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Design of Honing Coolant Temperature Control System Based on Fuzzy Self-tuning PID

Lian-zheng Ye*, Chan-Su Lee*, Seung-Yub Park*

Abstract In the paper, a kind of self-tuning PID control system is designed to keep the honing coolant temperature constant in the process of automobile engine production. The conventional PID control method and the Fuzzy PID control method both are used to design and make the simulation experiment in Matlab. According to the simulation result, the performance of Fuzzy PID control method is obviously better. The Fuzzy PID control system can react faster to get the target temperature and resume normal when external conditions exchanged.

Key Words : Temperature control, Honing, Fuzzy PID control, Parameter Setting, Simulation

1. Introduction

Honing is a precision grinding process that produces a precision surface on a metal workpiece by scrubbing an abrasive stone against it along a controlled path.[1] Honing is not only a kind of large-size and small-size machining method, but also used to improve the geometric form of a surface and its texture.[2] In the mechanical manufacturing industry, especially in the Auto Industry, Honing is widely used. During the honing process, a large amount of energy will be released, most of which will turn back to the production process by the form of thermal energy. As a result, in the processing region , we will see a temperature rise, which will seriously affect the surface microstructure and the surface stress of the workpiece, and finally affect the processing accuracy. Therefore, during the honing process, honing coolant is used for cooling to ensure that the processing conditions and the measuring conditions are the same. In recent years, the influence of honing coolant temperature on machining process and measuring process has been confirmed by more and more researches. And people start to pay more and more attention to this problem.

For now, most of the honing machines don't have specialized cooling device, they only have a large enough coolant tank and reduce the temperature by environment heat exchange. A small part of honing machines have cooling device, but just use switch control, or even the manual control method. Using these solutions, the system stability will be poor, the temperature overshoot will be large, and the response to the external environment will be slow and otherwise, the real-time performance won't be good. In addition, frequent switching also has a great effect on the power grid, which is not suit to the continuous production in the factory.

In the paper, we will use the conventional PID control which has been widely used in the

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*Corresponding Author :Department of Electronic Engineering, Changwon National University
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temperature control field, and Fuzzy self-tuning PID control method to design a honing coolant temperature control system. Compare the advantages and disadvantages of these two methods, and choose an optimal solution to design the system and apply to the improvement of honing machine.

2. Object analysis

2.1 Honing coolant

During the honing process, Honing coolant works in three ways: Washing, Lubricating and Cooling. In the honing equipment, there are a large number of coolant nozzles. Here we just choose those nozzles which are contact with the workpiece to reduce the workload, and enhance the pertinence and reduce the design difficulty.

2.2 System structure

Honing coolant temperature control system mainly includes Honing Machine, Filter Unit, Cooling Tank and other detection and control system which is shown in Figure 1. This design is mainly based on the original equipment, choose the temperature of the coolant as the object and make the equipment to have the ability to keep the temperature unchanged.

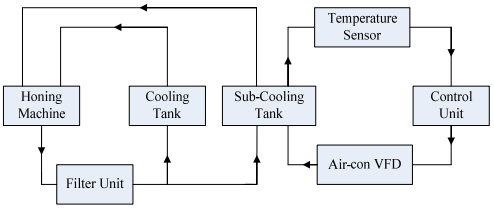

Fig.1 Honing coolant control system structure

In the coolant control loop, we choose the coolant temperature of the Tank as the controlled parameter, while the actuator is the Air-con on the tank which has VFD (variable frequency drive) function. The VFD is the final control module, which drives the Air-con at full speed, and the temperature Sensor record the temperature and after a few minutes, due to the heat exchange, the temperature is reduced. According to the related researches, generally speaking, the temperature of Honing coolant should be controlled at 18~20°C. [3] Considering the consistency of the processing condition and measurement in the design, we use 20°C as the standard value.

2.3 Transfer fuction

Honing coolant temperature control is a common temperature control process, which is a typical deterministic system that can be represented by a first-order inertia object. The transfer function model can be expressed as follows.[4]

$$G(s) = \frac{Ke^{-\tau s}}{Ts+1} \quad \cdots\cdots (1)$$

And then we use the upwards curve method [3] to identified the system parameters.

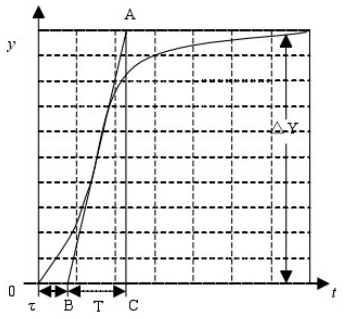

Fig.2 Upwards curve method

Generally speaking, the room temperature around the honing machine is 25°C. Firstly, we should make the coolant temperature of the

sub-cooling tank to 50°C, keep the coolant tanks still, and set the target temperature of Air-con at △M=20°C, and then let it work under normal conditions, and record the temperature change every minutes. And then we should choose Time as the x-axis, and the temperature change as y-axis, and we will get a curve as is shown in Figure 2. And then make a tangent line at the maximum slope, which intersects y=20 at A point and intersects y=0 at B point. C point is the time of the A point. And then the B point is the lag time τ, and BC is the time constant T, △Y/△M is the gain K. Then we will get the transfer function.

