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A Digital Implementation Method of Control Inner Loop of Ship-borne Servo System Based on PWM Power Amplifier

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Abstract. In order to realize the full digitalization and miniaturization of the ship-borne antenna servo system, a fully digital inner loop design method can be used to adjust the digital PID parameters through DA or AD conversion between signals. Large scale integrated circuits, such as PWM pulse width modulation amplifiers, can be used to achieve the desired antenna motion and response characteristics and achieve the acquisition and tracking of space targets and command control. The digital design scheme proposed below is simple, stable and reliable, and has certain universality.

1. Introduction

In the field of automation control, digitization has become a major development direction, and the focus of servo system digitization is the digitization of loop control. In the past, analog PID control technology has been used for large ship-borne antennas, which was developed at the beginning of last century. It has also been widely used because of its strong robustness, fast response speed, relatively simple physical design, good control performance and meeting the control requirements of ship-borne large antennas. More than 90% of the regulators are analog PID regulators to date. However, the debugging of analog PID parameters is very inconvenient, and each resistor has 2% to 5% error, which leads to the limited control accuracy of PID regulator.

Digital servo system is composed of control unit and drive unit. The control unit usually consists of industrial computer, PC card and single chip microcomputer to realize the closed loop of antenna position. The drive unit controls the speed and current loop of the antenna and drives the motor.

For the sake of miniaturization and digitization, we can also simplify the drive unit as much as possible and digitize the speed and current loops. Large scale integrated circuits and PWM pulse width modulated amplifiers, such as the SA Series PWM amplifiers from APEX, may be used for driving where power permits. DC pulse width modulation (PWM) amplifier is new types of power amplifier, which can make the motor have excellent low-speed performance, wide speed range, fast dynamic response, strong anti-load disturbance ability, good energy-saving effect and no pollution to the power grid, so it has a bright application prospect.

2. Design of Control Inner Loop

In addition to the traditional position loop, velocity loop and current loop, gyro stabilizing loop should be added to isolate the influence of ship rolling disturbance on target tracking in ship-borne radar

servo system. In addition, to further improve performance or add functionality, it is possible to add additional auxiliary loops or circuits, or to optimize control effects by changing loop parameters.

Ship-borne antenna drive system generally refers to the things within the speed loop, including the current loop and the drive power amplifier. The purpose of setting the current loop: The characteristics of speed loop control object are reformed, which creates convenient conditions for current loop correction. Overcoming the dead-time and non-linearity of SCR rectifier and the influence of inductance change of reactor, the static control precision and dynamic response bandwidth of current are improved. Limit the maximum current to ensure safe driving of the power amplifier. In this system, the method of measuring the resistance of feedback element with high power and small resistance has the advantages of simple and reliable, small volume, light weight and so on.

The main purposes of setting the speed loop: It provides a good control object for the position loop and makes it easy to correct. Increase the speed response bandwidth of the drive motor; Reduce the low-speed crawl and driving dead zone caused by the friction of the transmission chain, improve the low-speed stability of the motor and enlarge the range of speed regulation; Improve the servo system anti-load disturbance ability, so as to reduce the error caused by gust. Velocimeter is the key component of velocity measurement feedback. It should have good linearity, symmetry, small ripple, low-speed output noise, stable performance and coaxial connection with the drive motor.

