

The Design of Adaptive Control System of Electric Load Simulation System

CHEN Hao¹, WU Dingding², RAO Guoxi³, ZHAO Xuchang⁴

^{1,2}College of Mechanical and Electrical Engineering, Southwest Petroleum University, Sicuan Chengdu 610500

^{3,4}College of Mechanical, Beijing Jiaotong University, Beijing 100044

Abstract: This paper introduces the ELSS and analyses the structure and working principle of the ELSS. The numerical model of the electric load simulation system is established in this paper. On the basis of it, an adaptive control system is designed to suppress the surplus torque of the system. We obtain the adaptive laws of the system. Finally, through the numerical simulation results verify the validity of the control method.

Keywords: ELSS, surplus torque, design, adaptive control, numerical simulation

1. Introduction

Load simulation system, can be applied to simulating the load spectrum of air hinge moment of aircraft's control surface under ground experiment conditions^[1]. Furthermore, electric load simulation system(ELSS) has been widely applied in small and medium-sized or highly accurate simulation owing to its rapid response, control agility and high loading precision^[2].

Electric load simulation system is a typical passive torque servo system loaded by the mutual torsion of loading motor and steering gear, in which the rotation of steering gear will have a significant impact on load torque and its resultant torque is called surplus torque. Therefore, the problem that suppressing the surplus torque in ELSS is needed to be addressed as a matter of urgency. Nowadays, a lot of researching results has been produced in the studies on that problem at home and abroad, in which introducing the feed-forward controller into the system based on the structure invariable principle is considered as a relatively effective way^{[3]-[4]}. However, this kind of compensation is entirely dependent on an exact numerical model in the interference link. In some system with operating mode changes, it cannot achieve the effective suppression^[5]. Also, there are other methods to solve the problem such as

position synchronization, optimum control and robust control^{[6]-[13]}, all of which have certain limitation more or less and cannot be applied effectively on actually engineering project.

In this paper, a designed method that can automatically adapt to the disturbance torque at the inhibition location based on feed-forward control and adaptive control principles will be introduced. This method can make the system adjust the parameters of controller with self-adaptation and suppress the disturbance of surplus torque to improve the output accuracy of torque in the system on condition that actual system parameters change slowly or are unknown partly. By the results of numerical simulation simulation, the effectiveness of this adaptive control system has been confirmed as well in this paper.

The Principle and Numerical Model of ELLS

In the loading process of steering gear, torque sensor collects the torque values that are actually loaded on bearing rudder shaft. In the same time, encoder collects the collected torque values and steering angles, computer will be ordered to calculate the given torque values of loading motor and output the result to motor actuator. The working principle diagram of ELLS is shown in Figure 1.

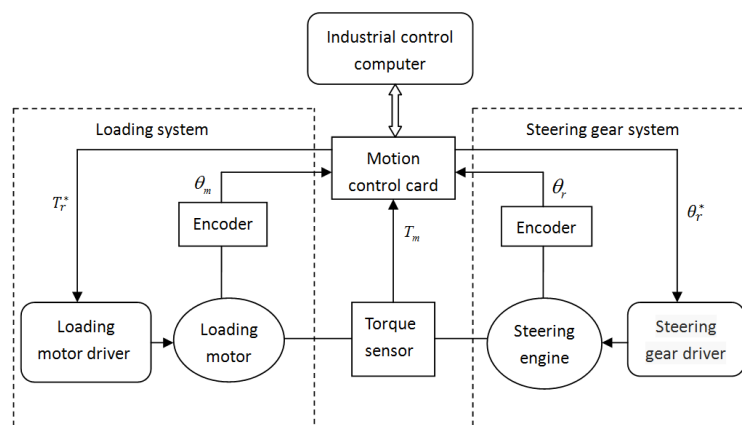


Figure 1: Working principle diagram of ELSS

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Through analyzing the working principle of load servo motor and the mechanism of torque generation, we can draw the numerical model of load simulation system, as shown in Figure 2. $U(s)$ is the control quantity of the controller output voltage. L_m and R_m are the working inductance and resistance of the loading motor. I_m is the armature current. K_T is the torsion coefficient of the motor. T_m is

electromagnetic torque of the loading motor. T_L is the actual output torque of the loading system. J_m is the equivalent moment of inertia converted onto the loading motor shaft. ω_m is the speed of the loading motor. θ_m is the rotation angle of the loading motor. θ_r is the steering angle. K_f is the torsional stiffness of the torque sensor. K_e is the back electromotive force of the motor.