These transfer function parameters are mainly determined by the tank volume and the power of Air-con, and only after installation, this experiment can be done. So now, during the laboratory stage, we can just determine parameters according to actual requirements.

(1) Gain (K): According to the experiment method, the temperature change △Y=50-20=30°C, the target temperature △M=20°C. And then K=△Y/△M=1.5.

(2) Lag time (τ): Due to the continuous production, in order to ensure the consistency, the cooling system should respond to the temperature change as soon as possible. Because the cycle time of honing machine is 60s, choose the lag time τ at 60s.

(3) ime constant (T): In general, it was seen as abnormal if the honing machine stopped for more than 10min. So choose a half of 10min, 300s as the time constant.

Then we will get the transfer function as follows:

$$G(s) = \frac{1.5e^{-60s}}{300s+1} \quad \cdots\cdots (2)$$

3. Design of Fuzzy-PID control

The combination of Fuzzy control and PID control is widely used in recent years. PID control has a simple structure and high reliability, and is easy to be operated and realized, and to some degree, it can also remove the stabilization error. So for now, PID has been widely used in industry production. Here we choose PID control as the basic control part. And at the same time, we use the Fuzzy control method to make the parameters of the PID controller can be adjusted with the changing of process characteristic. The structure of the Fuzzy-PID control is as follows.[5]

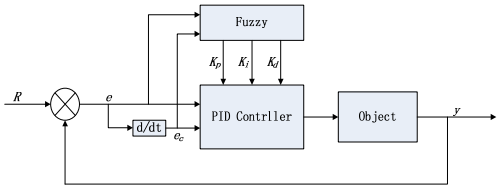

Fig.3 The structure of the Fuzzy-PID control

3.1 Variables analysis

According to the Fuzzy logic control, we choose the time-varying deviation value e and deviation variation rate ec as the inputs, the parameters of PID controller Kp, Ki, Kd as the outputs, and then set {NB,NM,NS,ZO,PS,PM,PB} as the fuzzy subset of the input e and ec, and output Kp, Ki, Kd., which 'N' represents 'Negative', 'ZO' represents 'Zero', 'P' represents 'Positive' and 'B' represents 'Big', 'M' represents 'Medium', 'S' represents 'Small'.[6] The universe of the inputs and outputs in Fuzzy controller is [-6,6] , the basic field of e and ec is[-30,30]. The membership function curve chooses the triangle curve which is as shown as follows,

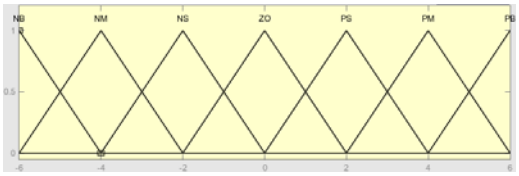

Fig.4 Membership function curve of e,ec,Kp,Ki,Kd

3.2 Variables analysis

According to different e and ec , there are different rules.[7]

(1) If |e| is large, choose a large Kp and a small Kd and make the system have a better tracking performance. In general, choose a small Ki to weaken the integral, and prevent the system to have a large overshoot.

(2) If |e| and |ec| both are middle size, choose a little small Kp to make the system to have a small overshoot, and choose a small Kd and a middle size Ki will be better.

(3) If |e| is small, choose a large value of Kp and Ki to make the system have a better system stability. In order to have a better anti-jamming performance, if |ec| is large, choose a small size Kd, and on the contrary, choose a middle size Kd.

Through the practice experience of the honing machine and the rules upside, we can get the rule base as follows:

Table.1 The rule base of Kp,Ki,Kd

e	e_c						
	NB	NM	NS	ZO	PS	PM	PB
NB	PB/NB/PS	PB/NB/NS	PM/NM/NB	PM/NM/NB	PS/NS/NB	ZO/ZO/NM	ZO/ZO/PS
NM	PB/NB/PS	PB/NB/NS	PM/NM/NB	PS/NS/NM	PS/NS/NM	ZO/ZO/NS	NS/PS/ZO
NS	PM/NB/ZO	PM/NM/NS	PM/NS/NM	PS/NS/NM	ZO/ZO/NS	NS/PM/NS	NS/PM/ZO
ZO	PM/NM/ZO	PM/NM/NS	PSNS/NS	ZO/ZO/NS	NS/PS/NS	NM/PM/NS	NM/PM/ZO
PS	PS/NM/ZO	PS/NS/ZO	ZO/ZO/ZO	NS/PS/ZO	NS/PS/ZO	NM/PM/ZO	NM/PB/ZO
PM	PS/ZO/PB	ZO/ZO/PM	NS/PS/PM	NM/PS/PM	NM/PM/PS	NM/PB/PS	NB/PB/PB
PB	ZO/ZO/PB	ZO/ZO/PM	NM/PS/PM	NM/PM/PM	NM/PM/PS	NB/PB/PS	NB/PB/PB

