Comparison and Simulation of Tuning Methods for PID Parameters

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Abstract: Three different tuning methods for PID parameters were introduced. The tuning methods are as follows: Ziegler-Nichols method, ISTE optimization method and analytical method. PID controllers were designed and the dynamic performance indicators were analyzed through Matlab emulation for a critical damping second order system.

1. PID Controller Introduction

PID controller is the most commonly used controller in analog control system. The principle block diagram of analog PID control system is shown in Figure 1 [1].

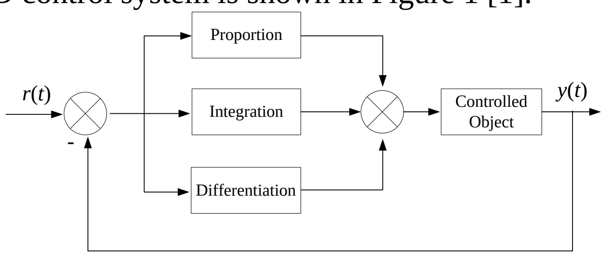

Fig. 1 Principle block diagram of analog PID control system

Deviation signal formed by control system given value r(t) and actual output value y(t):

$$e(t) = r(t) - y(t) \tag{1}$$

The control signal u(t) is formed by e(t):

$$u(t) = K_p(e(t) + \frac{1}{T_i}\int_0^t e(t)dt + \frac{T_d de(t)}{dt} \tag{2}$$

In equation (2), kp-proportional coefficient; ti-integral time constant; td-differential time constant.

Write the form of the transfer function:

$$D(s) = \frac{U(s)}{E(s)} = K_p(1 + \frac{1}{T_i s} + T_d s) \tag{3}$$

Increasing the proportional coefficient will generally speed up the response of the system and reduce the static difference. However, an excessively large proportional coefficient will cause the system to have a large overshoot and the stability will deteriorate.Increasing the integration time is beneficial to reduce the oscillation, but the system static elimination time becomes longer.Increasing the differential time is beneficial to speed up the response of the system and reduce the overshoot, but the system's ability to suppress disturbances is weakened.The essence of the tuning is to improve the dynamic and static indicators of the system by changing the parameters of the controller to achieve the best control effect.

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2. PID Controller Parameter Tuning Method

2.1 First-order Delay Model Approximation

Since the response curve of the process control model is similar to that of the first-order system, it can be directly fitted. Most PID controller algorithms are based on a first-orderlag plus delay (FOLPD).If the system unit step response curve appears to be an S-shaped curve, the object transfer function can be approximated as:

$$G(s)=\frac{K}{Ts+1}e^{-Ls} \tag{4}$$

In equation (4), k is the gain of the system, t is the time constant, and l is the pure lag time of the system.

2.2 Ziegler-Nichols (ZN) Tuning Method

$$\begin{cases} K_p = 1.2T/(K*L) \\ T_i = 2L \\ T_d = 0.5L \end{cases} \tag{5}$$

The zn method is an earlier method based on the frequency domain design of the PID controller. First approximate the resulting parameters in the first-order model (4), from empirical formula (5)[2]:

The parameters of PID controller can be adjusted. Some codes are as follows:

```
a=K*L/T;
Kp=1.2/a;Ti=2*L;Td=0.5*L;
G2=Kp*(1+tf(1,[Ti,0])+tf([Td 0],[Td/N 1]));
y=step(feedback(G*G2,1),t);
plot(t,y,'-.')
```

2.3 Iste Optimal Tuning Method

According to the optimal PID parameter tuning algorithm[1] of the setpoint signal, consider the optimal index formula given by equation (6):

$$J_n(\theta)=\int_0^{\infty}[t^n e(\theta,t)]^2 dt \tag{6}$$

The optimal index given in equation (6) generally considers three cases, namely n=0, abbreviated as ISE (integral squared error) criterion; n=1, abbreviated as ISTE criterion; n=2, shorthand For the IST2 E guidelines.

If the mathematical model of the known system is as shown in equation (3), an empirical formula can be established for a typical PID structure:

$$S_1 = |s_1| e^{j\beta} \qquad K_p=\frac{a_1}{k}\left(\frac{L}{T}\right)^{b_1}, T_i=\frac{T}{a_2+b_2(L/T)}, T_d=a_3T\left(\frac{L}{T}\right)^{b_3} \tag{7}$$

For different L/T ranges, the (a, b) parameter Table can be obtained as shown in Table 1.