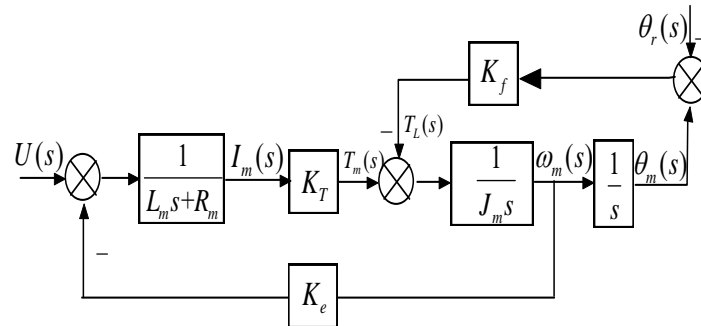


Figure 2: Numerical model of ELSS

2. The Adaptive Control Design

The adaptive control is an adaptive control strategy. Since it was put forward by the professor of MIT in the late 1950s, a variety of different control schemes of it had emerged^{[13]-[16]}. A new control method is designed in this study based on the model reference adaptive system(MRAS) and combining the feed-forward control compensation principle. The basic structure of model reference adaptive system is shown in Figure 3. The control object is to make the deviation(e) from the actual output(y_p) and the output of the reference

model(y_m) equal to 0. When the controller and controlled object change making the actual output of the system deviate from the target output, that is to say, the actual output of the system is not equal to the target output, the deviation signal will be input to the adaptive mechanism that can generate a regulation scheme in accordance with the pre-established adaptation law and change the parameters of the controller to make the main circuit tend to be consistent with the reference model and the actual output approximate to the object reference output.

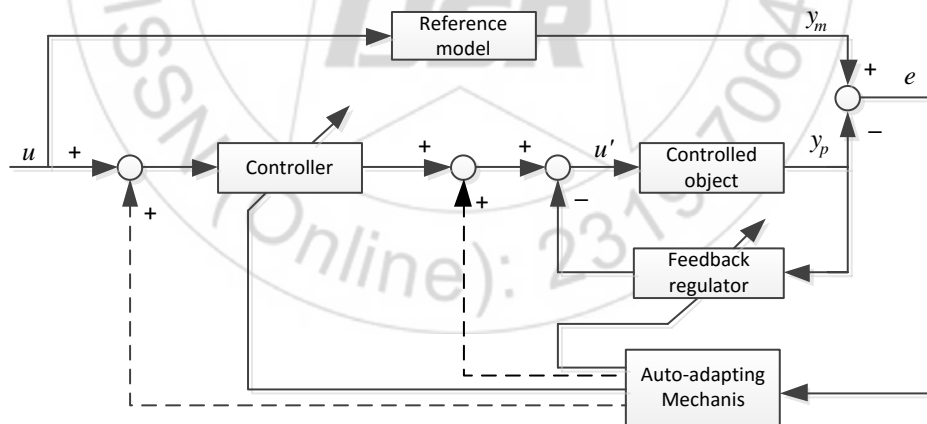


Figure 3: Basic structure of MRAS

According to the characteristics of the controlled object of ELSS, the state-space numerical model of the reference model is

$$\begin{cases} \dot{x}_m = A_m x_m + B_m u \\ y_m = C_m x_m \end{cases} \quad (1)$$

The state space of the actual system is described as

$$\begin{cases} \dot{x} = Ax + Bu \\ y_p = Cx \end{cases} \quad (2)$$

Figure 4 is the adaptive control system diagram of the design. In this design, on account of the position disturbance

of servo motor in loading motor, the actuator motion disturbance is considered as a part of the controlled model in the system when designing the controller. Also, a separate control link has been designed aimed at the position disturbance of bearing motor and feed-forward controller been introduced into the self-reference control system of conventional model. Due to the introduction of the angular velocity of the position motion and for having a corresponding adjustable controller to adapt to this change, we have added a differential term to the feed-forward controller of the system and introduced new controller

parameters, after which the adaptive mechanism will adjust the parameters of the controller with differential term through the angular velocity of the motor shaft to generate a compensation to reduce the surplus torque. As a result of the surplus torque being related to the angular velocity and angular acceleration of the shaft and the majority of the

surplus torque caused by the angular velocity in the middle and low frequency, the differential terms will be introduced as the compensation for angular velocity. So eventually the main controller is designed as a proportional controller and the feed-forward compensation controller as a proportional-derivative controller.

