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Research on Precise Control of 3D Print Nozzle Temperature in PEEK Material

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Abstract. 3D printing technology has shown more and more applicability in medication, designing and other fields for its low cost and high timeliness. PEEK (poly-ether-ether-ketone), as a typical high-performance special engineering plastic, become one of the most excellent materials to be used in 3D printing technology because of its excellent mechanical property, good lubricity, chemical resistance, and other properties. But the nozzle of 3D printer for PEEK has also a series of very high requirements. In this paper, we mainly use the nozzle temperature control as the research object, combining with the advantages and disadvantages of PID control and fuzzy control. Finally realize a kind of fuzzy PID controller to solve the problem of the inertia of the temperature system and the seriousness of the temperature control hysteresis in the temperature control of the nozzle, and to meet the requirements of the accuracy of the nozzle temperature control and rapid reaction.

Key words: 3D printing; PEEK; fuzzy PID control; precise control of temperature.

INTRODUCTION

3D printing, known as the third industrial revolution symbol, is the production of manufacturing to the application of digital and artificial intelligence. This method has changed the traditional industrial manufacturing model. It will print out the new product through heating and melting the PLA, ABS or other metal materials, and superimposing the materials, in a very short period of time. The method is characterized by short printing time, low cost, product ever-changing. At present 3D printing is widely used, including product design, scientific research, construction, medical, manufacturing, aerospace, jewelry, personalized jewelry, and other fields. Nowadays, 3D printing has become an important development direction of advanced manufacturing technology and has a broad development prospects with lots of huge challenges.

PEEK is a kind of excellent engineering plastic. As a new semi-crystalline aromatic plastic engineering plastics, it has excellent physical and mechanical properties, and it can replace metal, ceramics, and other traditional materials in many specialty areas. Especially in reducing the quality, and improving performance contribution, PEEK has become one of the most popular high-performance engineering plastics. PEEK, which has good resistance to heat, can be used for a long time under 250℃, and the instant using temperature can reach 315℃. It is close to the metal aluminum material with rigidity, dimensional stability, and small linear expansion coefficient. PEEK has good chemical resistance, excellent resistance to acid, alkali and almost all organic solvents, flame retardant and anti-radiation properties. PEEK is resistant to sliding wear and fretting wear, even at high temperatures and low friction at 250 ° C. In addition, this material is easy to squeeze and injection molding. With this excellent comprehensive performance, PEEK has a wide range of applications in aerospace, machinery, petroleum, chemical, nuclear power, rail transportation and other fields. Even in the 200℃ of steam, its tensile strength, quality, and appearance do not occur significant changes can be long-term use. Under the action of high alternating stress PEEK has a good anti-fatigue,

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and long-term load resistance, good wear resistance, can be used for high-end machinery, nuclear engineering, and aviation technology.

Due to the excellent properties of PEEK in many aspects, PEEK will be used in more and more important areas. Compared with the traditional injection molding process, 3D printing has better flexibility, controllability, repeatability and other characteristics. Applying PEEK material to 3D printing technology will must be a development trend and have a high practical value. Compared with PLA, ABS and other materials widely used in 3D printing, PEEK has a higher melting point (334 ℃) and glass transition temperature (143 ℃), the continuous use of this material temperature can reach 260℃. Performance of most of the 3D printer is not enough to melt PEEK so we need to apply a nozzle which can adapt to 400 ℃ high temperature to solve this problem. At the same time, the temperature control of the 3D printer has a great influence on the precision of the printing. The temperature directly affects on the quality of extruded wire. The excessive temperature will cause the material flowing out of the print nozzle with too much residual temperature, it will affect the cooling and molding, also may affect the part has been solidification before through the heat conduction. If temperature is too low will affect the integration between the model.

In summary, how to achieve the precise control of temperature for printer nozzle will be the main content of this study. In this paper, fuzzy PID control will be used to control the system to a certain extent. Then we can make the nozzle squeeze out the PEEK material in its best molding temperature, realize the accuracy of the temperature control of the printer nozzle.

