Research on parameter adjustment method of servo controller based on genetic algorithm

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Abstract: In view of the problem that the controller parameters of the servo system of launch vehicle cannot be adjusted after installation, the parameter adjustment method of the servo system controller parameters is designed by the optimization method based on the genetic algorithm. Set the scale, the notch frequency and the damping coefficient as the variable to be adjusted. The adjusted ITAE guideline module is the error criterion, and the notch filter parameters are adjusted. The experimental verification results of servo system simulation test bench show that the method of this paper can effectively optimize the parameters of servo system controller and improve the quality of servo system.

1. Introduction.

The servo system is the executive mechanism of the launch vehicle engine, which is used to control the angle of the engine nozzle, thus controlling the flight direction of the launch vehicle. The control performance of servo system directly affects the stability of the launch vehicle and the accuracy of the orbit. However, the rocket engines have the characteristics of high inertia and low structural strength, which brings problems such as resonance, phase hysteresis, and slow attenuation of high frequencies [1] In order to solve the above problems, the researchers used proportional plus notch filter control to reduce phase lag, suppress resonant peaks, and achieved good control effect [2]

However, in the existing design, the controller parameters do not change once they are determined, and all servo controllers use the same set of parameters. Although the design is stable and reliable, the parameters of each servo are slightly different and the parameters of the engine are different. Control of the servo system and the production of servo valves create some difficulties:

First, a number of products due to the use of unified control parameters, control parameters to take into account each product, there is a small gain and wave limit frequency and the actual existence of a larger deviation problem, resulting in low final control characteristics, small margin;

Second, the determination of control parameters is the use of the production plant engine, the engine and vehicle-mounted engine characteristics are biased, will lead to a further reduction of the control balance;

If the parameters of the notch filter controller can be adjusted according to the parameters of the specific servo system after the servo system is installed in the launch vehicle, the control effect will be better.

After the servo system is installed in the launch vehicle, there are several limitations to adjust the controller parameters: first, the time of controllable adjustment of the controller parameters is limited, the adjustment speed has to be fast.
In order to solve the above difficulties, this paper combines the identification model of the servo system with the optimization method based on the genetic algorithm, and researches the method of adjusting the controller parameters after the servo system is installed in the launch vehicle.

2. Establish servo system identification model

The servo system cannot be tested after installed in the launch vehicle, and adjusting the controller parameters needs to rely on the model of the servo system after installed for simulation. System identification method only rely on input and output data. Can be very convenient to obtain the mathematical model of the servo system. In this paper, the model of servo system is established by method of system identification.

2.1. Identification scheme design

According to the requirements of the research content of this paper, it is necessary to adjust its identification parameters after the servo system installed, and adjust its controller parameters according to the adjusted identification parameters. There are two requirements implied here: first, the servo system needs to refer to the previous identification and control parameters; second, the parameters of controller and model need to be adjusted online.

Combining the above requirements with the electro-liquid servo system block diagram in Figure 1, the identification data, identification model and identification method of this study are designed[3].

The identification model uses the ARX[441] model[4], which has a model structure of formula (1).

style,

\[ A(z^{-1}) y(k) = B(z^{-1}) u(k) + v(k) \]  

\[ A(z^{-1}) = 1 + a_1 z^{-1} + a_2 z^{-2} + a_3 z^{-3} + a_4 z^{-4} \]  

\[ B(z^{-1}) = b_1 z^{-1} + b_2 z^{-2} + b_3 z^{-3} \]  

The parameter matrix is to be identified. \( \theta = [a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4] \)

The identification method uses the least square (LS) to identify the initial value, and the online method of adjusting the identification parameters using forgetting factor recursive least square (FFRLS)[5]. The parameter estimation formula for the forgetting factor recursive least square is:

\[
\hat{\theta}(k) = \hat{\theta}(k-1) + K(k)[y(k) - h^T(k)\hat{\theta}(k-1)] \\
K(k) = \frac{P(k-1)h(k)}{\lambda + h^T(k)P(k-1)h(k)} \\
P(k) = \frac{1}{\lambda}[I - K(k)h^T(k)]P(k-1)
\]  