3.3 Fuzzy PID controller

According to the inputs, outputs and rules which have been decided upside, build the Fuzzy PID control system in the Fuzzy Logic Toolbox of Matlab as follows,

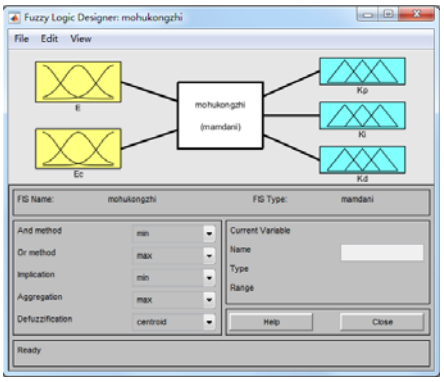

Fig.5 Fuzzy Logic Toolbox window

Edit the rules in the Rule Editor window with the form of "if...then..." as follows,

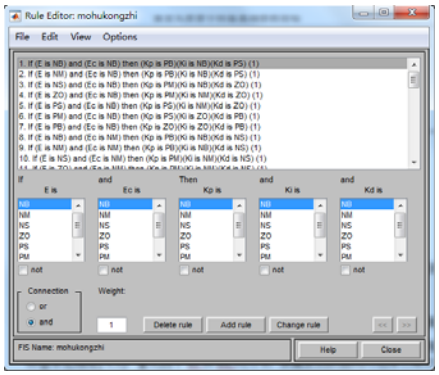

Fig.6 Rule Editor Window

4 Design of Fuzzy-PID control

In the Simulink environment of Matlab, the simulation block diagram of the system is designed according to the Figure 7.

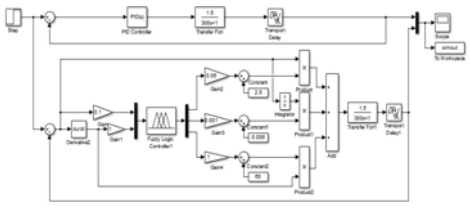

Fig.7 Fuzzy PID controller block diagram

In this system, set the temperature change at 10°C, that is to say, let the coolant temperature reduces from 30°C to 20°C, and use conventional PID method and Fuzzy PID method separately make simulation. And then use the PID tuner Tool in Matlab to find the suitable Kp, Ki, Kd. After combining the production reality and making many adjustments, we got the optimal parameter combination as follows,

(1) The conventional PID: Kp=2, Ki=0.008, Kd=0.1.

(2) The Fuzzy PID: _Kp=2.5, _Ki=0.006, _Kd=60, Fuzzy multiplier ke=0.1, kec=1, k1=0.06 , k2=0.001, k3=1.

Simulation time set at 1000s, the simulation result is as follows:

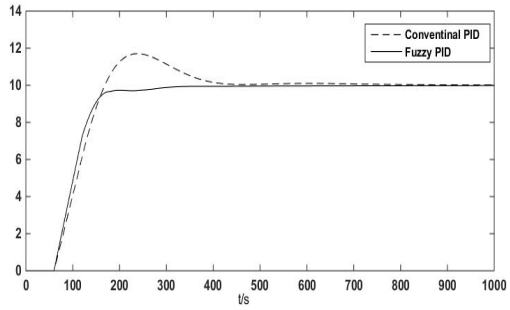

Fig.8 Fuzzy PID control system simulation

According to the simulation result, the conventional PID control and Fuzzy-PID control both can fulfill the task of honing machine itself automatically temperature control. By contrast, the Adjust-time of conventional PID is 500s, overshoot is 19%, while the Fuzzy PID is 280s, and within 200s, the system has almost reached the target and there is almost no overshoot. Although the structure of Fuzzy PID control is a little complex, the advantage is more obvious, less overshoot, faster system response speed, and good steady-state performance, full of which make the fuzzy PID control to be the optimal solution.

5 Conclusion

The paper analyzed the honing coolant flow in the honing machine, chose the coolant that contact with the workpiece to make the temperature automatically under control, used Fuzzy PID control method, built a honing coolant temperature control system based on Matlab, and made a simulation. Through the simulation, we confirmed the feasibility, advantages and disadvantages.

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