RESEARCH ON CONTROL ALGORITHM

PID Control

The PID control algorithm consists of the proportional unit P, the integrating unit I and the differential unit D. The flow chart is shown in Fig.1.

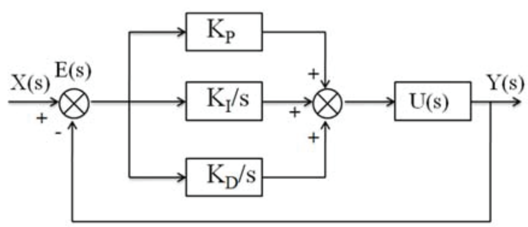

FIGURE 1. The PID flow chart

The PID control transfer function is;

$$U(s)=Y(s)/E(s)=k\ p\ [1+1/(TI*s)+TD*s] \tag{1}$$

Where TI is integral time constant and TD is differential time constant.

In the PID control, the proportional control P is the most basic control. And the proportional regulator P of the PID can speed up the system response, but it cannot guarantee the steady state and transient performance. Therefore, adding integral and differential control can meet the actual system of different control indicators, like PI control, PD control and PID control.

PI control: If the integral regulator I is added to the control, the system can be in the steady state when the reference input quantity R (t) equal with the controlled input Y (t). While the control amount u (t) does not change, can eliminate the steady-state error and improve the control accuracy. But the integral will increase the reaction time, and pure integral adjustment may make the control system unstable. So, for this reason, it cannot be used independently.

PD Control: If the integrator D is added to the control, the overshoot can be reduced while increasing the system damping. PD control can make the output reflect the error signal changes in the situation in advance, ahead of the effective correction signal to speed up the transient response, reduce the system over shoot. At the same time, the differential will interfere with the amplification and produce saturation phenomenon which may impact control of the implementing agencies, so this method does not apply to the situation where the noise is more serious.

The implementation of PID control in the computer is a method of numerical approximation. When the sampling period T is short enough, sum instead of integral, using difference quotient instead of differential. Making the PID discretization algorithm, we can make the following approximate transformation:

$$
\begin{aligned}
&t \approx kt \quad (k=0,1,2,\ldots) \\
&\int_0^t e(t)\,dt \approx T\sum_{j=0}^{k} e(jT) = T\sum_{j=0}^{k} e(j) \\
&\frac{de(t)}{dt} \approx \frac{e(kT)-e[(k-1)T])}{T} = \frac{e(t)-e(k-1)}{T}
\end{aligned}
\tag{2}
$$

Where T is the sampling period.

After digitization, the transfer function of the PID control can be expressed as shown

$$u(k)=K_p e(t)+K_i \sum_{j=0}^{k} e(j)+K_D[e(k)-e(k-1)] \tag{3}$$

Where k is the sampling number, k = 0, 1, 2, ...

U (k) is the computer output value at the kth sampling time;

E (k) is the deviation value entered at the kth sampling time;

E (k-1) is the deviation value entered at the (k-1)th sampling time;

Fuzzy control

Fuzzy control is an important aspect of the fuzzy set theory. It is a kind of computer numerical control based on the fuzzy set, fuzzy language variable, and fuzzy logic reasoning. It is a kind of control method based on the ambiguity of human thinking. The fuzzy logic control technology imitates the thinking way of human to accept inaccurate, incomplete information and carry out logical reasoning. It works with intuitive experience and heuristics thinking in technology that covers model-based systems. The method does not use a precise formula to represent a transfer function or a state equation, but rather a vague language control rule to describe the control process. Control rules are usually based on the experience of experts, so the basic idea of fuzzy control is to use the computer to achieve human control experience.

Fuzzy control system composition diagram is shown in Fig.2.

