided by the Gas cylinders, pressure of which is released by the relief valve. On-off status of the high speed valve is controlled by the control system according to the open time point and duration time of the engine. The CNG is sprayed into the combustion chamber at the end of the compression stroke.

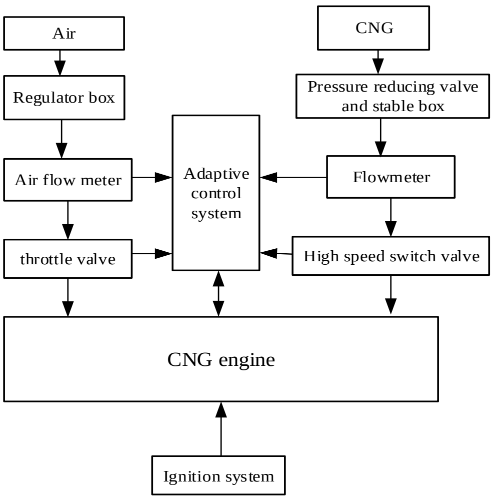

Figure. 1 The Test System for the Adaptive Control for the Ignition System of CNG Engine

2.2 The Adaptive Control Method

Ignition advance angle θ_s , CNG injection advance angle θ_i , and CNG injection quantity G_c have great influence on the power performance, economic performance, and emission performance of the CNG engine. It can be described as:

$$P_e = f(\theta_s, \theta_i, G_h) \tag{1}$$

$$\eta_e = f(\theta_s, \theta_i, G_h) \tag{2}$$

$$\varphi = f(\theta_s, \theta_i, G_h) \tag{3}$$

Optimum ignition advance angle θ_s and injection advance angle θ_i are the complex nonlinear function of engine operating parameters including engine speed n, load Q, cooling water temperature T_w, air inlet pipe pressure P_{air}, etc.

$$\theta_{optimum} = f(n, \rho, T_w, P_a, ...) \tag{4}$$

Where, P_e is the power performance,

η_e is the economic performance,

φ is emission performance,

$\theta_{optimum}$ is the optimal ignition and injection advance angle.

In fact, it is difficult to achieve the optimal performance of all the parameters at the same time, which means that the optimal ignition angle and injection angle are difficult to obtain. The feasible method is to use the optimization method of multi objective to optimize the target with different operating conditions for different performance indexes, and to take into account the optimization of other performance parameters. The traditional optimal ignition advance angle of the engine is obtained by a large number of experiments to simulate the function of the target index and the variables. However, the test work increases greatly with the increase of geometric progression when the number of independent variables increases.

Aiming at the disadvantages of the above method, the neural network, which has strong modeling advantages in the uncertainty system with nonlinear and multi variable, can be selected to solve the problem. In this paper, radial basis (RBF) network method for the best ignition advance angle is adopted.

The optimal ignition advance angle θ_s on the variable of rotating speed N and load Q is considered to the model establishment. Therefore, the optimal ignition advance angle θ_s is the output parameter, and rotating speed N and load Q are the input parameters. The input data is obtained from the test system. These experimental data are obtained by optimizing the control method of the other performance parameters in different operating conditions.

3. Verification

3.1 The CNG Engine

This CNG engine is a port fuel injection. It keeps the basic structure of the original machine unchanged, such as crankshaft and connecting rod mechanism, cooling system and lubrication systems. There is just a little improvement for the engine. The main parameters are shown in table 1.

Table 1. The Main Parameters of the Engine

parameters	value	parameters	value
cylinder diameter (mm)	105	Rated power (kW)	150
Stroke (mm)	120	Rated speed (r/ min)	2 300
The total displacement (L)	6.37	Rotating speed for maximum torque (r/min)	1 400
Ignition mode	ignition	Maximum torque (N/m)	680
Injection mode	Port fuel injection	The emission level	Euro III
Compression ratio	12.0		

When it uses the CNG as the fuel, the performance will be worse. Then, the optimization of the parameters will be efficient for improving the engine performance.

The main test instruments are listed in Table 2. Pressure sensor locates on the cylinder cover to measure the cylinder pressure. DELTER2613B angle meter is set to judge the engine parameter, and the angle meter with an accuracy of 0.1°.

