Study on the Simulation of the APT Rough Tracing Subsystem Based on the Fractional Order Controller

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Abstract

Because of many advantages such wide bandwidth, high code rate, and low power consumption, the laser space communication has been the new direction of the space communication development, and the APT (acquisition, pointing and tracing) technology is one of key technology for the laser space communication. The ATP rough tracing servo turntable studied in this article adopts two-axes-four-frame structure and the fractional order PI^{λ} control strategy is adopted in the rough tracing position loop. The simulation result shows that, comparing with common PI controller, the fractional order PI^{λ} controller could improve the dynamic response characteristics of the system.

Keywords: Laser space communication, Rough tracing, Fractional order control

1. Components of the APT system

The components of the composite axis APT system are seen in Figure 1, and the rough tracing subsystem is composed by the gimbal servo turntable and the rough tracing CCD. The characteristics of the rough tracing subsystem include large dynamic range, narrow control bandwidth, and lower resonant frequency, and it could accomplish the initial orientation of laser axis, and realize the capturing and rough tracing (Liu, 2006, P. 101-106 & Ahmad, 2004, P. 141-150).

2. Mathematical model of the rough tracing subsystem

From Figure 1, the rough tracing subsystem is composed by the speed loop and the position loop.

The mathematical model of the speed loop motor and the load is

$$W_m(s)=\frac{1/K_b}{(T_m s+1)(T_e s+1)}=\frac{0.1483}{(1+3s)(1+0.0031s)} \tag{1}$$

To make the compensated speed loop satisfy the bandwidth requirement, the cut-off frequency of the compensated speed loop is $\omega_c = 100 rad/s$, and the compensation system of the speed loop designed by adopting the frequency characteristic method in the classical control theory is

$$G_c(s)=\frac{4046(0.01s+1)(0.0031s+1)}{(0.02s+1)(0.002s+1)} \tag{2}$$

According to the tracing error index of the system and the maximum work angle speed and the peak acceleration of the system, the open loop gain required by the system can be confirmed by K=2000.

The uncompensated transfer function of the position loop is

$$P_0(s)=\frac{2000(6s+600)}{s(0.0001s^3+0.066s^2+8.02s+601)} \tag{3}$$

3. Selection of the control algorithm

Because the margin rate of the system is 1, if the PI control algorithm is adopted, the margin rate of the system will increase to 2, and the system is hard to be stabilized. Though the lag-lead compensation or the quadratic lag-lead compensation could improve the performance of the system, but the robustness of the system will become worse, and when the gain of the system changes, the system characteristics will go to worse and even could not satisfy the given indexes and requirements.

To enhance the robustness of the rough tracing subsystem and improve the dynamic response characteristic and tracing precision of the system, a new compensation algorithm, the control algorithm combining the fractional order PI^{λ} compensation with the lag-lead compensation is proposed in this article, aiming at the rough tracing subsystem (Zhang, 2005, P. 653-656 & Wang, 2004, P. 517-520).

4. Design of the fractional order PI^{λ} + lag compensation controller

Aiming at the position loop of rough tracing, the structure of the PI^{λ} + lag-compensation controller is

$$C_{11}(s) = K_p(1 + K_i/s^{\lambda})\frac{1+T_1 s}{1+T_2 s} \quad (4)$$

According to the classical control theory design method, the transfer function of the lag compensation part in the compensation system could be selected by

$$\frac{1+T_1 s}{1+T_2 s} = \frac{1+0.44s}{1+20s}$$

, and to further compute K_i, K_P and λ in the controller, the lag compensation part is added into the mathematic model of the system, so the equivalent mathematic model of the uncompensated rough tracing subsystem is

$$P(s) = \frac{2000(6s+600)(1+0.44s)}{s(0.0001s^3 + 0.066s^2 + 8.02s + 601)(1+20s)} \quad (5)$$

To enhance the robustness of the rough tracing system, the design idea of the PI^{λ} controller is the level-phase idea (A. Oustaloup, 1999, P. 21-30 & Ying Luo, 2008, P. 121-130), so $K_i = 7.361$, $\lambda = 1.277$, and $K_p = 0.54$.

The transfer function of the position loop FOPI + lag compensation controller is

$$C_{11}(s) = 0.54(1 + 7.361s^{-1.277})\frac{1+0.44s}{1+20s} \quad (6)$$

5. Analysis of the position loop simulation of the APT rough tracing subsystem

The step response of the system is seen in Figure 2, and the system overshoot of the system is $\sigma_P = 13\%$, and the steady-state error of the system is 0. The open loop frequency characteristic of the compensated position loop is seen in Figure 3, and the system has the characteristic of level phase, and the compensated cut-off frequency is $\omega_c = 20.1rad/s = 3.2Hz$, and the phase angle margin is $\phi_m = 67.7^0$, and the system is stable and could satisfy the requirements of the performance indexes. The closed loop frequency characteristic of the position loop is seen in Figure 4, and the bandwidth of the position loop is 35.8 rad/s (5.7 Hz), which could satisfy the bandwidth requirement of the APT system for the rough tracing subsystem.

