

Design of Idle Control System for Diesel Engine Based on T—S Model

Haiyan Wang

Changchun Sci-Tech University, Changchun, China

Corresponding author e-mail: 13742883@qq.com

Abstract. For the characteristics of large time delay and inertial of diesel's idle control system, a method of fuzzy PID controller is proposed based on T—S model. The controller adopts the fuzzy rules of T—S model that converted from expert experience and the output form of traditional PID controller, which can make the traditional PID controller's mature experience about parameters adjustment be fully absorbed and establishment of fuzzy control rules be more simple, the physical meaning also become clearer. Through the simulation of large lag objects, it is proved that the fuzzy controller has strong adaptability and robustness, obviously improves the dynamic and static performances of the system. The controller has a simple structure, and it is more compact and easier to calculate in form compared with Mamdani system. In addition, the T—S system model can be easily created by using self-adapting thinking and widely used in other actual engineering projects that need keep constant pressure, so it is worth to research.

1. Introduction

The starting performance of diesel engine is regarded as one of the important performance indexes of diesel engine. Generally, the starting process of diesel engines can be divided into four stages: the initial stage, the acceleration stage, the transition period and the speed closed-loop control period.

At the beginning of startup, the starting motor first drives the diesel engine to a certain speed (about 120 r/min) to initially establish the oil supply pressure and the environmental conditions required to form combustion in the cylinder. At the same time, the ECU (electronic control unit) collects crankshaft signals and camshaft signals for cylinder action. After the cylinder action is completed, the ECU sends out the control signal, the fuel injector begins to spray oil, the combustion in the cylinder begins, the engine speed rises rapidly and enters the acceleration period. In the acceleration stage, the oil supply mode of starting oil pulse spectrum is generally adopted to inject oil quantity of order. In the low speed section, in order to make the speed rise rapidly, the oil amount of starting is large, and then the oil amount of starting with the speed rising will gradually reduce, which can make the speed smooth transition and reduce the overshoot amount. When the rotating speed exceeds the set threshold value n , the automatic oil supply mode of idling closed-loop PID control will be automatically entered, and the oil pulse spectrum will lose its effect.

At present, there are two main design ideas of idling closed-loop control system in China: one is a control system based on conventional PID, the other is a control system based on fuzzy PID. The



conventional PID has the advantages of simple algorithm, mature technology and high reliability. However, due to the fixed control parameters, when the controlled object changes, it cannot be adjusted automatically and has poor adaptability. Therefore, for the complex control system of electronically controlled diesel engine with multiple parameters, time-varying, large delay and non-linearity, if the conventional PID is adopted, a series of problems such as overshoot, substantial increase of oscillation number and significant extension of transition time will occur, and the control effect is often not as expected. The fuzzy controller can realize online self-adjustment of PID controller parameters according to working conditions and parameter changes. It has strong adaptability and robustness. It not only absorbs the advantages of conventional PID, but also makes up for its deficiencies. However, the current fuzzy controller mostly adopts the Mamdani system. Although it can meet the control requirements, it has many fuzzy rules and the physical meaning is not clear, and it is not easy for mathematical analysis and modeling.

Therefore, a fuzzy PID controller based on t-s model is proposed. The controller is simple in structure and high in computational efficiency, which is very suitable for mathematical analysis and system modeling. Problems encountered by the Mamdani system.

2. Control system model

2.1. Principle of idle closed loop control

Idle speed control principle is: the ECU will be collected after the signals of crankshaft and camshaft signal processing to get the real-time speed of engine, sent to the input port, the control system according to the target speed value and the actual speed deviation according to the Fuzzy - PID controller to the size of the control strategy of automatic tracking the actual running situation, the various parameters of the real-time control system output pulse width of the control command, which controls the engine fuel delivery per cycle, to adjust the real-time speed of the engine, make it always in near the target speed, and achieve the best energy saving effect. The ECU used in the control system is a 32-bit high-performance electronic control unit based on SPC563 independently developed by China yituo.

The structure diagram of idle speed control is shown in figure 1.

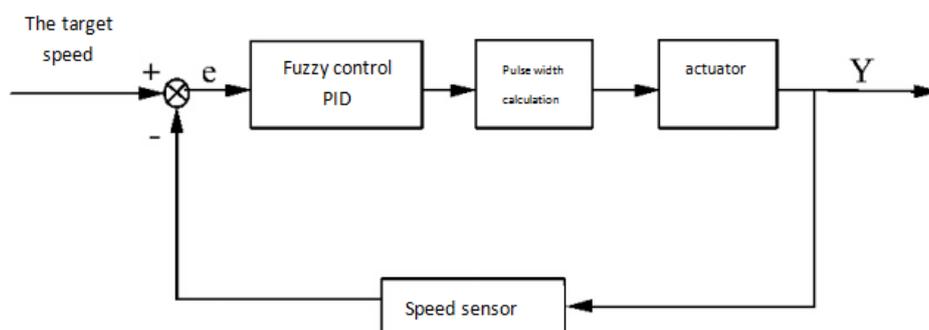


Figure 1. Functional Block Diagram of Idle Control System

Among them, the controlled object is composed of oil pump, electromagnetic valve, motor and other links, involving many parameters, some of which are difficult to measure accurately, while others change with the operation of the system. The working characteristics of the oil pump are very non-linear. The changes of the engine speed and load will lead to the changes of the operating point of the oil pump, and then the system parameters will be changed. In addition, the control system controls the rotating speed by adjusting the fuel supply of the engine. Considering the hysteresis of the solenoid valve, the length and torsion of the high-pressure tubing, and the combustion process in the cylinder,

the variation of engine speed will have a certain lag time compared with the variation of oil content, so the controlled object is also a large delay system.