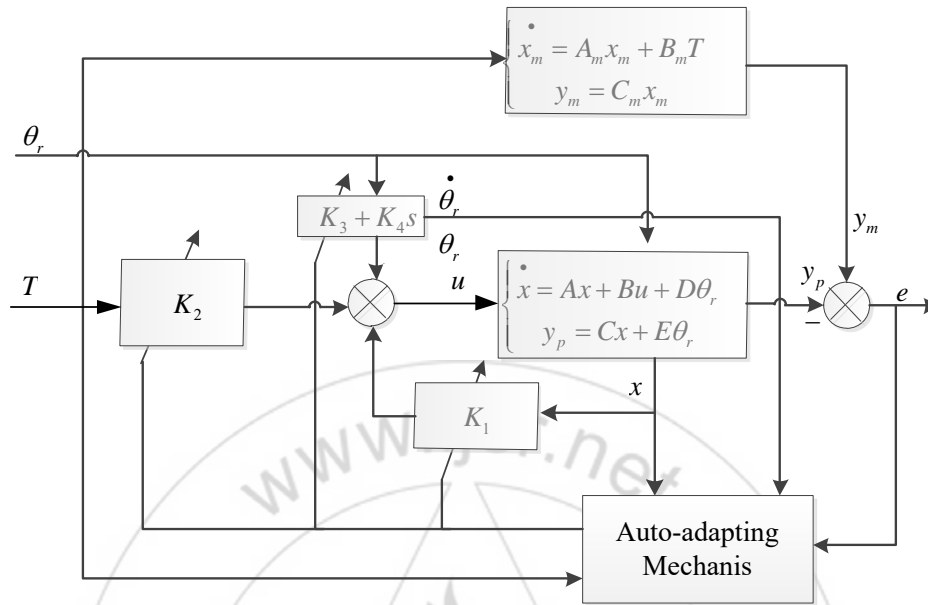


Figure 4: Adaptive control system diagram

At this time the controlling quantity of the system is

$$u = K_1x + K_2T + K_3\dot{\theta}_r + K_4\theta_r \quad (3)$$

The output error of the system is

$$e = y_m - y_p \quad (4)$$

The first derivative of the system error is

$$\dot{e} = C_m\dot{x}_m - C\dot{x} - E\dot{\theta}_r \quad (5)$$

Let matrix revertible and state-space equation (1) and (2) and control equation (3) used to the above formula, and differential equation of system error will be presented as

$$\begin{aligned} \dot{e} &= \Phi e + \Phi_1x + \Phi_2T + \Phi_3\dot{\theta}_r + \Phi_4\theta_r \\ &= C_mA_mC_m^{-1}e + (C_mA_mC_m^{-1}C - CBK_1 - CA)x \\ &\quad + (C_mB_m - CBK_2)T \\ &\quad + (C_mA_mC_m^{-1}E - CBK_3 - CD)\theta_r \\ &\quad + (-E - CBK_4)\dot{\theta}_r \end{aligned} \quad (6)$$

It can be seen from the above that by increasing the control of angular velocity, we can construct a simple Lyapunov function to make generalized error converging asymptotically and obtain the adaptive laws for parameters of the controller K_1 , K_2 , K_3 and K_4 .

Defining the system Lyapunov function as

$$V = \frac{1}{2} (pe^2 + \Phi_1\Phi_1^2 + \Phi_2^2 + \Phi_3^2 + \Phi_4^2) \quad (7)$$

In equation (7), $p > 0$, then $V > 0$, so the Lyapunov function is positive definite.