6. Robustness test of the rough tracing position loop

If the common control algorithm is adopted, the open loop gain of the rough tracing loop will fluctuate, and the dynamic tracing error of the system will increase, which will directly influence the rough tracing precision (Zeng, 2004, P. 465-469). If the open loop gain change of the rough tracing loop equals to the change of the gain K_p of the PI^{λ} controller, when K_p change positive or negative 10% near the rated parameter 0.54, the step response curve of the rough tracing system is seen in Figure 5. It is obvious that when the PI^{λ} controller is adopted and the open-loop gain of the rough tracing position loop change positively or negatively 10%, the influence on the system overshoot and the adjustment time is less, and the rough tracing system has strong robustness.

7. Conclusions

In the design of the tracing algorithm of the rough tracing subsystem, to overcome the deficiency that the traditional PID algorithm has bad robustness, and enhance the tracing precision and the robustness of the rough tracing subsystem, a new control algorithm combining the fractional order PI^{λ} control with the lag-compensation is proposed this article, and the level phase idea is used to respectively identify the parameters of the controller, and the simulation result shows that the rough tracing system has strong robustness.

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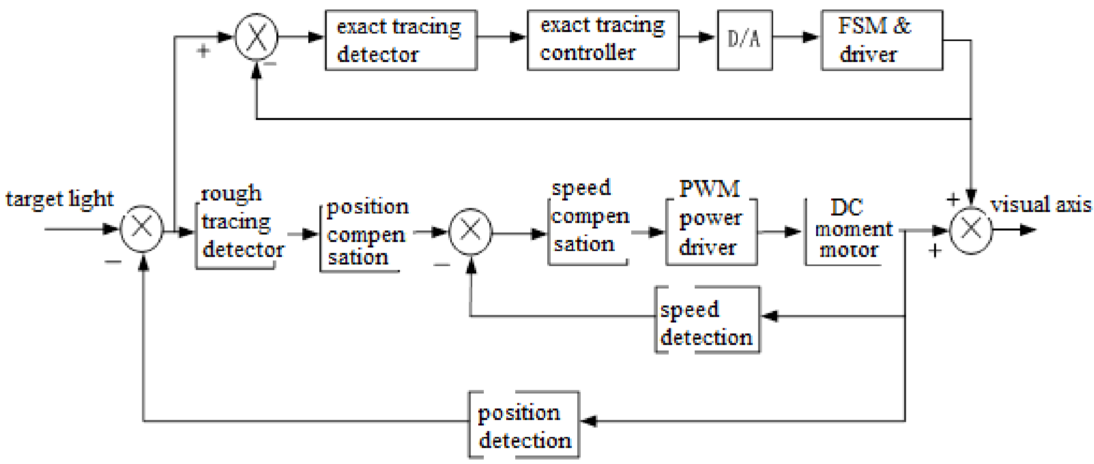