Table 2. The Main 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

In the simulation and experiment, rotating speed of 1450 r/min, 1750 r/min, 2050 r/min and load of 50%, and 100% have been studied. Except ignition time, the other parameters will keep constant. RBF neural network learning is used to map relation best ignition advance angle and rotating speed and load into the network connection. Multi group test sample is used in the simulation. Some training sample is shown in Figure. 2.

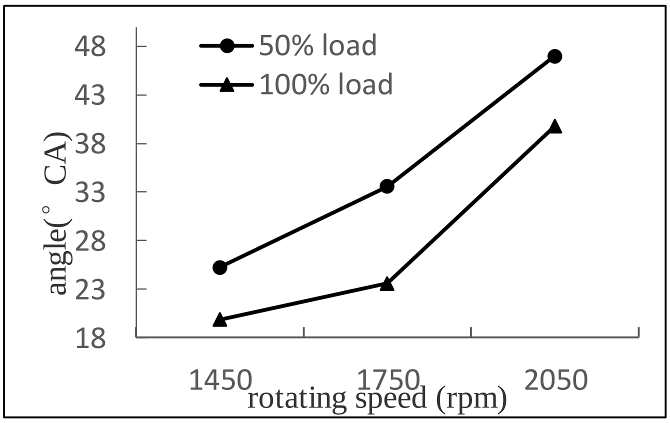

Figure 2. Some Training Samples for the Neural Network

3.2 Analysis of the Results

According to the training sample, the optimal ignition advance angle of the CNG engine was calculated by RBF neural network. The results are shown in Table 2. Experimental results are shown in figure 3-8. Compare the simulation value and the experimental results, the maximum absolute error of the angle is 0.3 °CA, and the maximum relative error is 75%. The RBF neural network used to get the best ignition advance angle has a relatively higher accuracy.

Table 2. Optimal

Rotating speed (rpm)	load	The optimal ignition time
1450	50%	25.29
	100%	31.27
1750	50%	29.32
	100%	34.79
2050	50%	35.98
	100%	39.67

From the figure.3 to figure.5, it can be seen that the torque output only has just little difference under the condition of 100% load. This means that maximum torque is generated by a certain quantity of the CNG. However, there will be fluctuation appeared under the condition of half load. This means that the control method is necessary to control the ignition time to improve the efficiency of the engine.

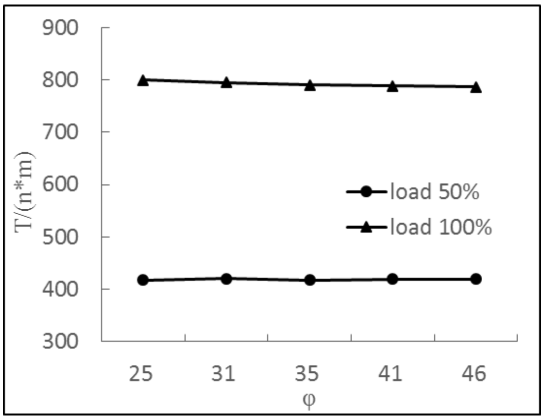

Figure 3. Variation of Output Torque with Ignition Advance Angle (1450 R/Min)

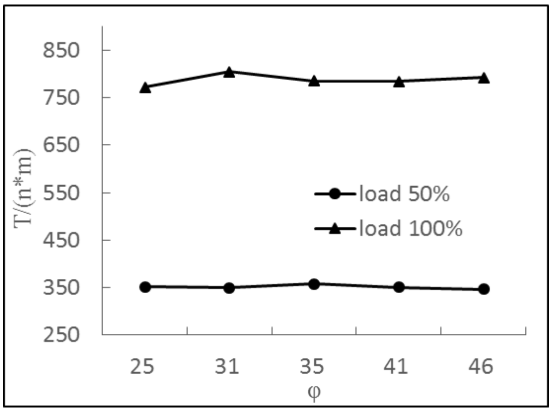

Figure 4. Variation of Output Torque with Ignition Advance Angle (1750 R/Min)

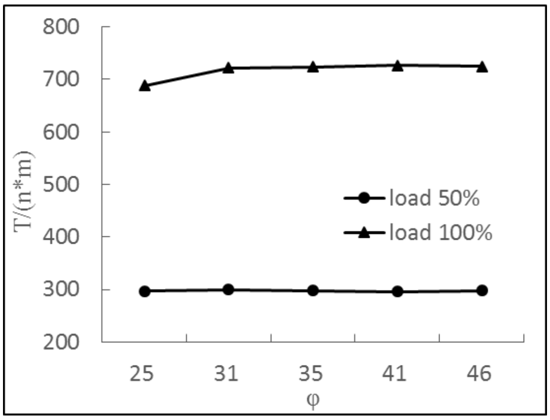

Figure 5. Variation of Output Torque with Ignition Advance Angle (2050 R/Min)