2.2. *T - S model*

The t-s model, proposed by Takagi and Sugeno in 1985, is a very active branch of fuzzy control. It is a very typical fuzzy model, which can be used to identify, control and express the dynamic characteristics of complex systems easily. Generally, rules based on t-s model have the following forms.

R: If x1 is A1, x2 is A2... Xn is an, then

$$Y = b_0 + b_1x_1 + b_2x_2 + \dots + B_NX_N \tag{1}$$

The characteristics of t-s model are as follows: the rule forepart adopts the form Ai of fuzzy quantity, and the latter part adopts the form of linear combination of precise quantity. Compared with general fuzzy model, it is more beneficial to the systematic representation and operation of information. For a single rule, the t-s model is represented as a linear map of local area. With the overlapping of multiple rules, the t-s model realizes a global nonlinear map.

2.3. *Analysis of the structure and principle of t-s fuzzy controller*

If the t-s model, the selection of error e and error change of ce, the accumulation of error se as before a variable of fuzzy rules, the output of fuzzy controller select PID in the form of linear function, u, and the PID parameters setting experience into t-s fuzzy rules, then get the fuzzy PID controller based on t-s model [4]. Its schematic diagram is shown in figure 2.

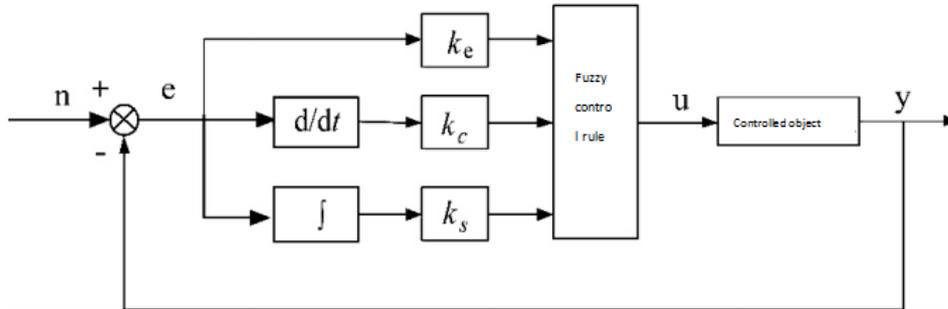


Figure 2. Functional Block Diagram of Fuzzy PID Controller

Among them, ke, kc and ks are used to adjust the range of fuzzy sets in the antecedent variables. According to formula (1) and b0 = 0, the fuzzy rule k can be obtained. namely:

$$R^k : \text{If } e \text{ is } A_1^k, ce \text{ is } A_3^k, \text{ then } u^k = b_1^k e + b_2^k se + b_{3k} ce \tag{2}$$

If the error of the current input is e, the output of the fuzzy rule Rk is

$$u^k = b_1^k e + b_2^k \int e + b_3^k e \tag{3}$$

Assuming that the system has N fuzzy rules, the t-s fuzzy controller output can be obtained by using the algebraic product - barycenter method

$$u = \frac{\sum_{k=1}^N \omega^k u^k}{\sum_{k=1}^N \omega^k} \tag{4}$$

Among them

$$\omega^k = \mu_{A_{k_1}}(e) \mu_{A_{k_2}}(\int e) \mu_{A_{k_3}}(e) \tag{5}$$

This is called the absolute weighting coefficient, and in practice only the relative weighting coefficient is used

$$p^k = \frac{\omega^k}{\sum_{k=1}^N \omega^k} \tag{6}$$

It can be obtained by substituting it into formula (4)

$$u = \sum_{k=1}^N p^k u^k = \sum_{k=1}^N [p^k (b_1^k e + b_2^k \int e + b_3^k e)] = \left(\sum_{k=1}^N p^k b_1^k \right) e + \left(\sum_{k=1}^N p^k b_2^k \right) \int e + \left(\sum_{k=1}^N p^k b_3^k \right) e \tag{7}$$

Compared with the conventional PID algorithm, it can be seen that: $\sum_{k=1}^N P^k b_1^k$, $\sum_{k=1}^N P^k b_2^k$ and $\sum_{k=1}^N P^k b_3^k$ correspond respectively to the proportion coefficient, integral coefficient and differential coefficient in the conventional PID controller. However, there are some differences. In the conventional PID controller, proportion, integral and differential coefficient are generally constant, while the three parameters of the fuzzy PID controller based on the t-s model are all variables and related to error e, error accumulation se and error change ce, so it can be regarded as a PID controller with variable parameters. In addition, it can be seen from formula (7) that the output control u is the overall output of the precise output corresponding to each fuzzy rule after weighted average, thus avoiding the deblurring process required by the Mamdani model.

