第3卷 第4期 控制理论与应用 Vol. 3, No.4
1986年12月 CONTROL THEORY AND APPLICATIONS Dec., 1986

A Model-reference Adaptive Flight Simulator Servo System

Feng Guonan, Lu Bingren, Yu Rui

(Beijing Polytechnic University)

Abstract

This paper presents a design method based on the Lyapunov stability theory for a model-reference adaptive feedforward-feedback control flight simulator servo system. An example and the result of its digital simulation and parameter optimization are included.

I. Introduction

The feedforward-feedback control system can be generally used for a flight simulator servo system[1]. In theory, the band-width of this kind of system compensated ideally is infinite. But the performance of the system is very sensitive to variations of the plant parameters and feedforward compensator parameters. The system frequence response will be deteri orated markedly, when the plant parameters vary. This is a serious problem which has existed in feedforward-feedback control servo systems.

To solve this problem, we can add an adaptive mechanism to the conventional feedforward-feedback control system, thus having a model-reference adaptive feedforward-feedback control servo system achieved. When the plant parameters change due to environmental disturbance and the case of the ideal compensation does not hold, the adaptive mechanism will automatically adjust the feedforward compensator parameter values so that servo system can possess the idealized frequence response or approach to it.

Manuscript received January 9, 1985, revised August 9, 1985.

Ⅱ. System dynamic equation

Fig.1 shows the block diagram of a feedforward-feedback control flight simulator servo system. An analog (or digital) computer generates a reference input r(t) and its first-and second-order derivative $\dot{r}(t)$, $\ddot{r}(t)$. β_1, β_2 are the adjustable parameters of the feedforward compensator.

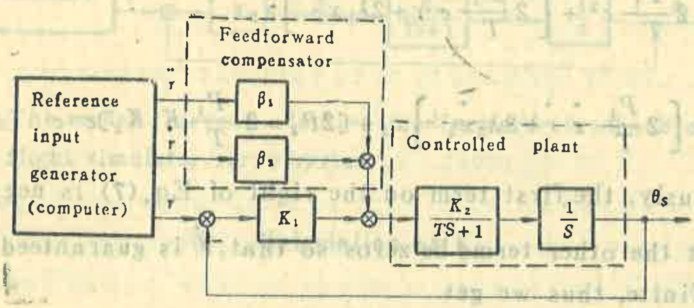


Fig. 1 Block diagram of a feedforward-feedback control flight simulator servo system

According to Fig.1, we have the dynamic equation of the system

$$T\ddot{\theta}_s+\dot{\theta}_s+K_1K_2\theta_s=K_2\beta_1\ddot{r}+K_2\beta_2\dot{r}+K_1K_2r \tag{1}$$

The reference model is assumed to be ideal, i. e. the relationship between its input $r(t)$ and the output $\theta_m(t)$ is

$$\theta_m(t)=r(t) \tag{2}$$

and the generalized error is defined as

$$e=\theta_s-\theta_m=\theta_s-r \tag{3}$$

According to Eq.(1) and (3), the dynamic equation of the generalized error can be obtained as

$$T\ddot{e}+\dot{e}+K_1K_2e=x_1\ddot{r}+x_2\dot{r} \tag{4}$$

where
$$x_1=K_2\beta_1-T,\quad x_2=K_2\beta_2-1 \tag{5}$$

Ⅲ. Design of the adaptive mechanism

Now we design an adaptive mechanism based on Lyapunov stability theory.[2],[3] When the controlled plant parameters vary, the adaptive mechanism is required to adjust parameters x_1 and x_2

automatically (or equivalently to adjust β_1 and β_2), so that e, $\dot{e}$, $\dot{X}$ and $\dot{X}$ are gradually becoming zeros as $t \to \infty$, where $X = [x_1, x_2]'$.

We choose the following Lyapunov function

$$\dot{V} = P_1 \dot{e}^2 + P_2 e^2 + \lambda_1 x_1^2 + \lambda_2 x_2^2 \tag{6}$$

where P_1, P_2, λ_1, λ_2 are constant and greater than zeros. Deriving V with respect to t and considering Eq.(6), we can get

$$\dot{V} = -2\frac{P_1}{T}\dot{e}^2 + \left[2\frac{P_1}{T}\dot{e}\ddot{r} + 2\lambda_1 \dot{x}_1\right]x_1$$

$$+\left[2\frac{P_1}{T}\dot{e}\dot{r} + 2\lambda_2 \dot{x}_2\right]x_2 + [2P_2 - 2\frac{P_1}{T}K_1K_2]e\dot{e} \tag{7}$$