The main purposes of the gyro stabilizing ring: Realize the effect of ship rocking isolation to a certain extent. The two-axis rate gyro is mounted on the reference surface of the pitching arm of the antenna pedestal, and the velocity information of the azimuth axis and the pitching axis inertial space can be sensed. The feedback closed-loop control of the velocity information can realize the design of the gyro stabilizing loop. The loop design diagram for adding a gyro stabilization loop is shown in Figure 1.
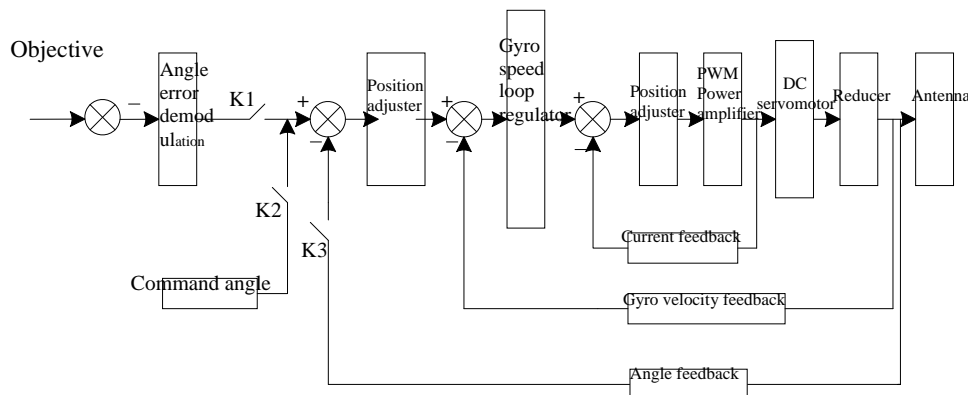

Figure 1. Schematic diagram of Loop Design with Gyro Stabilizing Loop

Position control of antenna is the purpose of all antenna servo control systems. For servo equipment, the current loop and speed loop are its control inner loop, and the position loop is its working loop. Although the position loop has different modes of operation, such as self-tracking loop, digital pilot loop and so on, they are all the same from the loop point of view, but there are different focuses in different modes of operation.

According to this design method, combined with the actual project, a digital control inner loop design and implementation scheme is given.

3. Practical Engineering Application
Take SA07 produced by APEX Company as an example.

The SA07 op amp is a 40V, 500 KHz pulse width modulated (PWM) operational amplifier. The full-bridge output circuit provides 5A of continuous output current and has a wide range of

applications for high-fidelity audio control and brushless motor control. An integrated op amp is provided that is directly connected to the PWM input pin for connection to the digital action control circuit. The protection circuits provide overheating due to overload and short-circuit protection of the power supply and ground. A programmable circuit limit determines whether to use one or two current limiting resistors depending on the application and 18-pin steel profile in sealed package. The external connection is shown in Figure 2:
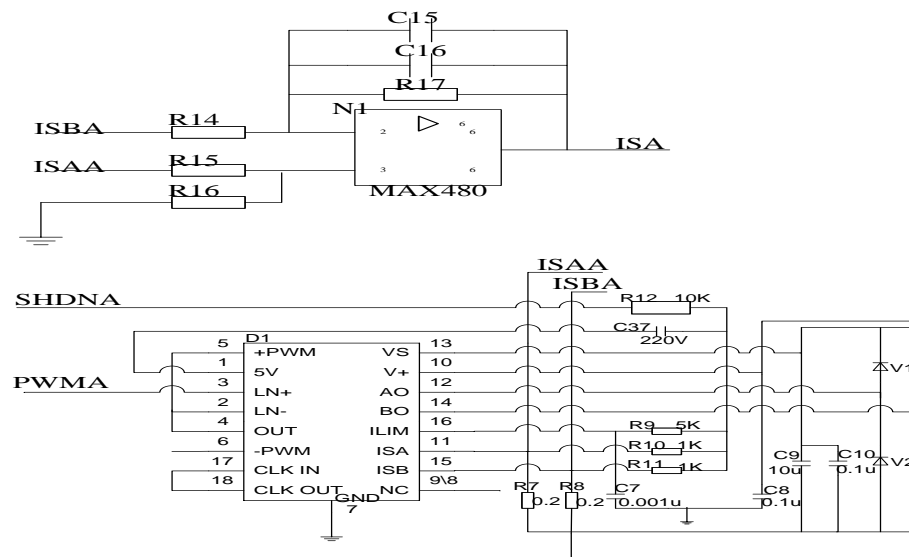

Figure 2. SA07 Connection Diagram.

As shown in Figure 2, we can sample the armature current using the 11-pin and 15-pin sampled signals that are amplified.