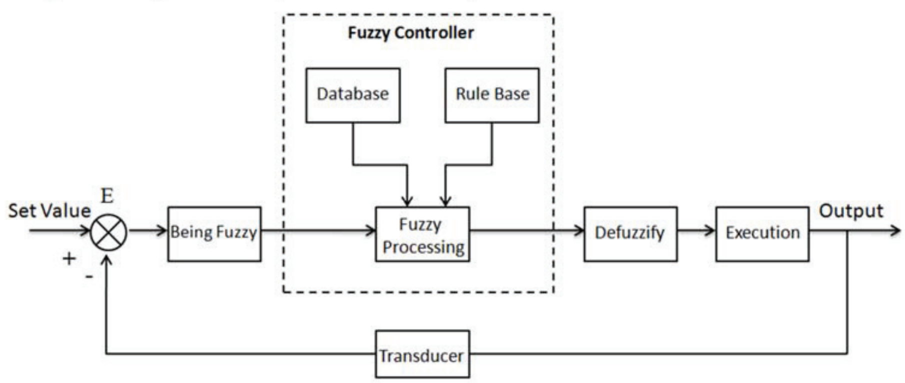

FIGURE 2. The fuzzy control flow chart

The implementation of the fuzzy control algorithm are as follows:

Firstly, actual value is sampled by computer. Secondly, the exact value obtained is compared with the given input value, the error signal e and the fuzzy value E are obtained, and the fuzzy vector subset is deduced. Finally, this subset is passed through the fuzzy rule of the synthesis rules and fuzzy relations with the fuzzy decision to get the output.

By observing Figure 2, it can be seen that the fuzzy control system in addition to the fuzzy controller, is almost identical to the conventional control system. As the core of the fuzzy control system, the fuzzy controller is also called fuzzy logic controller, reasoning algorithm, fuzzy decision, structure composition or fuzzy rules. Fuzzy logic controller not only affect the whole controlled process and the final control effect but also are the criterion of their performance indexes.

Fuzzy PID controller design

Fuzzy PID control is based on the PID control system, and involve to the fuzzy inference engine. This system take the system deviation and the deviation rate as the input of the fuzzy inference engine and make the correction value of the three parameters of the PID controller as output. It realizes the fuzzy PID control system structure according to the response analysis based on fuzzy reasoning and actual sampling to achieve fuzzy PID control to achieve high control effect. As shown in Fig.3.

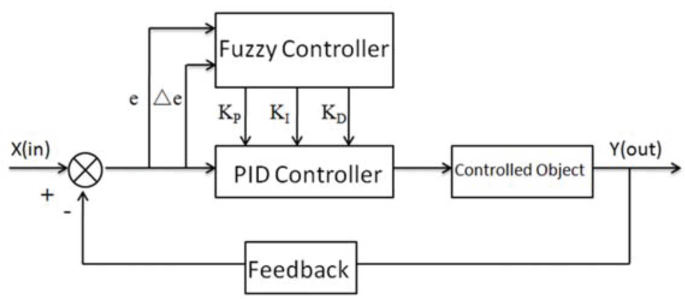

FIGURE 3. The fuzzy PID control flow chart

The composition of fuzzy controller

Being fuzzy

The input of the fuzzy interface receives only the error signal e, which is regenerated by the error change rate Δe or the integral of the error. The fuzzy interface needs to complete two functions:

The transformation in parameter domain: Both e and Δe are certained variables, their domain (the range of change) is a real domain, with a and b to represent respectively. In the fuzzy controller, the real range of values to be transformed into the fuzzy domain becomes A and B. Whether for D-FC (discrete fuzzy controller), or C-FC (continuous fuzzy controller), domain transformation after e and Δe becomes E and EC, which is equivalent to taking a scale factor (and possibly offset).

Being fuzzy: After the parameter domain transforms E and EC. Here they are divided into several fuzzy subsets, as shown in Table 1

TABLE 1. Fuzzy subsets

NL	NM	NS	Z	PS	PM	PL
Negative Large	Negative Medium	Negative Small	Zero	Positive Small	Positive Medium	Positive Large

The number of fuzzy sets can be changed according to the needs of the practical application. The more vague language variables, the more accurate the fuzzy control rules. But at the same time, it will increase the burden on the computer, and increase the complexity of the control rules.