Obviously, the first term on the right of Eq.(7) is negative definite. Let the other terms be zeros so that $\dot{V}$ is guaranteed to be negative definite, thus we get

$$\dot{x}_1 = -\frac{P_1}{T\lambda_1}\dot{e}\ddot{r} \tag{8}$$

$$\dot{x}_2 = -\frac{P_1}{T\lambda_2}\dot{e}\ddot{r} \tag{9}$$

and
$$P_2 = \frac{P_1}{T}K_1K_2 \tag{10}$$

Condition (10) is easy to be satisfied. According to Eq. (8), (9) and $\dot{x}_1 = K_2\dot{\beta}_1$, $\dot{x}_2 = K_2\dot{\beta}_2$, the adaptive law can be obtained as

$$\beta_1 = -\int_{t_0}^{t} B_1 \dot{e}\ddot{r}\, d\tau + \beta_1(t_0) \tag{11}$$

$$\beta_2 = -\int_{t_0}^{t} B_2 \dot{e}\dot{r}\, d\tau + \beta_2(t_0) \tag{12}$$

where $B_2 = \dfrac{P_1}{\lambda_1 T K_2}$, $B_2 = \dfrac{P_1}{\lambda_2 T K_2}$ and they can be obtained by simulating and optimizing.

From the above analysis, we can know that P_1, P_2, λ_1 and λ_2 are only requested to be constant and greater than zeros. They are not restricted by any other conditions.

Fig. shows the block diagram of the model-reference adaptive feedforward-feedback control flight simulator servo system.

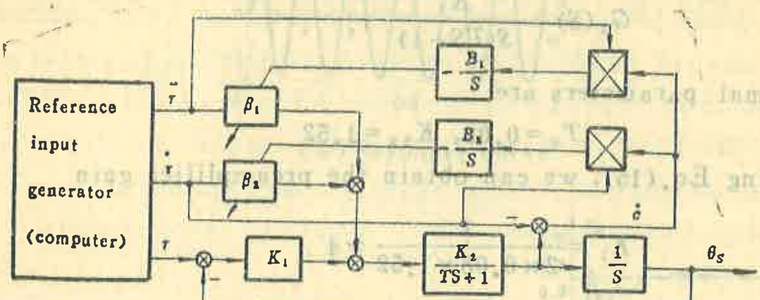


Fig. 2 The model refrence adaptive feedforward-feedback control flight simulator servo system

Ⅳ. Calculation of K_1

We can determine K_1 in such a way that under normal condition the damping ratio ξ of the closed-loop system with no feedforward compensator is made to retain a value of $\frac{1}{\sqrt{2}}$. A system like this will possess a better transient response.

Suppose normal values of the plant parameters T and K_2 are T_0 and K_{20} respectively. The transfer function of this second-order system is

$$\frac{\theta_s(S)}{R(S)} = \frac{\omega_n^2}{S^2 + 2\xi\omega_n S + \omega_n^2} \tag{13}$$

where we let $\xi = \frac{1}{\sqrt{2}}$, then

$$\omega_n = \frac{1}{\sqrt{2T_0}} \tag{14}$$

So we can get

$$K_1 = \frac{1}{2T_0K_{20}} \tag{15}$$

V. An example

The controlled plant transfer function is given by

$$G_2(S)=\frac{K_2}{S(TS+1)}$$

its normal parameters are

$$T_0=0.08,\ K_{20}=1.52$$

Using Eq.(15), we can obtain the preamplifier gain

$$K_1=\frac{1}{2\times 0.08\times 1.52}\simeq 4$$

B_1 and B_2 can be obtained by using parameter optimization technique as following

$$B_1=0.00057,\ B_2=0.085$$

We use a sinusoid with 1 Hz as a reference input signal. Fig.3 (b) and (c) show that the feedforward compensator parameters can quickly (about two seconds) converge to their desired values:

$$\beta_1^*=0.0526,\quad \beta_2^*=0.658$$

From Eq.(1) we know that the ideal transfer function must be

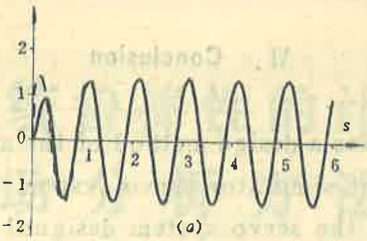
$$\frac{\theta_s(S)}{R(S)}=\frac{K_2\beta_1S^2+K_2\beta_2S+K_1K_2}{TS^2+S+K_1K_2}=1$$

So we get

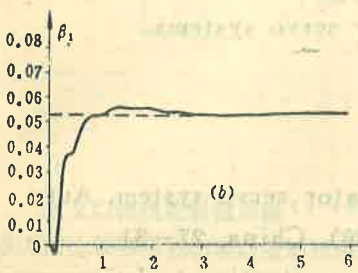
$$\beta_1^*=\frac{T_0}{K_{20}}=\frac{0.08}{1.52}=0.0526,\quad \beta_2^*=\frac{1}{K_{20}}=\frac{1}{1.52}=0.658$$

Obviously, the result of the simulation corresponds with the theoretical analysis.

