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The Servo System Drive and Control of Pneumatic Actuator

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Abstract. This paper briefly describes the characteristics of the electric actuator and the pneumatic actuator, and introduces the method of controlling the declination of the pneumatic actuator servo system. This paper mainly analyzes the design idea of the drive circuit and the PID control algorithm design, and also gives the response time, control accuracy and vibration amplitude of actuator servo system.

1. Introduction

The actuator is an important part of the guided ammunition to control flight direction, which determines the attitude and direction of the projectile. At present, there are two types of electric actuator and pneumatic actuator. The electric actuator can operate continuously and get less amplitude. However, the response time of the electric actuator is long and it is not suitable for the rapid flight control of the guided ammunition. The response of the pneumatic actuator is fast and the structure is simple. However, it is difficult to control the speed and position. Therefore, for pneumatic actuator, two-position or three-position control mode is generally adopted.

When controlling the actuator, if the rudder deflection angle is too large, the control accuracy will be reduced, and it will easily deviate from the target when approaching the target. If the rudder deflection angle is too small, although the accuracy can be improved, the servo control efficiency is reduced. The controlled radius of the projectile's flight is reduced, resulting in a missing correction distance of the projectile within a specified time, so as to miss the target. After analysis and verification, in order to achieve rudder deflection angle adjustment, an angle feedback potentiometer is added to the rudder; half-bridge drive circuit is added to the circuit, and combined with the PID control algorithm. High-speed continuous angle control can be achieved.

2. Power drive circuit

The drive circuit of the FET is selected from the IR2101S chip of IR Corporation. The chip is a dual-channel, gate-driven, high-voltage and high-speed driver. It adopts a highly integrated level conversion technology, simplifies the logic circuit requirements for power devices improves circuit reliability. The chip's top tube is powered by an external bootstrap capacitor, which reduces the number and size of the driving power supply and the control transformer, and also reduces the cost. Drive circuit shown in Fig. 1 and Fig. 2.

IR2101S chip can drive the N-channel MOSFET of the bridge arm. MOSFET is a kind of voltage-driven device with a high gate impedance. Simply adding a certain voltage can drive the drain and source of the MOSFET to conduct. When designing the actual drive circuit, especially with modulation control, due to the presence of the gate capacitance, it is necessary to considered that the drive pulse can pull out and bleeder the high current to ensure fast conduction and rapid turn-off of the



tube, and the loss of the MOSFET is reduced, otherwise MOSFET is easily burned. The outlet of the IR2101S is a push-pull output, allowing the charging and discharging of large pulse current. In order to keep the drain and source of the MOSFET transistor conducting, the drive circuit needs to ensure that there is a certain voltage difference between the source and the gate.

The source of the MOSFET of the lower bridge arm of the half-bridge circuit section is grounded. It is possible to control the on/off of the MOSFET by adding high and low level to the gate; the source of the MOSFET of the upper bridge arm is connected to one end of the load. The other end of the load is grounded. When the MOSFET is in the off state, the load has no current and the source is at low level. Adding a high level to the gate controls the MOSFET on/off. Once the electric current flowing through the upper bridge arm of MOSFET, the source electric potential of the tube is raised, and the MOSFET may turn off immediately. The high level of the gate with respect to ground does not maintain the MOSFET conduction. Therefore, the electric potential of the gate must be floating.

The IR2101S's upper and lower bridge arm drive output reference points are separate. When driving the upper arm, the reference point of the upper arm drive output is connected to the source of the MOSFET of the upper arm, and a small capacitor is added between the reference point and the power supply of the upper arm. After the gate is high level to make the MOSFET conducting, the electric potential of the reference point rises, and the potential of the output port HO will rise accordingly. However, due to the influence of the diode D2, the increased electric potential makes the capacitor unable to discharge, and the voltage difference between the gate of the HO and the source is still 12V, which can maintain the conduction state of the MOSFET. When the HO outputs the low level, the HO is shorted-circuit to the reference point, and there is no potential difference between the gate and the source. At this time, the MOSFET of the upper arm is turned off.

