Simulation of CNG/ Gasoline Engine Speed Controller Based on MATLAB

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Abstract— The studies of CNG/gasoline dual-fuel engine system model are relatively few. The design deficiencies of CNG/gasoline dual-fuel engine speed controller exist. In this paper, the design and simulation of CNG/gasoline engine speed controller based on Matlab were put forward. On the basis of reasonable CNG engine model, the digital PID speed controller and adaptive fuzzy PID speed controller model were built respectively using Simulink platform. By tuning PID parameters and correcting fuzzy rules, the optimal results of controller parameters were obtained. The simulation results shown that the engine could be greatly improved by using the adaptive fuzzy PID controller on the CNG engine speed control modules. The speed control overshoot, steady time and steady-state error were significantly improved, among them, overshoot reduced 20%, steady state time reduced 4s, and steady-state error reduced 15 percent. The adaptive fuzzy PID speed controller improved the CNG/gasoline dual-fuel engine control performance, which has higher value of practice and application.

Keywords— CNG/gasoline engine    Simulink model    PID adaptive fuzzy PID    speed controller

I. INTRODUCTION

The classical control theory, modern control theory and intelligent control theory have been studied and used in automobile engine control[1]. The engine speed control was realized primarily by changing the engine throttle position and load size. The specific means is not unique. Under normal circumstances, the accuracy, stability and speedability of engine speed controller in the complex work environment are general difficult to achieve the expected requirements, so the engine speed control effects are often less than ideal. The main purpose of the engine speed control is that engine speed can quickly stabilize in determined conditions.

CNG/gasoline engine power will decline generally when using CNG fuel, and emissions is worse at higher load conditions[2]. It has great practical significance that researching the speed control systems of CNG/gasoline dual-fuel engine, which improve the current dual-fuel engine management level, enhance the engine dynamic performance, and reduce emissions furthest.

II. THE CONSTRUCTION OF TWO PID SPEED CONTROLLER MODEL

2.1 The Simulink model Construction of digital PID speed controller and parameter tuning

The digital PID control is widely used in industrial process control because of its simple algorithm, high reliability and robustness. The linear combination of deviation Proportional(P), Integral(I), Derivative(D) constitute a control amount, by using the control outputs, the controlled object was controlled by digital PID controller[3-4]. The control laws and Simulink model are as follows.

\[
 u(t) = K_p [e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_d \frac{de(t)}{dt}]
\]

Figure 1   Simulink model of digital PID controller
The control quality of digital PID speed controller mainly depends on the parameter tuning. If the parameter tuning is improper, the entire system may be imprecise, and it is also possible to make the system fall into a state of collapse. Digital PID parameters are determined generally by using Trial and error method, Empirical data law or Critical proportion of the law.

In this paper, digital PID parameters tuning use Trial and error method on the basis of Empirical data law. According to the principle of the first proportion, then integration, using the Table 1, Table 2 and Table 3 data, Digital PID speed controller achieve the best control effect by comparing parameters tuning effect curves gradually.

### Table 1

<table>
<thead>
<tr>
<th>Parameters $K_p$ tuning</th>
<th>0.01</th>
<th>0.03</th>
<th>0.05</th>
<th>0.07</th>
<th>1.00</th>
<th>1.05</th>
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</thead>
<tbody>
<tr>
<td>overshoot/%</td>
<td>25</td>
<td>25</td>
<td>18</td>
<td>23</td>
<td>25</td>
<td>32</td>
</tr>
<tr>
<td>steady state time/s</td>
<td>6.0</td>
<td>4.7</td>
<td>3.8</td>
<td>4.5</td>
<td>5.4</td>
<td>6.5</td>
</tr>
<tr>
<td>steady-state error/%</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
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</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Parameters $K_i$ tuning</th>
<th>0.05</th>
<th>0.10</th>
<th>0.15</th>
<th>0.20</th>
<th>0.25</th>
<th>0.30</th>
</tr>
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<tbody>
<tr>
<td>overshoot/%</td>
<td>30</td>
<td>21</td>
<td>26</td>
<td>30</td>
<td>32</td>
<td>35</td>
</tr>
<tr>
<td>steady state time/s</td>
<td>4.5</td>
<td>3.7</td>
<td>3.4</td>
<td>4.1</td>
<td>4.8</td>
<td>4.9</td>
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<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.5</td>
<td>2.5</td>
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</tbody>
</table>

### Table 3

<table>
<thead>
<tr>
<th>Parameters $K_d$ tuning</th>
<th>0.01</th>
<th>0.03</th>
<th>0.05</th>
<th>0.07</th>
<th>1.00</th>
<th>1.05</th>
</tr>
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<tbody>
<tr>
<td>overshoot/%</td>
<td>40</td>
<td>34</td>
<td>36</td>
<td>30</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>steady state time/s</td>
<td>5.0</td>
<td>5.4</td>
<td>5.0</td>
<td>4.5</td>
<td>4.5</td>
<td>4.3</td>
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<tr>
<td>steady-state error/%</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

2.2 Construction of adaptive fuzzy PID speed controller Simulink model and parameter tuning

Adaptive fuzzy PID control does not require mathematical model of the controlled object, and has online real-time correction parameters, so the controller adapt to any parameters changes of the controlled object\(^5\). In order to achieve the ideal control effect, Real-time optimization of Proportional (P), integral (I), differential (D) coefficient was conduct by using fuzzy logic algorithm and some fuzzy rules.

Fuzzy PID control parameters include fuzzy parameters, fuzzy inference rules, parameters solution of the fuzzy and the PID controller. Based on the setting input and the feedback signal, a computer compute the deviation $e$ and the current deviation change $e_c$ of the actual position and the theoretical position, then process fuzzy reasoning according to the fuzzy rule, finally fuzzy parameters was processed the solution fuzzy and output the proportional(P), integral(I), differential(D) coefficient of PID controller.
The simulation diagram of adaptive fuzzy PID control system was designed with Simulink software, as shown in Figure 2.