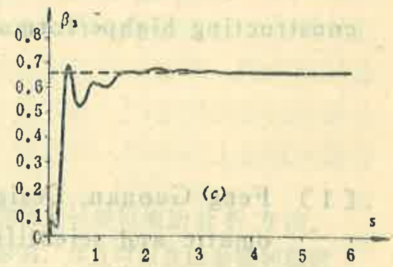
Fig.4 shows the response curve $\theta_s(t)$ of the system which is shown in Fig.2 and in which the reference input is a sinusoid with 10Hz and the plant time constant is increased 20%. Fig.5 shows the response curve $\theta_s(t)$ of the system with no adaptive mechanism if the system has the same input signal as the system in Fig.4, the plant time constant is also increased 20%, and the feedforward compensator parameters are $\beta_1=0.0526$, $\beta_2=0.658$. These curves show clearly that when plant parameters vary, the closed-loop system with the adaptive mechanism will show a good performance of tracing a sinusoid signal. However, without the adaptive mechanism, the system output will have noticeable amplitude and phase errors produced.



(a) Response curve



(b) β_1 parameter curve



(c) β_2 parameter curve

Fig. 3 The performance curves

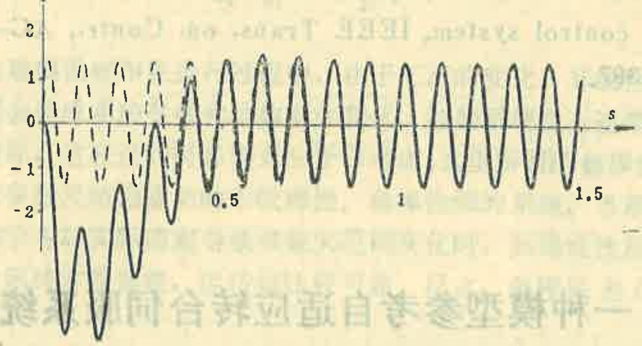


Fig. 4 Response curve of the system with the adaptive loop

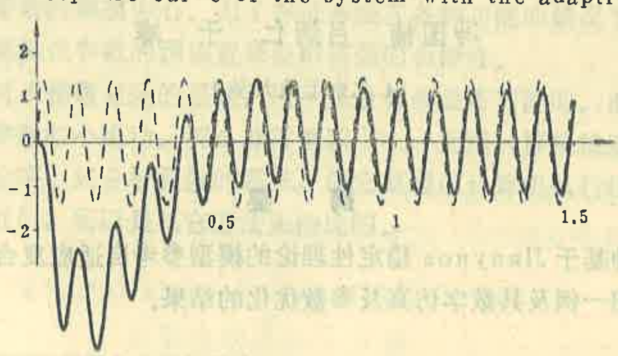


Fig. 5 Response curve of the system without the adaptive loop

Ⅵ. Conclusion

This paper proposes a design method of the adaptive feedforward-feedback control flight simulator servo system. The results of digital simulation show that the servo system designed by using this technique can effectively overcome some disadvantages entailed by variations of plant parameters. Therefore a design method is provided for constructing highperformance flight simulator servo systems.

Reference

〔1〕 Feng Guonan, Design of a flight simulator servo system, Automatic and scientific instrument, 2,(1980), China, 27-31.

〔2〕 Landau, I. D. Asurvey of model reference adaptive techniques-theory and applications, Automatica, **10**, 4, (July, 1974), 353-379.

〔3〕 Patrick C. Parks, Lyapunov redesign of model-reference adaptive control system, IEEE Trans. on. Contr., AC—**11**, (1966), 362—397.

一种模型参考自适应转台伺服系统

冯国楠 吕炳仁 于 睿

（北京工业大学）

摘 要

本文提出一种基于 Ляпунов 稳定性理论的模型参考自适应复合控制转台伺服系统的设计方法，介绍一例及其数字仿真及参数优化的结果。