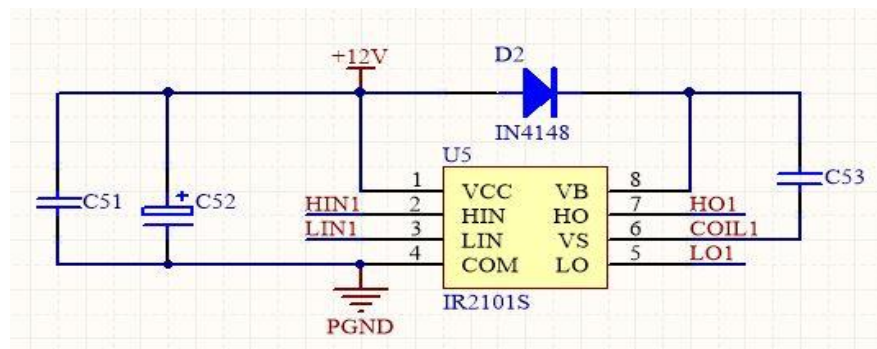


Fig. 1.drive circuit (a)

The half-bridge circuit is composed of two N-channel MOSFET IRF7854 of IR company. The upper and lower arms adopt push-pull output PWM signal control, and the average power on the load is adjusted by controlling the duty cycle. A certain dead-time must be set between the two arms of the MOSFET to prevent the upper and lower arms from being conducted to cause the short circuit. The MOSFET of the upper arm provides power to the load. The MOSFET of the lower arm is freewheeling the load when the upper arm is shutdown, and the MOSFETs of the two arms are connected in parallel with the RTC buffer circuit and the TVS tube for freewheeling clamp.

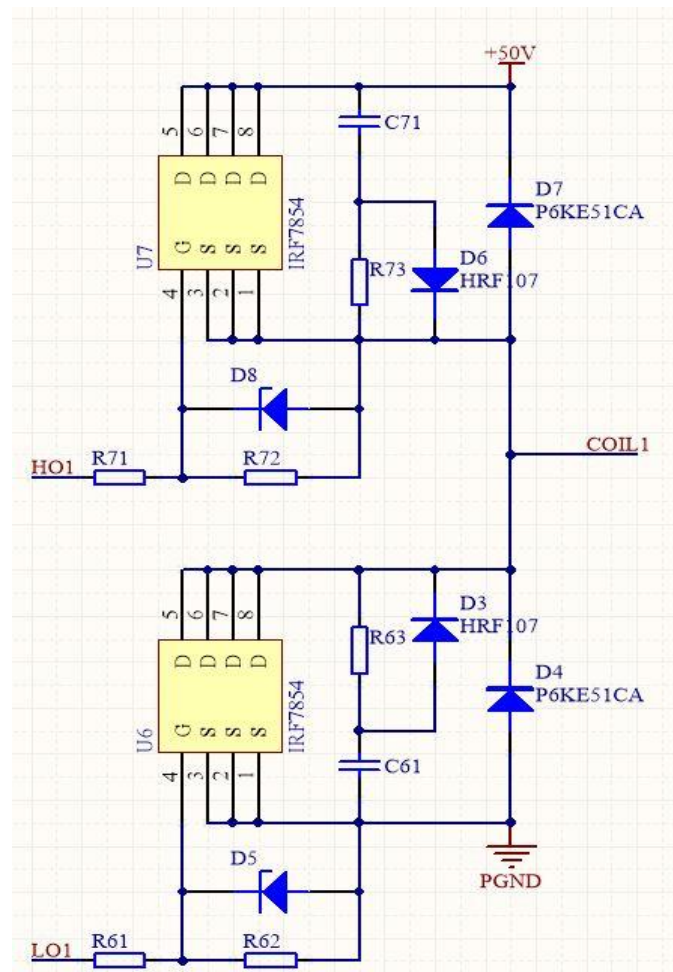


Fig. 2. drive circuit (b)

3. Potential detection circuit

The main chip used for control has a high level 3.3V and a low level 0V. This is used as the reference voltage for the A/D conversion module and the high-precision potentiometer is installed on the loaded actuator plane. When the actuator deflects to a certain angle, the resistance in the potentiometer will have linear variation with the change of the deflection angle, so that the feedback voltage will also have linear variation. This signal is connected to the A/D unit of the main controller. The filter circuit is mainly composed of two different capacitors. The large capacitor mainly uses its charge-discharge characteristics to make the output pulse waveform more stable and achieve filtering of low-frequency signals. The small capacitor has relatively low capacitive reactance in high frequencies and can reduce the effect of high-frequency interference signals on the chip through grounding.