The main controller of the control unit can be a single chip microcomputer, DSP and so on. In this example, T1 DSP chip TMS320F240 is selected as the main control chip, and MAX1270 is selected as the AD sampling chip in the process of interface design. This chip is 8-channel input, SPI interface, and can be easily connected with DSP chip. The MAX1270 wiring is shown in Figure 3:
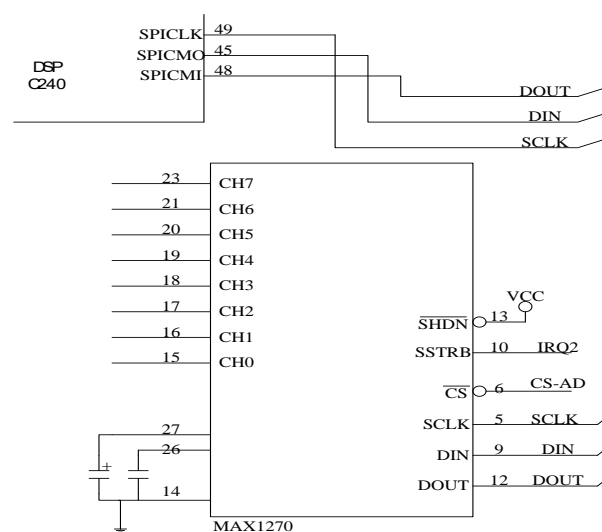

Figure 3. MAX1270 Wiring Diagram

We choose MAXIM's AD conversion chip MAX1270, the resolution is 12-bit, 8-channel input. Its interface mode is serial data interface, which mainly consists of three lines, one clock line SCL, one serial data input line SI and one serial data output line SO. Compared with the parallel data interface, it has the advantages of simple connection, flexible control, and the conversion and transmission rate can fully meet the requirements of the application.

Analog signals are collected via MAX1270. The current loop is formed by collecting the armature current signal, and the acquisition period is 5MS. A position loop is formed by collecting the resolver angle signal or the receiver error voltage signal, and the acquisition period is 20MS. The speed loop is formed by collecting the signal of the speed measuring machine, and the collecting period is 10MS.

After the signal is collected, it is sent to DSP and the control algorithm is realized by software. In the software, the loop control is realized by digital PID regulator.

A schematic block diagram of a digital regulator composed of a CPU, AD, DA, and the like is shown in Figure 4:

$$e(t) \rightarrow \boxed{A/D} \xrightarrow{e(k)} \boxed{CPU} \xrightarrow{u(k)} \boxed{D/A} \xrightarrow{u(t)}$$

Figure 4. Digital Regulator Block Diagram

The digital PID control expression is:

$$U(k) = u(k-1) + \alpha_0 e(k) + \alpha_1 e(k-1) + \alpha_2 e(k-2)$$

Of which:

$$\alpha_0 = K_\rho \left(1 + \frac{T}{T_1} + \frac{T_d}{T}\right)$$

$$\alpha_1 = -K_\rho \left(1 + \frac{2 T_d}{T}\right)$$

$$\alpha_2 = \frac{T_d + K_\rho}{T}$$

Where: $u(k)$ Output value at sampling time k

$U(k-1)$ Output value at sampling time $k-1$

$E(k)$ Deviation at sampling time k

$E(k-1)$ Deviation at sampling time k-1

K_ρ: Scaling factor

T_i: Integral time constant

T_d: Differential time constant

T: Sampling time

In order to realize the negative feedback of position, speed and current, three regulators are set in the system to adjust the position, speed and current respectively, and the three regulators are connected in cascade. That is, the output of the position adjuster is taken as the input of the current adjuster, the output of the tachometer is taken as the input of the current adjuster, and the controlled object is controlled by the output of the current adjuster. Seen from the closed loop structure, the current regulation loop is inside, the tachometer is in the middle, and the position regulation loop is outside, so as to form a position, speed and current three-loop system.

4. Conclusion

In the actual implementation process, the design and implementation of digital speed loop makes the adjustment of speed loop PID parameters easier, makes the switch between speed loop and gyro speed loop feasible, and improves the control accuracy of speed loop. According to this method, the

equipment runs stably and reliably, the loop adjustment is convenient, the control characteristic is good, the step and isokinetic test all meet the index requirement, and the system operation requirement under the offshore condition is satisfied.

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