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Study of Compound Fuzzy-PID Control Method for Gasoline Engine Idling Speed Control

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***Abstract*—Gasoline engine idling instability is a common problem of engine idling control system. In order to improve steady and dynamic characteristics of gasoline engine idling control, a new type compound fuzzy-PID control system was designed and compared with the traditional PID system through simulation by MATLAB/ Simulink and test in dynamometer. The results confirm that the compound fuzzy-PID control system can decrease remarkably idling speed fluctuation, the maximum transient ripple value is still less than 15 r/ min with the air-conditioner load added and it has an enough robustness so that it is suitable for actual vehicles.**

Keywords-IC Engine, Gasoline Engine, Idling Speed, Compound Fuzzy-PID, Robustness.

I. INTRODUCTION

Ninety percent of vehicle speed in city is less than 40 km/h in our Country.1 Idling emission and oil combustion affect all of condition that speed is less than 40 km/h directly. It is clear that higher speed lead more oil combustion at idling condition, so idling speed should be decreased as much as possible to reduce the oil combustion. However, emission of CO and HC is increased when the speed of engine is low, so idling speed can not be too lower. The temperature of cool water, air condition, auto transmission and so on, all of this things will lead to engine working unstable even dead in idling condition.

In order to make engine work at lowest speed and to improve engine's emission and fuel economy, this paper proposed a method that combined fuzzy control and traditional PID, designed a new compound fuzzy-PID engine idling speed control system to improve engine idling condition stability.

II. STUDY OF GASOLINE ENGINE IDLING CONDITION CONTROL ALGORITHM

In control theory, because of idling condition that is obviously no-linear, time-varying and uncertainty, it is hard to build accurate models than traditional PID control, which people tend to adjust online based on experience. If we add feed forward adaptive control which based on the traditional PID control, then change each parameter according to working condition and working environment, in this condition we can change idling control result. This method is feasible in theory, but need a large number of experiments to get the accurate math model.

Parameter adaptive fuzzy-PID control algorithm adopted fuzzy reasoning method to on-line self-tuning parameter, which not only keep PID control's advantages of principle simple, easy to use, and high control accuracy, but also has fuzzy control's advantages of adaptability and so on. Because of fuzzy control need to calculation of fuzzy rules, which lead to respond slowly, rough action and steady-state accuracy poor, we adopted compound fuzzy-PID control system in this paper. Gasoline engine idling compound fuzzy-PID control systems' block diagram is shown in figure 1.In this figure ,large dashed box figure is compound fuzzy-PID control systems including traditional PID control module, parameter adaptive fuzzy PID control module(small dotted),and intelligent switch module.

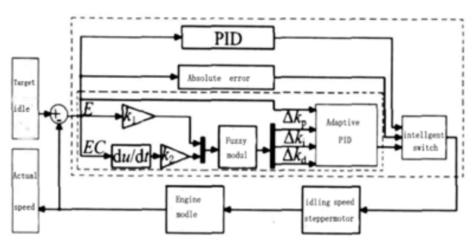

Figure 1. Gasoline engine idling compound fuzzy-PID control systems' block diagram

III. DESIGN OF COMPOUND FUZZY-PID CONTROLLER

A. Design of traditional PID controller

Traditional PID control has the advantages of simple in principle easy to use and stability and so on. Specific control algorithm is as follows:

$$u = k_p e + k_i \int e dt + k_d de / dt \tag{1}$$

Where, u is throttle opening, e is speed error, k_p, k_i, k_d is proportion, integral, differential coefficient, determined by the specific engine operating conditions and used the experience value under normal circumstances.

B. Design of parameter adaptive fuzzy PID

1) Design of adaptive PID module

Parameter adaptive fuzzy -PID control system structure diagram is shown in figure 1(small dashed box

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figure).According to the system response, we taken idling speed deviation E and error change rate EC for input, and use fuzzy control rules to do fuzzy reasoning and fuzzy decision-making. Then modify the PID parameters online. Adaptive PID module in Simulink structure is shown in Figure 2.