(3)

The scope of the forgetting \( \lambda \) factor is usually taken. \( 0.95 \leq \lambda \leq 1 \) Take the performance indicator as:
\[ J = \sum_{k=1}^{L} \lambda^{L-k} [y(k) - h^T(K)\hat{\theta}]^2 \]  

(4)

2.2 Identification results and validation.
According to the experimental scheme designed, the results are as follows using the MATLAB/Simulink experiment.

First of all, the electro-liquid servo system is identified offline by using LS, and the identification result system model and error are shown in Figure 2.

![Figure 2. The LS identifies the output and errors.](image)

The output standard error is calculated to be 0.0649 and the maximum error is 0.1956. The fit of the system output and the identification model output is evaluated by a determining factor of 90.88%. Accuracy meets design needs.

After that, the identification model parameters are used as the initial value, and the online identification in the vehicle state is carried out using FFRLS. After installed in the launch vehicle, the servo system parameters will change due to load changes. The output of the identification model is shown in Figure 3.

![Figure 3. The FFRLS identification output.](image)
The standard error of the dialectic model is 0.0464, the maximum error 0.1239, and the decision factor is 93.59%. Accuracy meets design needs.

3 Controller parameter adjustment scheme

The servo controller parameter adjustment process is shown in Figure 4, after the online identification model of the servo body is obtained by chapter 2, the original controller parameters are the initial value, the online model of the solved servo is the servo system model, and the controller parameters are solved and analyzed using the optimization algorithm based on genetic algorithm to obtain the optimal controller parameters.

![Diagram of controller parameter adjustment process](image)

**Figure 4. The servo controller parameter adjustment process.**

To take into account the two variables of line displacement and angular displacement, the criterion function of the optimization algorithm uses the integrated time absolute error (ITAE), in the form of.

$$J_{ITAE} = \int_{0}^{\infty} t |e_a(t)| + |K_b e_b(t)| dt$$  \hspace{1cm} (5)

Where, $e_a(t)$ is the line displacement error, the $e_b(t)$ angular displacement error, and the $K_b$ weight of the angular displacement error.

The adjustment method uses a genetic algorithm[6] The parameter module to be adjusted can be represented as

$$K_a = \frac{s^2 + 2 \xi_a \omega_a s + \omega_a^2}{s^2 + 2 \xi_b \omega_b s + \omega_b^2}$$

$$K_b = \frac{\omega_a^2}{\omega_b^2}$$

$$K_{ss} = \frac{\omega_a^2}{\omega_b^2}$$

Where, $K$ is the scale, $\omega_a, \omega_b$ are the notch frequency, $\xi_a, \xi_b, \xi_c, \xi_d$ are the damping coefficient.

Set the scale $K$, the notch frequency, $\omega_a, \omega_b$ the damping $\xi_a, \xi_b, \xi_c, \xi_d$ coefficient as the variable to
be adjusted, the adjusted ITAE guideline module is the error criterion, and the notch filter parameters are adjusted.

4. Experimental validation and analysis.

4.1 MATLAB/Simulink simulation experiment.
(1) Experiment 1: Optimize the controller parameters.

The model angular displacement output under the control of the original parameters is shown in Figure 5a, and the model output after adjusting the control parameters is shown in Figure 5b, which shows that the overshoot of the model output after adjusting the control parameters is better than the original control parameters.

![Figure 5. The angular displacement of the system under the control of the original parameters(a) and the angular displacement of the system under the adjusted parameters(b).](image)

The angular displacement output error of the system under the control of the original parameters is shown in Figure 6a, and the angular displacement output error of the system under the control of the adjusted parameters is shown in Figure 6b. The original control parameter system over routed 37.99%, the standard error was 0.5688, the maximum error was 2.735, and after adjusting the control parameters, the system over routed 21.24%, the standard error was 0.5342, and the maximum error was 2.463. It can be seen that after adjusting the control parameters, the over simulation of the system is greatly reduced, the error is also reduced, and the adjusted parameters are better than the original parameters.