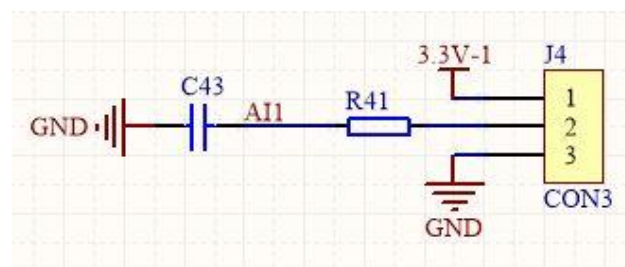


Fig. 3. potential detection circuit

4. Pid control algorithm

Pneumatic actuator servo system regulates the change of air pressure by controlling the conduction of the air circuit and controlling the air PWM, and realizes the control of the angular position of the rudder. Through a feedback potentiometer, the rudder deflection angle can be measured in real time and fed back to the controller. This forms a closed loop. The PID control algorithm is used in the control process. The difference between the current rudder deflection angle and the target position angle of the control is the input signal, and the duty cycle of the PWM signal is the output signal. When the input error signal is generated, the output is adjusted in the opposite direction, thereby eliminating the deviation and stabilizing the rudder at a fixed angular position.

This article uses incremental PID control algorithm, which is:

$$\begin{aligned}\Delta P_n = P_n - P_{n-1} &= K_c \left[(e_n - e_{n-1}) + \frac{T_s}{T_i} e_n + \frac{T_s}{T_d} (e_n - 2e_{n-1} + e_{n-2}) \right] \\ &= K_c (e_n - e_{n-1}) + K_I e_n + K_D (e_n - 2e_{n-1} + e_{n-2})\end{aligned}\quad (1)$$

Including:

$$K_I = K_c \frac{T_s}{T_i} \quad (2)$$

$$K_D = K_c \frac{T_d}{T_s} \quad (3)$$

Rewrite the incremental PID control equation as:

$$\Delta P_n = K_c \left(1 + \frac{T_s}{T_i} + \frac{T_d}{T_s} \right) e_n - K_c \left(1 + \frac{2T_d}{T_s} \right) e_{n-1} + \frac{K_c T_d}{T_s} e_{n-2} \quad (4)$$

In the above equation, P is the output control amount corresponding to the opening of the solenoid valve, that is, the duty cycle of the PWM. e is the difference between the current rudder deflection angle and the set rudder deflection angle, which is the actual measurement. K_c is the proportionality coefficient, which is a constant value, determined according to the experiment. K_I is the integral coefficient and K_D is the differential coefficient. T_s is the sampling time; T_i is the integration time; T_d is the derivative time. Sampling time is the time interval sampling rudder deflection angle. Both the integration time and the derivative time are constants that are set, and the integration time must be greater than the sampling time, and the derivative time must be less than the sampling time. Both P and e must be normalized, that is to say, they are relative values corresponding to their own ranges. PID control flow chart shown in Fig. 4.

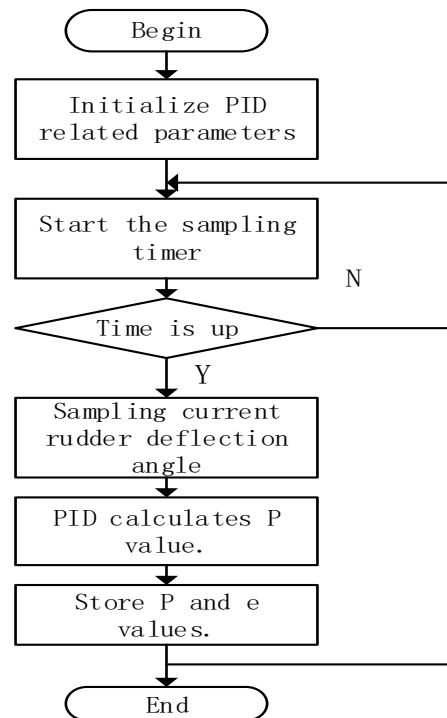


Fig. 4.PID control flow chart

Tested, the response time of the rudder blade within $\pm 15^\circ$ is less than 20ms. Fig. 5 and Fig. 6 show the left limit position and the right limit position of the rudder blade respectively. The control accuracy of the rudder deflection angle is less than 0.8° , and the vibration amplitude of the rudder blade is less than 0.6° .



Fig. 5.left limit position



Fig. 6.right limit position

5. Conclusions

In terms of hardware design, emphasis is placed on improving the reliability of the system. In order to eliminate the self-interference on the PCB, the driving module leads are as short as possible to minimize the malfunction of the power device, and the design method of the isolating circuit needs to be adopted. Actuator servo system is a time-variation, severely nonlinear position servo system. In terms of control effect, PID control algorithm is very effective in engineering practice, but it also has certain limitations. Improving the PID algorithm and applying it to engineering practice is the top priority of the next work.

6. References

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