The first derivative of the Lyapunov function is

$$\dot{V} = pe\dot{e} + \Phi_1\dot{\Phi}_1^T + \Phi_2\dot{\Phi}_2 + \Phi_3\dot{\Phi}_3 + \Phi_4\dot{\Phi}_4 \quad (8)$$

Plugged the differential equation of system error (6) into equation (8), we get

$$\dot{V} = p\Phi e^2 + [(pex + \dot{\Phi}_1^T)\Phi_1 + (peT + \dot{\Phi}_2)\Phi_2 + (pe\dot{\theta}_r + \dot{\Phi}_3)\Phi_3 + (pe\theta_r + \dot{\Phi}_4)\Phi_4] \quad (9)$$

Let the last item of the above formula equal to zero

$$\begin{aligned} (pex + \dot{\Phi}_1^T)\Phi_1 + (peT + \dot{\Phi}_2)\Phi_2 + (pe\dot{\theta}_r + \dot{\Phi}_3)\Phi_3 + \\ (pe\theta_r + \dot{\Phi}_4)\Phi_4 = 0 \end{aligned} \quad (10)$$

Due to the stability of the system reference model, the eigenvalue $A_m < 0$. From this we know $\Phi < 0$. Therefore $\dot{V} < 0$, and the function \dot{V} is negative semi-definite. Lyapunov function is positive definite and The first derivative of the Lyapunov function is negative semi-definite, which satisfies the Lyapunov stability theorem and the system is stable. At this time the error converges to 0 and the adaptive law is

$$\dot{\Phi}_1 = -pex^T \quad (11)$$

$$\dot{\Phi}_2 = -peT \quad (12)$$

$$\dot{\Phi}_3 = -pe\dot{\theta}_r \quad (13)$$

$$\dot{\Phi}_4 = -pe\theta_r \quad (14)$$

3. The Analysis of Numerical Simulation

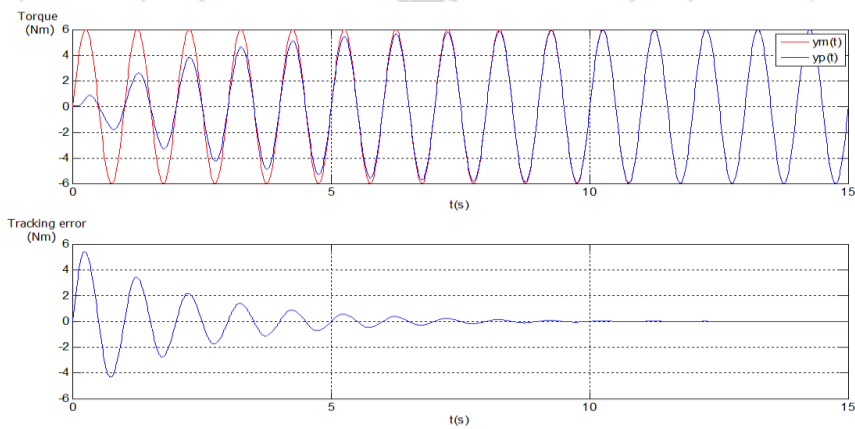
To verify the effectiveness of the adaptive control system, the structure diagram of the system is constructed on the basis of Simulink in this study. Also, computer simulation is made for the system under the condition that the sinusoidal frequencies of steering gear when it's in motion are 1Hz, 5Hz and 10Hz respectively. System related parameters are set as shown in Table 1.

Table 1: System related parameters

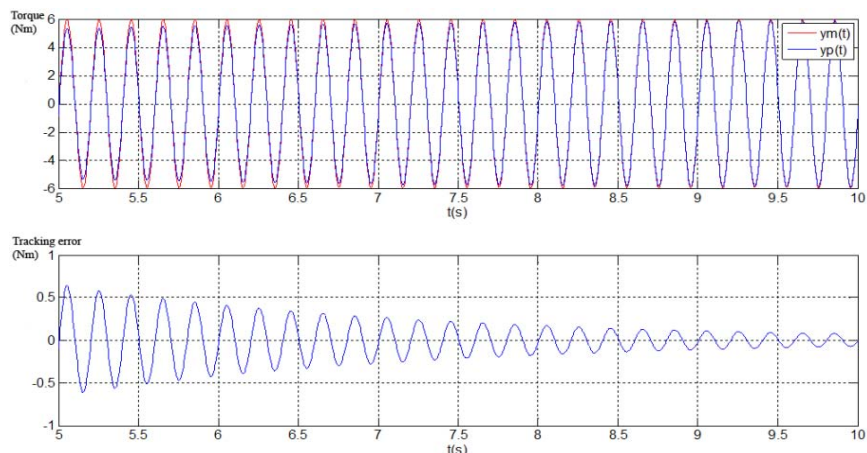
Related parameters	Numerical value
Proportionality factor P	1000
Initial value of the input (Nm)	0
Initial value of the output (Nm)	0
Initial value of state variable X_m	0
Initial value of adjustable gain K_1	0
Initial value of adjustable gain K_2	0
Initial value of adjustable gain K_3	0
Initial value of adjustable gain K_4	0
Moment of inertia ($\text{Kg}\cdot\text{m}^2$)	0.01
Amplitude of the input torque (Nm)	6
Motion amplitude of steering gear (rad)	$\pi/6$
Simulation step size	0.001

