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Study on Control Strategy of Electro-Hydraulic Servo Loading System

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Abstract

Since extraneous torque is the key factor to affect the accuracy of electro-hydraulic servo loading system, the forming mechanism of extraneous torque was discussed in this work. And then several design methods of loading system controller based on modern control theory were introduced, such as internal model control, Cerebella model articulation control and adaptive backstepping control.

Keywords: *loading system, extraneous torque, modern control strategy*

1. Introduction

The function of aircraft electro-hydraulic servo loading system is to record the loading of rudder during the flight in the ground experiment and hardware in the loop simulation [1-5]. And the main problem of that loading system is because of the existence of extraneous torque during dynamic loading. The extraneous torque seriously affects the accuracy of the loading system. In the past twenty years, researchers have done a lot of work on overcoming the extraneous torque, and obtained certain achievements [6-11]. However, with the development of national defense, higher and higher tracking accuracy is required of the electro-hydraulic servo loading system. The design based on hardware correction and traditional control method could not satisfy the accuracy requirement of the loading system. Therefore, the forming mechanism of extraneous torque, and several design methods of loading system controller based on modern control theory were introduced in this work.

2. The Forming Mechanism of Extraneous Torque

The hydraulic motor is mainly adopted as the actuator of the aircraft electro-hydraulic servo loading system. The input and output expression of the actuating unit of the loading system is [12]:

$$T_g = \frac{\dfrac{K_q D_m}{K_{ce}} X_v - \dfrac{V_m J}{4\beta_e K_{ce}}\theta_d s^3 - (J + \dfrac{V_m B_c}{4\beta_e K_{ce}})\theta_d s^3 - (\dfrac{D_m^2}{K_{ce}} + B_c)\theta_d s}{\dfrac{V_m J}{4\beta_e K_{ce} G} s^3 + (\dfrac{J}{G} + \dfrac{V_m B_c}{4\beta_e K_{ce} G}) s^2 + (\dfrac{D_m^2}{K_{ce} G} + \dfrac{B_c}{G} + \dfrac{V_m}{4\beta_e K_{ce}}) s + 1} \quad (1)$$

In the aircraft simulation experiments, the loading system is tracked with the torque signal, namely T_g is changed with X_v. In this formula, the first item of numerator is the required amount of the loading system to ensure the loading torque. It could be also seen that the other parameters are related to the rudder, which means that the output of loading system T_g is still related with the location signal θ_d . While the torque is imposed to rudder by the loading system, the loading system was seriously interfered by the location signal of the rudder, namely the extraneous torque of electro-hydraulic servo loading system. The expression of the extraneous torque of the loading system could be seen as followed, after decomposition of Equation (1) above.

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$$T_{\theta_d} = \frac{-\frac{V_m J}{4\beta_e K_{ce}}\theta_d s^3 - (J + \frac{V_m B_c}{4\beta_e K_{ce}})\theta_d s^3 - (\frac{D_m^2}{K_{ce}} + B_c)\theta_d s}{\frac{V_m J}{4\beta_e K_{ce} G} s^3 + (\frac{J}{G} + \frac{V_m B_c}{4\beta_e K_{ce} G}) s^2 + (\frac{D_m^2}{K_{ce} G} + \frac{B_c}{G} + \frac{V_m}{4\beta_e K_{ce}}) s + 1} \quad (2)$$

From the above formula, it can be seen that the extraneous torque is not only related with the location of the rudder, but also with the velocity, accelerated velocity and jerk.

3. The Modern Control Strategy of Loading System

The traditional PID control mode can not well satisfy the loading system with time-varying parameters [13]. The structure uniformity principle is simple and easy, widely used as the control method in the development of the traditional electro-hydraulic servo loading system. However, since the high-order differential term of compensation is always simplified as the constant, the structure uniformity principle could not meet the design requirement of the high accuracy loading system. With the development of modern control strategy, some new methods were applied to the electro-hydraulic servo loading system, highly improved the accuracy and stability.

3.1. Internal Model Control Method

Internal model control algorithm, introduced by Garcial in 1982, is a simple and convenient control method. Designers can employ this method without understanding its interior mechanism and modeling process. The measured or estimated impulse response is used as model, and the extraneous torque is restrained or eliminated by the internal model controller [14-15]. When designing the internal model controller, the first step is to design a stable ideal controller without consideration of the model error and constraints. The second step is to introduce a feedback filter at the feedback loop at the appearance of model mismatch or interference [15]. The simulation and experimental results show that over 80% of the extraneous torque can be eliminated by operating internal model compensation to the loading system and the system tracking accuracy is obviously improved.