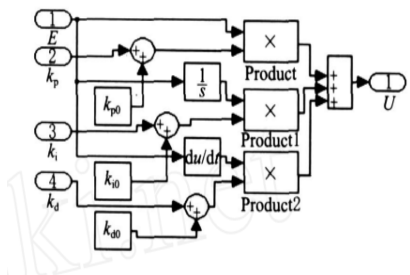

Figure 2. Adaptive PID module in Simulink

Fuzzy module continuously detected deviation E and error change rate EC and modify PID parameters online according to fuzzy control principle when it is operation. Specific formula is as follows:

$$k_p = k_{p0} + \Delta k_p g_1 \qquad (2)$$

$$k_d = k_{d0} + \Delta k_d g_3 \qquad (3)$$

$$k_d = k_{d0} + \Delta k_d g_3 \qquad (4)$$

Where, k_{p0} , k_{i0} , k_{d0} are using conventional PID parameters tuning to get the initial value under different condition. Δk_p , Δk_i , Δk_d are the three output of fuzzy controller. k_p , k_i , k_d can be automatically adjusted by the state of charged object. g_1 , g_2 , g_3 are the output scale factor of Δk_p , Δk_i , Δk_d , to realize the adaptive adjusted control parameters.

2) Determined Linguistic variables and membership function

We taken speed deviation E and speed error change rate EC as fuzzy input, and taken the corresponding fuzzy output proportional, integral, differential effect of the change in Δk_p , Δk_i , Δk_d as the corresponding output linguistic variables. All of the input variables and output variables of the fuzzy language set is defined as:{NB,NM,NS,ZO,PS,PM,PB}.

Where, PB represent positive large ,NS represent negative small, PM represent positive middle ,ZO represent zero, PS represent positive small, NM represent negative middle, NB represent negative large. The domain of fuzzy input variables and fuzzy output variables is {-6,-4,-2, 0, 2, 4, 6}.

Membership function with a resolution of a strong middle triangle-type function and the edge of the Gaussian-type function is shown in figure 3 and figure 4.

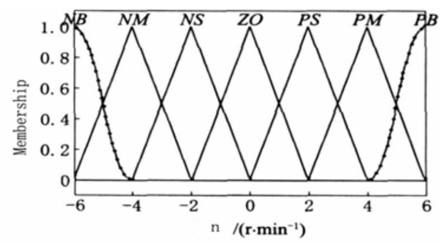

Figure 3. the membership function of input variables E and EC derivative

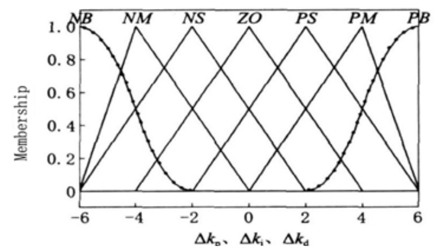

Figure 4. the membership function of output proportional integral

3) Created fuzzy control rule table

We should consider the affect of three parameters and the relationship between each other when modified the PID parameters. Generally, the requirement of control process to k_p , k_i , k_d under different deviation E and speed error change rate EC can be summarized as follows2:

(1) When E and EC is with the same positive and negative, the parameter of controlled is deviated from established value, k_p get the maximum value; when E and EC is with the different positive and negative meanwhile E is comparatively larger, k_p get the minimum value to accelerate the dynamic process of control.

(2) The size of EC indicated that the change rate of E, the bigger the EC ,the small the k_p ,also k_i is big, on the contrary ,too. Meanwhile, we should consider combined with E.

(3) Differential affect can improve the dynamic characteristics of this system, and prevent the change of E, which will be contributed to reduce the overshoot, eliminated the oscillation and shorten the adjustment time. Differential affect also will be allowed to increase k_d , reduce the steady-state error, improve the control accuracy and to realize the satisfactory results. In this condition, when E is large, the fact is PI control. When E is small and k_d get positive value, the fact is PID control. The corresponding fuzzy rules is shown in Table 1

4) Fuzzy inference and Defuzzification

Fuzzy inference is consist of three parts that is polymerization conditions, infer and cumulative. First, calculate the satisfaction of each rule in control rate. Then infer the size of single rule output. At last, cumulative outputs of all rules and obtain the total output of fuzzy.