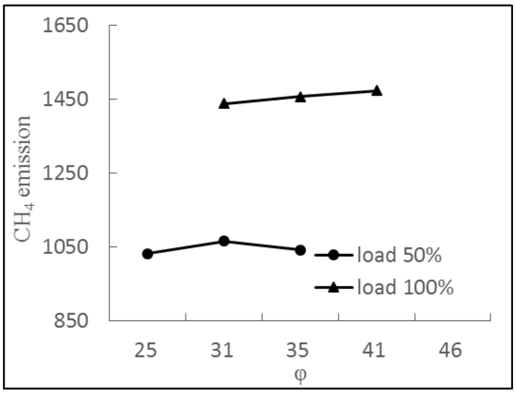

Figure 6. Variation of CH_4 Emission with Ignition Advance Angle (1450 R/Min)

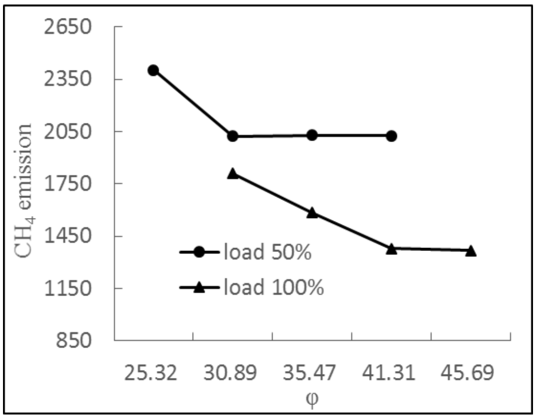

Figure 7. Variation of CH_4 Emission with Ignition Advance Angle (1750 R/Min)

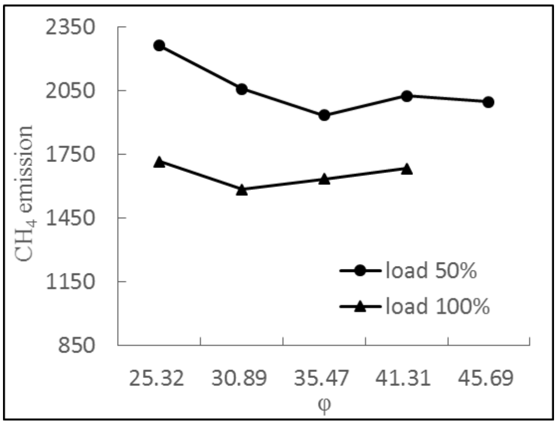

Figure 8. Variation of CH_4 Emission with Ignition Advance Angle (2050 R/Min)

Besides, the figure.6 to Figure. 8 show the CH4 emission principle. It can also be seen that the optimal ignition advance angle is fit for the optimal emission performance under the condition of half load. When the ignition advance angel is optimal to output the maximum torque the emission is relatively low. However, it is completely opposite when the engine is under the full load condition, the maximum torque output will lead to the emission increasing. Therefore, how to balance the torque output and the emission is an important problem.

4. Conclusion

The environmental problem has become one of the important problems and restricts the development of human society. Automobile exhaust emissions are one of the important pollution sources. How to reduce automobile emission is a hot topic in the research field. Research on the alternative fuel and alternative fuel engine has great potential application. Among all the alternative fuel and engine, the CNG engine is more promising due to its less emission and relatively rich resource

Existing research on the combustion process of CNG engine realize that the performance is affected by the boundary conditions, and the ignition time is a key parameter in reducing the emission and improving the efficiency. In this paper, an adaptive control method based on the radical basis function neural networks for the ignition time has been proposed. This control method is based on radial basis (RBF) network method for the best ignition advance angle. According to the training sample, the simulation results have great coincidence with the experiment results. According to the experiment, the necessity of the control method is proven, and the validity of the RBF neural network applied in the calculation of the ignition advance angle has been proven. It is also found that the optimal ignition advance angle is fit for the half load while it isn't fit for the full load condition.

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