Research and simulation analysis of an Electric-Servo-Actuator system

Shuping Li and Zhongxing Yan
Suzhou Industrial Park Institute of Services Outsourcing, Jiangsu Suzhou 215123, China, No 99, Ruoshui Road, Suzhou industrial park
Email: lis@siso.edu.cn

Abstract. In this paper a kind of missile Electric-Servo-Actuator system is studied, using Matlab Simulink software to electric servo system is analyzed in the modeling and simulation. The system is superior to conventional PID controller with the fast and accurate response, small overshoot, good dynamic performance and steady-state performance. The adopted (fuzzy) PID control parameter design to improve the response and signal tracking performance of the system has the guide meaning to the design of the actual system.

1. Introduction
Missile steering engine is an important part of missile flight control system and also a actuator of the missile control system. In the air a missile that in a certain flight trajectory relies on steering engine drive control surface to deflection correction course at any time to achieve, and the stand or fall of its performance directly affects the discretion of the missile performance[1]. Steering engine system is a high precision position servo system, the working principle of which accepts the declination angle signal of the control surface given by guidance computer., and use it’s output command to control the deflection of the missile control surface, in order to achieve the purpose of missile flight trajectory control[2]. The controller is the most important part of steering engine system, which influences the quality of the steering engine system[3]. A steering gear system with good performance is expected.

2. Composition and Mathematical Model of Steering Servo System
The steering servo system is an integral part of missile system, and the characteristics of its directly affects the performance of the missile. The essence of the steering system is a typical position servo system[4]. When the steering gear system works normally, steering controller accepts the rudder surface deflection signal from guidance computer, meanwhile, feedback real-time angle of the rudder surface to guidance computer. In case the system is a failure in the accident, steering controller accept guidance computer security instructions, drive the rudder surface deflection according to the established deflecting angle, and cooperate with ammunition self-destruct action to achieve protection function[5]. This system requires fast, accurate, small overshoot, good dynamic performance and steady-state performance. Therefore we can use the position loop, speed loop and current loop to compose the closed control system. The underlying working principle is that the projectile control instruction after the controller integrated amplifier, driven DC servo motor by actuator, then pass the movement and torque to the steering shaft through reducer , drive the rudder surface deflection, control the projectile flying until hitting their targets[6-8]. we can get the whole servo system block diagram as shown in figure 1.ACR in the picture means the current loop controller, ASR said speed loop controller, APR said position loop controller. The design process is according to the requirements of the system performance index, starting from the inner loop to outward design step by step.
Figure 1. Mathematical model of steering gear system

3. Fuzzy PID Control Principle
Fuzzy PID controller is added a fuzzy control rules on the basis of general PID control system, an adaptive control system using the fuzzy control rules to modify the PID parameters online. A fuzzy PID controller according to both static performance (is above or below a given value) and dynamic performance (is close to or deviates from the given value) of the controlled object response, depends on the current situation, also look at trends. Its algorithm process is using the rule set corresponding to make control indicators (conditions) blurred, then it matches with the fuzzy rules in the knowledge base, if there are any rules are matched, execute the result part of the rule, they can get the corresponding parameter adjustment. The new controller can get appropriate $K_p$, $K_i$, and $K_d$ parameters automatically by itself[9].

3.1. Input and Output Variables are Blurred
In this control system, the input is the rudder angle error $E$ and error change rate of EC, the output is the parameters after fuzzy inference and parameter correction, $\Delta K_p$, $\Delta K_i$, and $\Delta K_d$. Since that the amount of deviation and change rate of deviation are accurate, it is necessary to be blurred and changed into the elements of setting integer fields. Each fuzzy variables is divided into seven fuzzy state, including NB(negative-big), NM(negative-medium), NS(negative-small), ZE(zero), PS(positive-small), PM(positive-medium) and PB(positive-big).

The fuzzy domain of $E$ and $EC$ quantificat 7 level, all domain are continuity interval [-2, 2]. The error of the rudder angle allowed range is [-0.2, 0.2], that is the basic domain of error $E$ and the basic domain of error change rate $EC$ are [-2,2], the quantification factor of angle deviation is $ke=2/0.2=10$, the quantification factor of angle deviation change rate is $kec=2/2=1$.

The fuzzy domain of $\Delta K_p$, $\Delta K_i$ and $\Delta K_d$ also quantificat 7 level, the domain are continuity interval [0 25], [0 10], [0 7]. Through calculation and test, and according to the $K_p$, $K_i$ and $K_d$ three parameter sensitivity, declare theirs basic domain as [0 0.04], [0 0.01], [0 0.006]. So the scale factor of the output variable $\Delta K_p$, $\Delta K_i$ and $\Delta K_d$ respectively is 0.04/25=0.0016, 0.01/10=0.001 and 0.006/7=0.00086.

3.2. Membership Function
After the fuzzy sets and domain of error $e$ and error change rate $ec$ and control quantity are confirmed, it is necessary to determine the membership function of fuzzy variables. Reference input and output variables, usually use Gaussian membership functions that have low resolution in the area that have larger error, use triangle membership functions that have high resolution in the area that have little error.