![Figure 6. Original parameter angular displacement output error(a) and Adjusted parameter angular displacement output error(b).](image)

The frequency characteristics of the system are further tested by the sweep signal. Figure 7 shows the frequency characteristic curve of the system under the control of the original parameters and the frequency characteristic curve of the system under the control of the adjusted parameters. Because the
original parameter not accurate and the depth of the not enough, cannot suppress the first resonant peak very well, the second resonant peak with the suppression but not accurate enough, and after adjustment parameters not accurate, the depth of the notch is more reasonable, can add a larger proportional value to the controller. While the amplitude characteristics have improved slightly, the low frequency phase characteristics have been greatly improved, and the adjusted parameters are more reasonable.

Figure 7. The frequency characteristic curve of the system under the control of the original and adjusted parameters.

(2) Experiment 2: Change the flow gain of the servo valve.

Reduce the servo valve flow gain by 10%. The frequency characteristic curve of the system under the original controller parameters is shown in Figure 8(3).

Figure 8. Frequency characteristics of the servo system after reducing the gain of the servo valve.

Reduce the flow gain of the servo valve, the controller parameters remain unchanged, the amplitude and phase frequency curves are reduced, and the phase frequency characteristics are reduced.

The system frequency characteristics are shown in Figure 9 after adjusting the controller parameters.
As can be seen from Figure 9, the control system after adjusting the controller parameters can basically achieve the control effect before the parameters of the servo mechanism change. This is due to the servo valve flow gain decreased, the servo system resonant peak frequency changes little, but the overall curve moves down.

4.2 Rocket engine simulation test bench experiment

After using MATLAB/Simulink simulation, experiments are conducted using a simulation test bench[8]. The experimental equipment includes a rocket engine simulation test bench, servo controller, stand-alone test system and load control system. In order to test the controller parameter adjustment ability of the servo valve flow gain is different, four different servo valves are selected here to be installed on the servo mechanism, according to the design of the experimental scheme, to carry out experiments. The results of the experiment are shown in Figure 10.
You can see that the designed control method can adjust the controller parameters for different servo systems. The amplitude frequency characteristics of the adjusted controller parameters are not much different from the original controller. But because of more accurate notch frequencies and more reasonable notch depth, the ratio coefficient of the controller is larger, and the phase lag is reduced while raising the phase, which greatly improves the phase frequency characteristics. The adjusted controller phase frequency characteristic is obviously better than that of the original controller, which meets the performance index. It provides a greater degree of stability to the system, which will effectively improve the stability and reliability of the launch vehicle operation.

5. Conclusions
This paper analyzes the problems of servo system control and the shortcomings of the current use of the notch filtering control algorithm. On the basis of the existing notch filtering algorithm, the control method of adjusting the parameters of the notch filter controller is proposed by using the optimization method based on the genetic algorithm. Combining the intelligent algorithm with the traditional control method not only plays the advantages of the intelligence algorithm to find the best and accurate, but also retains the advantages of the stability and security of the traditional control method. At the same time, the standard function of the optimization algorithm suitable for the servo system on vehicle is developed. Finally, a set of methods for adjusting the servo control parameters of the current rocket measurement process is designed: the model after the servo system installed in launch vehicle is obtained by system identification, the controller parameters are calculated offline using the computing power of the ground computer, and then the adjusted parameters are entered into the servo controller. This problem is solved that the controller parameters of the traditional design method are fixed and the overall performance is not optimized enough. The research content of this paper is verified by using the servo system simulation test bench, and the simulation results show that the method of this paper can effectively improve the controller parameters of the notch filter.

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