Table 1 set point PID controller parameter Table

l/t range	a1	b1	a2	b2	a3	b3
0.1-1	1.042	-0.897	0.987	-0.238	0.385	0.906
1.1-2	1.142	-0.579	0.919	-0.172	0.384	0.839

The function getpid1.m is written, and the empirical data of the ISTE method is tabulated to determine six parameters such as a1 and b1. The calling format is as follows: [Kp, Ti, Td]=getPID1(T, L , k, key), where key represents the value of n.

2.4 Analytical Method

First, the position of the closed-loop dominant pole s1 is selected according to the performance index requirements.The root locus equation at s=s1 is:

$$D(s)G(s)|s=s1=-1 \tag{8}$$

Where G(s) is the transfer function of the controlled object, and s1 is expressed as:

$$S_1 = |s_1| e^{j\beta} \tag{9}$$

G(s1) is expressed as:

$$G(s_1) = |G(s_1)| e^{j\Psi} \tag{10}$$

Substituting equations (3), (9), and (10) into equation (8), the equation can be divided into two parts: the real part and the imaginary part.

$$K_p = -\frac{\sin(\beta+\Psi)}{|G(s_1)|\sin\beta} - \frac{2K_i\cos\beta}{|s_1|} \tag{11}$$

$$K_d = \frac{\sin\Psi}{|S_1||G(s_1)|\sin\beta} + \frac{K_i}{|s_1|^2} \tag{12}$$

among them $K_i = K_p/T_i, K_d = K_p * T_d$ The parameter ki is determined based on the steady state error.

The Matlab function of this method is analpid[3], and the calling format is: [KP, KI, KD]=analpid(G, ss, s1). Where G is the controlled object model and ss is the steady-state error required by the system. (in percent), s1 is the desired closed-loop dominant pole.Calling this function will return the three parameters of the PID controller Kp, Ki, Kd, and then calculate Ti, Td, the call file is analyze.m, part of the code is as follows:

```
[KP,KI,KD]=analpid(G,ss,s1)
D=tf([KD,KP,KI],[1 0])       % get the open-loop transfer function
Go=D*G                       % join controller
Gc=feedback(Go,1)
[Y,t]=step(Gc,N)             % gives the step response curve
plot(t,Y,'-')
```

3. Simulation Examples

Assuming that the transfer function model of the controlled object is G(s)=1/(s+1)^2, the first-order approximation result of the model is first obtained by the function getfolpd.m:

$$G(s) = \frac{1.008}{1+1.639s} * e^{-0.464S} \tag{13}$$

The three parameters obtained by approximating the first-order model in equation (13) are k=1.008, t=1.639, and l=0.464.For the critically damped second-order system, the PID controllers designed by the above three methods are respectively added. The unit step response curve is shown in Fig. 2.

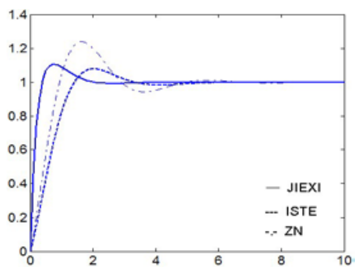

Figure 2 Unit step response of the system under the action of three PID controllers

Table 2 shows the parameters obtained by the three PID tuning methods and the dynamic performance indicators of the system.From the data, the characteristics of various tuning methods are known.The zn method has the largest overshoot, while the analytical method has a very fast response and a slightly higher overshoot. The iste method has the smallest overshoot but a slower response.

Table 2 Parameters and system dynamic performance indicators of each PID tuning method

Setting method	Kp	Ti	Td	Peak time tp/s	Adjustment time ts/s	Overshoot σ%
Z-N	4.2052	0.9280	0.2320	1.61	3.82	24.4
ISTE	3.2064	1.7822	0.2011	2.02	2.56	7.97
Analytical method	17.1421	0.8571	0.3400	0.76	1.41	11.3

4. Conclusion

There is less information on the dynamic process in the zn method, which makes the system generate strong oscillations when the set point is controlled.The iste method and the analytic method also have the characteristics of easy implementation method and simple program. The performance of the closed-loop system has its own advantages and disadvantages. The main disadvantage is that the transfer function of the controlled object must be known.

It can be seen from the above analysis that the rapidity and stability of the control system are mutually constrained, and it is necessary to make a compromise according to the actual situation.The above only selected three PID parameter tuning methods for comparison, although not comprehensive enough, but with a certain representative and reference value.

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