3.3. Rule of Fuzzy Control
According to the parameters $\Delta K_p$, $\Delta K_i$ and $\Delta K_d$ effect the output characteristic of the system, can
generalize a conclusion that system have automatic setting principle for different deviation, the deviation change rate, $K_p$, $K_i$, and $K_d$ in the controlled process. According to the different error and error change rate on the PID three parameters of the requirements and principles, the fuzzy rules of $\Delta K_p$, $\Delta K_i$, and $\Delta K_d$ with E and EC as shown in table 1 to 2.

| $\Delta K_p$ | $\Delta K_i$ |
|--------------|--------------|
| E | NB | NM | NS | Z | PS | PM | PB |
| NB | PB | PB | PM | PM | PS | Z | Z |
| NM | OB | PB | PM | PS | Z | NS | NS | Z | Z |
| NS | PM | PM | PS | Z | NS | NS | NS | Z | Z |
| Z | PM | PM | PS | Z | NS | NM | NM | Z | PS | PS | PM | PM |
| PS | PS | PS | Z | NS | NS | NS | NS | Z | PS | PS | PM | PM |
| PM | PS | Z | NS | NM | NM | NM | NB | PM | Z | Z | PS | PS | PM | PB | PB |
| PB | Z | Z | NS | NM | NM | NB | NB | PB | Z | Z | PS | PS | PM | PB | PB |

| EC | E | NB | NM | NS | Z | PS | PM | PB |
|----|---|----|----|----|---|----|----|----|
| NB | MB | PS | NS | NB | NB | NB | NM | PS |
| NM | PS | NS | NB | NM | NM | NS | Z | |
| NS | Z | NS | NM | NS | NS | NS | Z | |
| Z | Z | NS | NS | NS | NS | NS | Z | |
| PS | Z | Z | Z | Z | Z | Z | Z | |
| PM | PB | NS | PS | PS | PS | PS | PB | |
| PB | PB | PM | PM | PM | PS | PS | PB | |

3.4. Solution of Fuzzy Output

By the fuzzy reasoning can get the fuzzy quantity of corrected parameter $\Delta K_p$, $\Delta K_i$, and $\Delta K_d$. But fuzzy quantity cannot directly control the controlled object, at the time of actual operation need a precise value to control the controlled object. So, in order to get accurate value of the output, need to decision out an exact precision by the reverse-fuzzy method. The design uses the default solution of fuzzy method of fuzzy toolbox. After fuzzy solution, get precise adjustment output of $\Delta K_p$, $\Delta K_i$, and $\Delta K_d$, the 3 D map as shown in figure 2 a, b, c, respectively.
The determination of PID parameters in two steps, the first step is determine the initial PID parameters that is $\Delta K_p, \Delta K_i$ and $\Delta K_d$. The three parameters have been confirmed in the previous chapter. The second step is automatically correct the initial PID parameters based on the parameters of the initial value, according to the fuzzy reasoning and precise adjustment $\Delta K_p, \Delta K_i$ and $\Delta K_d$ of each parameter, calculation formula is:

\[
\begin{align*}
K_p &= K_{p0} + k_p \times \Delta K_p \\
K_i &= K_{i0} + k_i \times \Delta K_i \\
K_d &= K_{d0} + k_d \times \Delta K_d
\end{align*}
\]

(1)

of which: $K_p, K_i$, and $K_d$ is the scale factor of parameter correction $\Delta K_p, \Delta K_i$ and $\Delta K_d$ of which, $K_{p0}, K_{i0}$ and $K_{d0}$ are three parameters of the PID controller. $K_p, K_i$ and $K_d$ are the correction coefficients. Now the fuzzy PID controller has been designed, save the designed fuzzy rules of the kit finally, it can get a FIS file, which is a designed fuzzy PID controller.

4. Simulation and Analysis by MATLAB
The sampling time is 1ms, the input signal of the system is the unit step response, in the 300th sampling time, that is 0.3 s, join a disturbance in the system, then make the system simulation. Figure 3 is control error response, figure 4 is the output response of the fuzzy PID controller.

![Figure 3. The error response of the fuzzy PID control](image-url)
Figure 4. The output response of controller

After joining interference, the adaptive adjustment of proportional, integral and differential coefficient $K_p$, $K_i$ and $K_d$, respectively, as shown in figure 5(a)(b)(c).

By the above three figure can be seen, after joining a size of interference on the system in the 0.3 s, after fuzzy PID control of M as the control signal respectively made a spontaneous, different degrees of adjustment, and finally tends to another stable value again. This shows, when the system is disturbed, a fuzzy PID controller can adjust the proportion, integral, differential coefficient spontaneously with interference tend to the optimal portfolio, so as to improve the anti-interference ability of the steering system.

And after being disturbed, $K_p$, $K_i$ and $K_d$ quickly become larger. $K_p$ and $K_i$ recover to a new stable state after 0.2 s, and $K_d$ only recovers to a new stable value within 0.05 s. It can be seen that the PID fuzzy controller can restore the steady state in a very short time, and has a fast response capability and excellent dynamic performance.
Figure 5. The adaptive adjustment of $K_p$, $K_i$, $K_d$

5. Conclusion

This paper presents a missile electric steering gear system, and uses Matlab-Simulink software to carry on the modeling and the simulation analysis. The simulation results show that the proposed fuzzy PID control parameter design not only improves the response and signal tracking performance of the system but also changes it into small overshoot, good dynamic performance, steady-state performance and the ability to improve anti-interference, which is of great significance to the design of the actual system. And the results also show that the three parameters can have automatic adjustment in fuzzy PID controller properly. The expected system had become reality.

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