![Figure 2 Adaptive fuzzy PID controller model](image)

![Figure 3 Logical structure package model of PID controller](image)

### III. EXPERIMENTS AND ANALYSIS OF RESULTS

#### 3.1 The parameters tuning of digital PID speed controller

Figure 4 shows the digital PID speed controller effect curves which process multiple parameters tuning according to the data in Table 1, 2, 3. Data 8 is the effect curves of initial parameters, at this point \( K_p = 0.01, K_i = 0.5, K_d = 2.0 \). Data 4 was got through adjusting \( K_p \) gradually, the response speed of the control system is greatly improved in this process. A better response speed was reached when \( K_p = 0.05 \), the adjustment stopped. Data 7 was obtained through adjusting \( K_i = 0.2 \), whose steady time is shorter than data 4. Data 6 was obtained through adjusting \( K_i = 0.1 \). From these trends, we could see that the steady state error is big when \( K_i \) is small. Although Steady time is greatly reduced, it cannot meet the regulation requirements, finally \( K_i \) is 0.2. Data 5 was obtained through adjusting \( K_d = 0.5 \), whose steady-state error is improved. Data 2 was obtained through adjusting \( K_d = 1.0 \), which is the best effect curve. Finally we get the best parameters set: \( K_p = 0.1, K_i = 0.2, K_d = 1.0 \).

#### 3.2 Digital PID speed controller simulation results analysis

The simulation experiments show that: using empirical data law to demarcate, engine obtain relatively better results only at high speed, while in idle condition, steady state is too long, overshoot amount is too big (data 8 curve shown) and other issues. To get good control effect, in idle condition the digital PID speed controller use parameter tuning. After control variable adjustment, the most favorable effect parameter control set was determined, at this point \( K_p = 0.1, K_i = 0.2, K_d = 1.0 \), and the speed control results shown in Figure 5 (X- time t/s, y- speed n/rpm).

According to the model simulation, in idle condition, under the same speed of the idling condition (idling \( n = 1000 \) rpm), uncontrolled negative feedback control only produce a rough control effect, as shown in Figure 6. On the basis of empirical data law, using Trial and error method parameter tuning, the speed control effect has greatly improved in overshoot, steady time, steady-state error terms.
3.3 Adaptive fuzzy PID speed controller model simulation and experimental results analysis

Engine idle condition is a very important condition. In idle condition, the access to air conditioning, automatic transmission, power steering, etc. and the changes of cooling water temperature, air inflow, fuel, ignition, combustion, and other factors can make the engine speed instability. The joint action result of these factors make idle condition into a very complex system.

Because the idle condition has obvious nonlinear, time variability and uncertainty, it is difficult to establish a precise mathematical model. While the digital PID control depend on accurate mathematical model, so it is difficult to achieve the desired results.

In this paper, the simulation experiment of fuzzy PID control system in idle condition was conducted, and the control system parameters was determined by using Simulink simulation tool.

In order to facilitate the analysis of simulation data, under the fuzzy reasoning rules, the input and output curves was obtained, as shown in Figure 7.

Using Matlab/Simulink simulation software, inputting phase step idle condition speed signal n = 1000rpm, Adding load, Simulation studies of control algorithm of idle condition speed was conducted, the simulation curve shown in Figure 8.

The results show that fuzzy adaptive PID speed controller has the smaller overshoot, higher accuracy, shorter response time, better interference (load) capacity with respect to the digital PID.
kp changes relationship between the output and the input.
ki changes relationship between the output and the input.
kd changes relationship between the output and the input.

Figure 7 Changes relationship graph of each output and input

From the comparison of data graph, we can know that in idle condition, the deviation range of negative feedback regulation is -150 to 200, the deviation range of digital PID control deviation is -20 to 30, and the deviation range of adaptive fuzzy PID control is -10 to 10 whose effect is the most precise.

For the steady-state error, the adaptive fuzzy PID control precede digital PID control, is more than negative feedback regulation; For steady-state time, according to the steady-state standards, the standard value of adaptive fuzzy PID steady time is 4s, the standard value of digital PID steady time is 5.5s, while negative feedback regulation requires 7.5s to reach standard value. In the terms of steady-state time, adaptive fuzzy PID control still precede the PID fuzzy PID control, and is better than negative feedback regulation; For overshoot, negative feedback regulation overshoot reached 700rpm, digital PID controller overshoot drop to 200rpm, The overshoot of fuzzy adaptive PID control only reached 120rpm. In the terms of overshoot, adaptive fuzzy PID also reflects the relatively better control effect.

Overall, the effect of adaptive fuzzy PID speed controller is better than digital PID speed controller, and on the basis of negative feedback regulation, it greatly improved the stability performance of the speed controller. It has many superior performance and some practical and application value, and verify the feasibility of this program.
IV. OUTLOOK

Because of personnel, time, objective conditions and other restrictions, this study room for improvement in some areas are as follows.

(1) Because signal occurrence and processing all used software simulation, signal occurrence tends to be idealistic, but the real condition is very complex. Therefore, we can try to collect and store the actual waveform signal of hardware control module and then process corresponding simulation.

(2) The contrast with the actual situation is lacked, and there may be large errors in some places. So try to make material object and conduct Hardware-in-the-loop simulation and an experiment with real vehicle.

(3) The measured steady-state performances of adaptive fuzzy PID speed controller and digital PID speed controller are relatively good. But it only shows the feasibility and advantages of this program, in the actual situation, there are still many unknown confounding factors needing further debugging and verification.

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REFERENCES