Table 1 The fuzzy control rules of Δk_p, Δk_i, Δk_d

E/EC	NB	NM	NS	ZO	PS	PM	PB
NB	NB/NS/NB	NB/NM/NB	NB/PM/NM	NB/PM/NM	NB/PM/NM	NM/NM/NB	NM/NS/NB
NM	NB/NM/B	NB/NB/NB	NB/ZO/NM	NM/PS/NM	NM/PM/NB	NM/NM/NB	ZO/NM/NB
NS	ZO/NB/NB	ZO/NB/NB	ZO/NS/NM	NM/ZO/NM	PS/NS/NM	ZO/NB/NB	PS/NB/NB
ZO	PB/NB/NB	PM/NB/NB	PS/NS/NM	ZO/ZO/NM	PS/NS/NM	PM/NB/NB	PB/NB/NB
PS	PM/NB/B	ZO/NB/NB	ZO/NS/NM	NM/ZO/NM	NS/NS/NM	ZO/NB/NB	PS/NB/NB
PM	ZO/NM/B	NS/NS/NB	NS/ZO/NM	NM/PS/NM	NM/ZO/NM	NS/NS/NB	ZO/NM/NB
PB	NS/NS/NB	NM/NM/NB	NM/PM/NM	NB/PB/NM	NB/PB/NM	NM/NM/NB	NM/NS/NB

This paper selected of a Mamdani type reasoning method3, which is the most common and relatively simple kind of reasoning. After fuzzy inference, we used gravity method to strike the precise control value.

The precise control value can be expressed as follows:

$$u = \sum_{i=1}^{k} \mu_i y_i / \sum_{i=1}^{k} \mu_i \qquad (5)$$

Where, μ_i is the membership of the i-th fuzzy output; y_i is the i-th fuzzy output of a single point location; k is the number of fuzzy output.

C. Design of Intelligent switch

When idling speed deviation is large, use fuzzy-PID control which need a long time to adjust can lower steady-state accuracy. So when $|E| \geq \partial * r$, intelligent switch connect traditional PID module to reduce computation time and improve the accuracy when the system start to work or at working. When $|E| \leq \partial * r$, intelligent switch connect parameters adaptive compound fuzzy-PID to improve the robustness of system. Where, r is the intelligent switch system settings; ∂ $(0 < \partial < 1)$ should ensure that parameters adaptive compound fuzzy-PID has wider control space. In the experiment verification, we taken Yiheng C164CI for controller in control system, and interrupt programming control method intelligent for switch. we can ignore the effect on engine when change the intelligent switch, because of that C164CI frequency of the crystal reach 25MHZ and interrupt response time is 240~400ns4.

IV. SIMULATION AND EXPERIMENT VERIFICATION

According to compound fuzzy-PID control method, this paper established a gasoline engine idling speed control block diagram of composite fuzzy -PID, based on Matlab/simulink platform. In this simulation, target idling speed was set to 900r/min and the range of speed deviation was [-120,120], so fuzzy quantization factor k_1 was 6/120; the range of speed deviation change rate EC was [-24, 24], k_2 was 6/24 with the same principle5. The experience value of PID control module proportion, integral and differential coefficient was 0.6, 0.5, 0.15. The initial value of adaptive PID module k_{p0}, k_{i0}, k_{d0} was 0.2,0.2,0.01. Among proportion g_1, g_2, g_3 was 0.2/6,0.2/6,0.01/66. The parameter of intelligent switch ∂ and r optimization online obtained for 0.2,50. The engine prototype module was the transfer function of gasoline idling condition.7

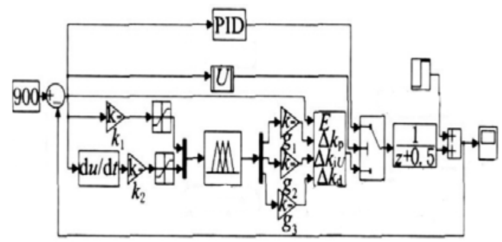

Figure 5. Using Simulink to achieve control block diagram of compound fuzzy -PID

Figure 6 is the response of the system without interference input. We can see that fuzzy-PID and traditional PID control system can reach the same target idling value at 5 seconds with a rapid response; also we can know that fuzzy-PID control system response slowly, and get the target value at 12 seconds.