Figure 1. Block Diagram of APT System

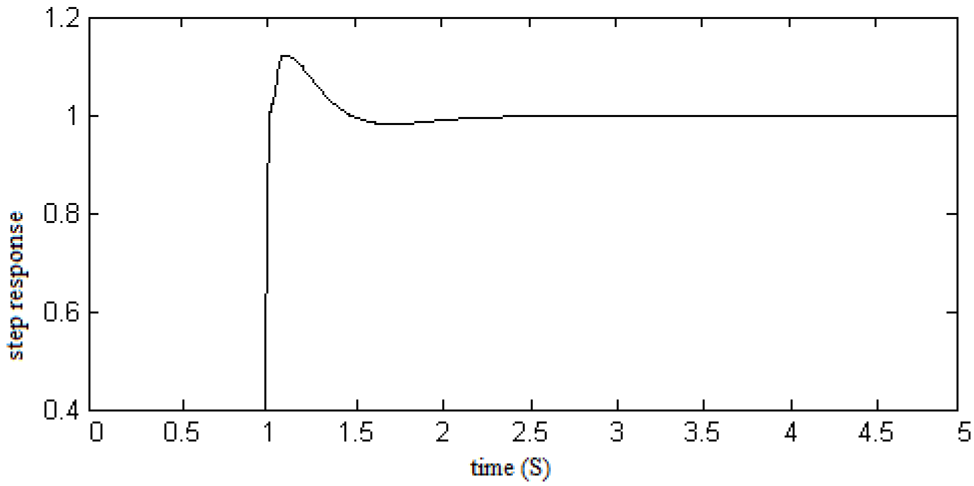

Figure 2. Step Response of Position Loop

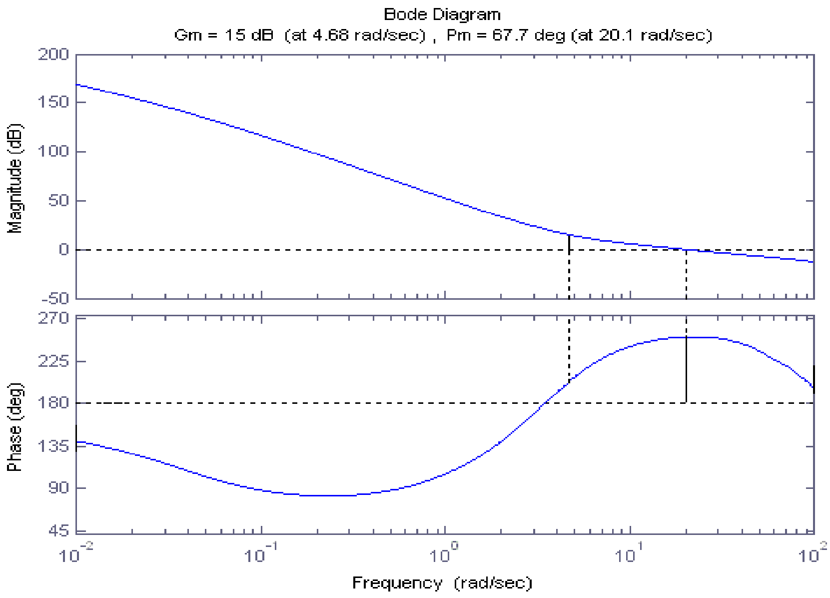

Figure 3. Open Loop Frequency Characteristic of the Compensated Position Loop

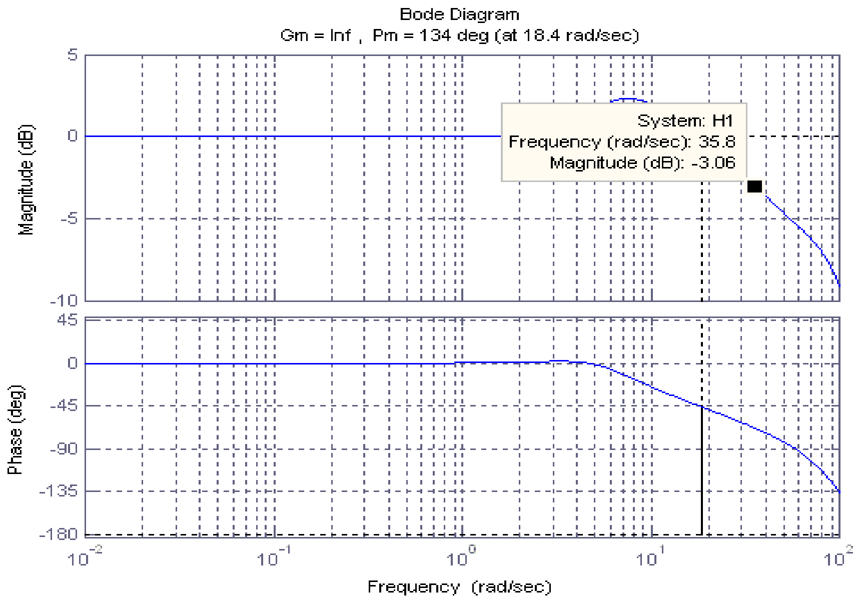

Figure 4. Closed Loop Frequency Characteristic of the Compensated Position Loop

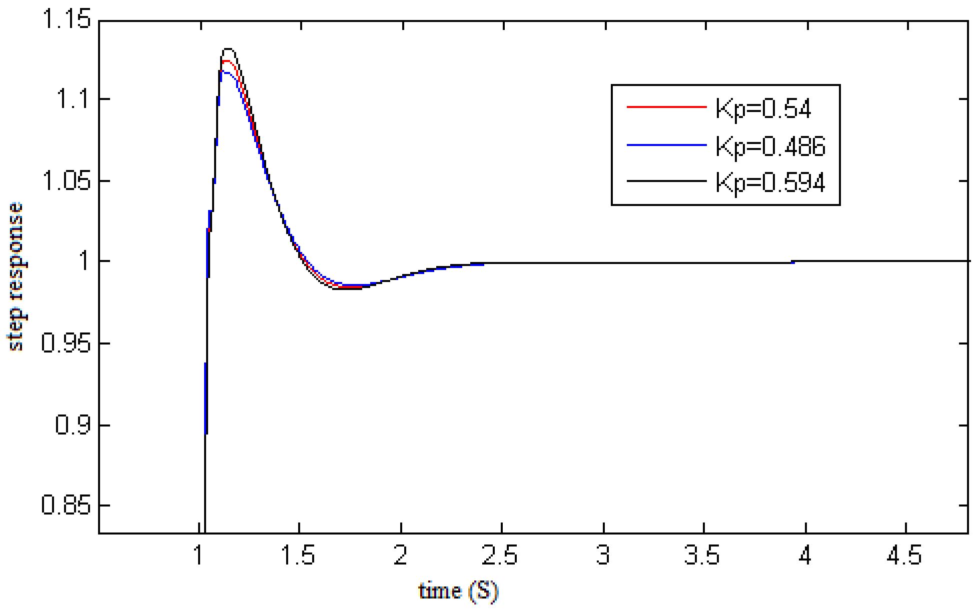

Figure 5. Robustness Test of Position Loop