The membership function is established by the characteristics of system and experience. There are no matures and effective method to establish the membership function, meanwhile the determination is very subjective.

For example, take the triangle curve as a membership function. As shown in Fig.4.

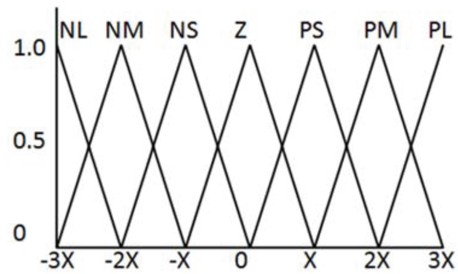

FIGURE 4. Triangle curve as membership function

Where the X corresponds to the error value and it needs to be determined according to the allowable temperature error range in the practical application.

The value of the input signals e and Δ e obtained by the universe after transformation of E and EC, and then E and EC can be obtained on each fuzzy set according to the definition of membership function, we put the value of the ordinary variable into a fuzzy variable value, and the fuzzy work is completed.

Database and Rule base

Database: The database was used to store the fuzzy, fuzzy reasoning, to disambiguate the relevant information, such as the domain transformation method and the input variable fuzzy membership of the membership function definition and so on.

Rule Base: The rules are used to store fuzzy controllers being based on the accumulation of human experience, which is a language representation of human intuitive reasoning. Fuzzy rules are usually composed of a series of machine languages, such as if, else, or.

Defuzzify

Defuzzify can be regarded as the inverse of the fuzzy process, which is a result of the fuzzy reasoning, as the output of the fuzzy controller. A certain input (E or EC) may meet a number of rules which need to use the solution fuzzy algorithm (commonly used with the maximum membership method, the center of gravity method, the median method, etc.) to solve the fuzzy domain control u(E) and u(EC). And then the results of the anti-transformation domain can be true control value.

Printer temperature control system

The printer temperature control system is a temperature loop for the main, including heating devices and temperature detection.

The temperature control of the micro controller input signal first comparing with the temperature of the feedback signal, calculate the error. Then the PID fuzzy controller gets the P, I, D three variables which can reduce the difference. Finally, the controller performs the operation to obtain the control amount of the input terminal which is required to eliminate the deviation. The current flowing through the heating device is controlled by the microprocessor to gradually eliminate the deviation. As shown in Fig.5.

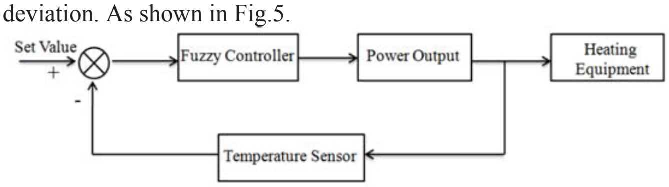

FIGURE 5. Temperature control system

CONCLUSION

At present, 3D printing has been a new processing and manufacturing industry with gradually highlighted advantages. And the Polyether-ether-ketone (PEEK), as a high-performance specialty engineering plastics, has a wide range of applications. If PEEK be used in 3D printing, which will certainly be a breakthrough in the processing technology and has a wide range of markets. Because PEEK has a high melting point, while the nozzle temperature control applied in the 3D printing technology will directly affect the product molding accuracy. In the process of PEEK materials of 3D printing, temperature control is very important.

In this paper, the fuzzy PID control algorithm, compared with other temperature control PID algorithm used in other 3D printers, theoretically improving the control accuracy in the printing nozzle temperature control, the temperature system inertia control, the temperature control lag adjustment and other fields. Due to the fuzzy PID control algorithm itself requires a lot of experimental data and accumulation of experience, can obtain the relatively ideal control results. So, in terms of different printing devices, the parameters in the algorithm need corresponding correction.

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