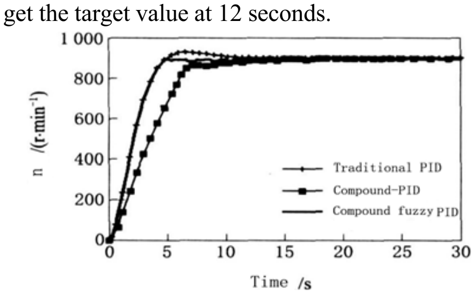

Figure 6. response of system without interference input

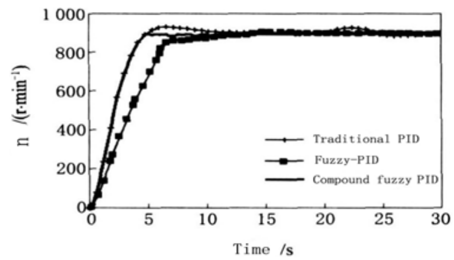

Figure 7. response of system with interference input

In order to observe system anti-jamming capability, we added a 50 r/min interference signal making a rapid increase in speed when it had worked 20 seconds, and observed controller's respond ability. The simulation result is shown in figure 7. Through this figure, we can see that traditional PID has obvious overshoot but fuzzy-PID and compound fuzzy-PID that response curve only with minimal jitter has strong robustness.

After engine compound fuzzy-PID controller commission completed, we put it on to engine test bench, and taken a test to measure the engine idling stability curve, meanwhile, compared with traditional PID and fuzzy-PID control system's curve. The results are shown in figure 8 and figure 9.The test results under 3 idling speed control system show that: The maximum deviation between compound fuzzy-PID idling speed and target speed is + 6 r/min without overshoot when water temperature is 45° C at normal idling condition. However, the maximum deviation of traditional PID and fuzzy-PID reach +22 r/min and +12 r/min. After idling speed steady 20 seconds, turning on the air condition, the maximum deviation of traditional PID and fuzzy-PID reach +32 r/min and +21 r/min .when we take compound fuzzy-PID control ,the maximum deviation still can be controlled in +15r/min. Also the compound fuzzy-PID and traditional PID control can reach target idling speed in 3 seconds, but fuzzy-PID need about 10 seconds to reach the target idling speed.

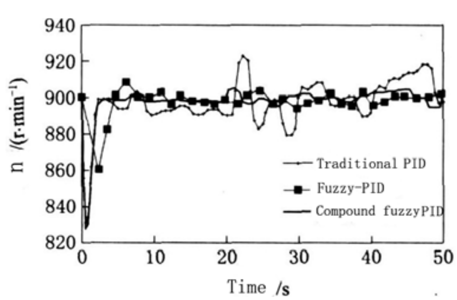

Figure 8. the normal idling speed under 3 control system

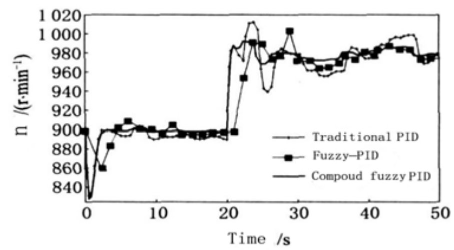

Figure 9. the idling speed under 3 control system (loaded air conditioning)

V. CONCLUSIONS

(1)The engine idling condition compound fuzzy-PID control system which designed in this paper combined advantages of PID controller and fuzzy controller, which made the control system not only had PID control's advantages, e.g., quick response and high accuracy, but also had fuzzy control's advantages,e.g., anti-interference ability and enough robustness.

(2)The engine idling condition compound fuzzy-PID control system can control the maximum transient ripple value within 15 r/ min, no matter under which conditions, e.g., normal or air condition loaded.

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