3.2. Cerebella Model Articulation Control Method

Cerebella model articulation control (CMAC) method is the outcome of the combination of neural network theory and control theory, and it broke a new path to solve the control problem for a system with complex nonlinearity and uncertainty. Literature shows that there are several ways to operate Cerebella model articulation control, such as CMAC, RBF, DRNN and RTRNN [16-19]. In this paper, the CMAC method is discussed in detail since its control mechanism is simpler and more effective compared to others [20-21].

CMAC learns from the working principle of the cerebellum, and is a partial neural network model based on table lookup input and output. The advantages of CMAC include partial learning, changing table content by studying algorithm, and the ability of information classification and storage. It reduces the correction weights by storing information into partial structures. Its learning is fast, and it is suitable for real-time control system while maintaining good performance of approximating nonlinear function.

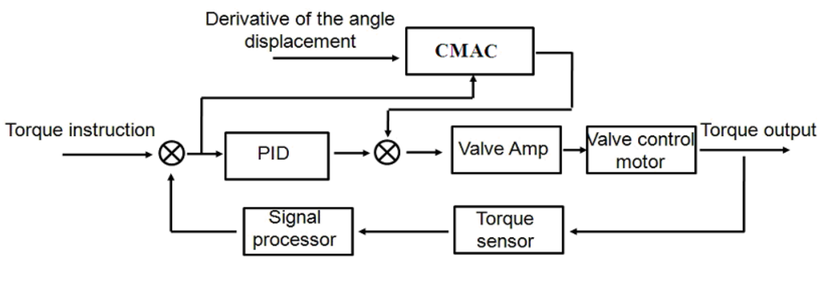

Figure 1. The Working Principle of the Extraneous Torque Compensator in CMAC

Figure 1 shows the working principle of the extraneous torque compensator in CMAC. The algorithm is a tutorial system, and it calculates u_{bcq} at the end of each control cycle. The sum of u_{bcq} and the PID output is the system input control signal, which is u. The total output of the control system is mainly produced by the extraneous torque compensator. From this point of view, the control algorithm makes use of the extraneous torque to improve the system dynamic characteristics.

Below are the main equations of the control algorithm.

$$u_{bcq}(k) = \sum_{i=1}^{c} w_i a_i \tag{3}$$

$$u_{pid}(k) = K_P ER(k) + k_I \sum_{j=0}^{k} ER(j)T + K_D \frac{ER(k) - ER(k-1)}{T} \tag{4}$$

$$u = u_{bcq} + u_{pid} \tag{5}$$

Where, a_i is the binary selection vector; w_i is the CMAC network weight coefficient; c is the CMAC network generalization parameter; T is the sampling control time; $ER(k)$ is the current sampling error; $ER(k-1)$ is the previous sampling error.

The CMAC control method, which takes advantage of the self adaptive control ability of neural network, eliminates the interference of speed and acceleration in the loading actuator, and overcomes the influence of the nonlinear and time-varying parameters and perturbation in the hydraulic system. Therefore it can greatly reduce the extraneous torque with good robustness.

3.3. Backstepping Self Adaptive Control

Backstepping self adaptive control is widely used in hydraulic servo control, motor control and other relative areas. According to the system characteristics of strong coupling interference, B. Zhang proposed a backstepping self adaptive controller considering the variation of parameters for the electro-hydraulic loading simulator [12, 22-25]. The design idea of backstepping self adaptive controller is to decompose a complex high order system into several low order simple subsystems, and design controller for each subsystem respectively. Then the coupling term though each subsystem is iterated into the final controller. In the design of the controller, the variation of the system parameters must be taken into account, as long as the adaptive rate of the parameters. The backstepping self adaptive controller was studied in detail under different condition in [12], which shows that it can restrain the extraneous torque effectively and improve the system loading property.

4. Conclusion

The suppression of the extraneous torque is one of the key technologies in the electro-hydraulic servo loading system design. For the design of modern high accuracy loading systems, the influence of the parameter variation on control accuracy must be taken into consideration. The control strategies introduced in this paper can restrain the extraneous torque in an electro-hydraulic servo loading system with time varying parameters, and therefore, the property of the loading system is improved greatly.

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