Figure 5 are the torque output and tracking error of adaptive control system. It can be known from the diagram (a) that when the motion frequency of steering gear is 1Hz and the regulation has just begun, the initial tracking error is very large because of the initial settings have had a value of 0. With the constant sampling adjustment of the adaptive law, tracking error will decrease and eventually tend to 0. At the moment the system is adjusted to the error of 0 with a time of about 10s.

The change rule of tracking error of the system is same when the motion frequency of steering gear is 5Hz or 10Hz as it is 1Hz that tracking error decreases and eventually tends to 0. But it will take 11s for the system to be adjusted when the frequency is 5Hz and 12s when the frequency is 10Hz, as shown in figure (b) and figure (c). Through comparison, we can know that the higher the motion frequency of steering gear is, the longer the adjustment time of tracking error of the system is.



(a) 1Hz



(b) 5Hz

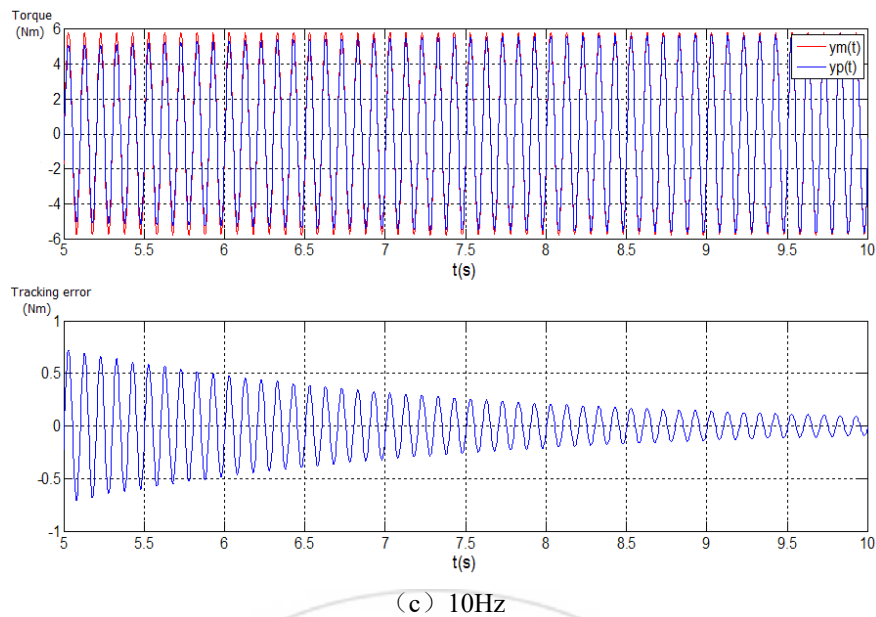


Figure 5: The torque output and tracking error of adaptive control system

The computer simulation of the adaptive system shows that the effectiveness of the adaptive control system to suppress the loading error. It can stabilize the system in the ideal output state through the output of the reference model in the small changes that the actual parameters of the system unknown or gradient. Also, it has a strong adaptability and robustness.

4. Conclusion

In this paper, the structure composition and working principle of the electric load simulation system are analyzed and the numerical model of ELSS is given. Also, an adaptive control system that can track the torque input and suppress surplus torque effectively is designed and the adaptive law of it is obtained. Moreover, the effectiveness of the system suppressing the load error is proved by computer simulation analysis and experiment.

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