2.4. Model T-S fuzzy controller

2.4.1. Determine the fuzzy subset and its membership function. Five fuzzy subsets are defined on the error theory domain e: {NB, NS, ZO, PS, PB}; Three fuzzy subsets are defined in the error change theory domain: {N, ZO, P}; Three fuzzy subsets are defined on the error accumulation theory domain: {N, ZO, P}. The membership functions of the fuzzy subset select all symmetric, all overlapping continuous, linear triangles and trapezoids, as shown in figs. 3 and 4.

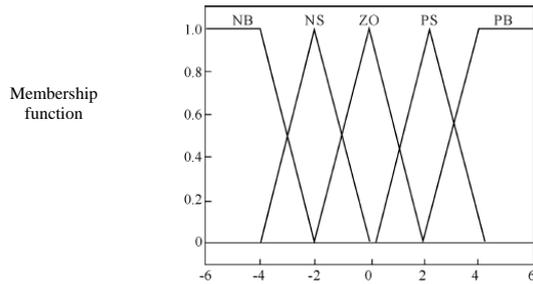


Figure 3. Membership Function of Error e

2.4.2. *Make vague rules.* According to the principle of PID parameter setting, when the error is large, a larger KP and a smaller kd should be adopted to make the system have better tracking performance. At the same time, in order to avoid large overshoot in the system, the integral action should be limited, so PD control can be adopted. When the error is moderate, KP and ki should be reduced and kd should be selected in order to make the system have a small overshoot. When the error is small, KP and ki take a moderate value to take into account the stability and control accuracy.

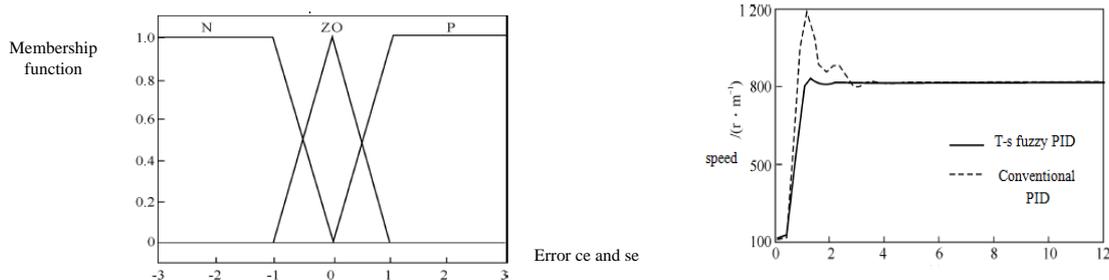


Figure 4. Membership Function of Error ce and se Figure 5. Speed Curve of Engine Start Condition

According to the above guidelines of PID parameter setting and combined with expert experience, the following 10 fuzzy statements can be listed to describe the fuzzy rules of parameter setting.

You can take any value. As for KP, ki and kd in the rules, for the control object that cannot determine the specific mathematical model, it can be adjusted in real time according to the overshoot, oscillation number and response speed of the system. For linear systems that can determine the mathematical model, the ziegler-nichols theorem can be used to determine, as follows.

Ziegler-nichols theorem: for a given transfer function of the controlled object, its root trajectory can be obtained, corresponding to the point crossing the virtual axis, the gain is km, and the w value of this point is wm. The setting formula is

$$k_p = 0.6k_m, k_i = \frac{k_p \pi}{4\omega_m}, k_d = \frac{k_p \omega_m}{\pi} \tag{8}$$

Where, km is the gain k value when the system starts to oscillate, and wm is the oscillation frequency. According to this idea, the value of KP, ki and kd can be easily obtained by Matlab software programming.

3. System verification and analysis

The ECU based on SPC563 was used to test and verify a type of ECU. The target idling speed is set to 800 r/min, and the marked speed is set to 600 r/min at the end of the start, that is, when the engine speed is less than this value, the oil supply mode of starting oil pulse spectrum is used, and when it is

greater than this value, the oil supply mode of idling closed loop control system is entered. The test results are shown in figure 5.

In the figure, the dotted line represents the speed response curve of the conventional PID controller and the solid line represents the speed response curve of the fuzzy PID controller using the t-s model. The experimental results show that: after adopting the t-s fuzzy PID controller, the overshoot of the control system is obviously reduced, the transition process time is greatly shortened, the number of oscillations is reduced, the stability is also improved, and it has strong adaptability and robustness, which are difficult to be realized by the conventional PID controller.

4. Conclusion

The t-s fuzzy PID controller has strong adaptability and robustness, which obviously improves the dynamic and static performance of the system and has good control effect. It designs the specification, controls the rule formulation and the parameter adjustment simple.

Simple and clear physical meaning can make the technical problem which the conventional PID can not solve readily solved. T-s fuzzy PID controller can also be widely used in other practical engineering projects requiring closed-loop control, so it has important theoretical value and engineering application value.

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