Design and Control of High Precision two Axis Servo Scanning System in Space

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Abstract: A high precision direct drive control two axis servo scanning system in space is designed and developed. Based on the requirement of technical indicators, the high-precision direct drive control two axis servo scanning system is divided into a rotating telescope and a half angle mirror servo system. The design and analysis of the servo system’s structural design, shafting accuracy and motor options are carried out. Taking the half angle mirror servo system as an example, the electrical structure of servo system is expounded, and a compound control strategy based on all digital control drive and high precision photoelectric encoder is established, which directly drives PMSM. The circuit design and working process of servo control module are described in detail. The test results show that the speed stability performance of the scanning system can reach ±0.28%, and the servo precision can reach ±16″, and it has the characteristics of long life, anti pollution, etc, which can meet the requirements of the space high precision and long life scanning system.

1. Introduction
In the field of space optical remote sensing imaging, in order to obtain a wider field of vision, the scanning system is usually used to expand the range of incident light to increase the field of vision of the ground and the width of the camera. In recent years, the imager represented by VIIRS[1-2] adopts the whole rotation of telescope and half angle mirror compensation imaging scheme, which makes the optical system have the advantages of no image rotation, small polarization, and conducive to full aperture and all-optical path calibration. But at the same time, the high-precision two axis follow-up scanning technology is the key problem to be solved, and its performance directly affects the imaging quality.

The paper introduces the design and implementation of the space high-precision two axis follow-up scanning system from two aspects of mechanical structure and drive control. The servo system adopts permanent synchronous torque motor direct drive control mode[3-4], and realizes the design and control of two axis servo scanning system of space optical remote sensor through full digital drive control circuit. It achieves high servo precision, and has the characteristics of long life, anti pollution and high precision.

2. Technical requirement of two axis servo scanning system
(1) The rotation range of two axis servo scanning system:
   Rotation telescope: -180°~+180°
   Half angle mirror: -180°~+180°
(2) Running speed of two axis servo scanning system:
   Rotation telescope: 68°/s
   Half angle mirror: 34°/s
(3) The angle indication accuracy:
   Two shafting are both less than ±2.8″;
(4) Speed control accuracy:
   Rotation telescope: the angle error ≤±10″ every 10ms
(5) Synchronized control error: ≤±16″
(6) Life: 8 years in orbit, long-term operation

3. Overall Structural Design

3.1 Design idea
The space high precision two axis servo system is composed of a telescope scanning device, a half angle mirror follow-up device and a controller. The controller controls the telescope system to rotate 360° around the axis in the direction of crossing according to the set scanning motion law. The half angle mirror can follow the rotation scanning according to the half angle of telescope system. The rotation axis of the half angle mirror is collinear with the rotation axis of the telescope system, in order to realize the scanning and imaging of the ground and calibration of blackbody. The schematic diagram of the scanning system is shown in Fig.1.

In order to achieve the 8-years long-life and high-precision requirements mentioned in the technical requirements, grease lubrication shafting and anti pollution measures\(^{[5-6]}\) are adopted to solve the long-life and high-precision problems of mechanism. Because of the accuracy of the servo system directly affects the imaging quality of the whole remote sensor, the torque motor direct acquisition mode is adopted, which has no transmission error and return error of the transmission device, and has good low-speed and high-speed performance, excellent dynamic characteristics. The control accuracy and indication accuracy meet the overall design requirement.

3.2 Design of telescope scanning mechanism
As shown in Figure 2, the telescope scanning mechanism is composed of 1 torque motor, 2 angular contact bearing, 3 deep groove ball bearing, 4 photoelectric encoder, 5 telescopic spindle, 6 contact flange, 7 main optical components, 8 main support frame, 9 bearing sealing cover.
The main shaft of the telescope adopts a hollow structure, which provides support for the motor and the photoelectric encoder. The bearing of the scanning component is installed in a two-way fixed swimming way, and the fixed end is installed in a diagonal contact ball bearing back to back. The diagonal contact ball bearing is loaded with preload to improve the rigidity of the shafting. The deep groove ball bearing is used at the moving end to solve the axial expansion problem.

### 3.3 Design of half angle mirror mechanism

As shown in Figure 3, the half angle scanning device is composed of 1 half angle mirror assembly, 2 half angle spindle, 3 torque motor, 4 photoelectric encoder, 5 deep groove ball bearing, 6 angle contact ball bearing, 7 bearing seat, 8 bearing sealing cover, 9 fixed seat. The half angle spindle is supported on the main support by a diagonal contact ball bearing and a deep groove ball bearing, and the rotating shaft provides support for the motor and the encoder.

### 3.4 Motor selection

In the load calculation of telescope scanning system, the total load moment is composed of friction moment and inertia moment, the sum of which is 1.03Nm. Considering that safety margin of the motor is greater than 2, the continuous output torque of the telescope motor in the acceleration stage should be greater than 3.09Nm.

In the load calculation of half angle servo system, the total load moment is composed of friction moment and inertial moment, the sum of which is 0.025Nm. Considering that safety margin of the motor is greater than 2, the continuous output torque of the half angle mirror motor in the acceleration stage should be greater than 0.075Nm.

### 3.5 Design of bearing lubrication

In order to ensure the 8-years long-life and high precision of the two axis follow-up scanning system,
the solid-liquid composite lubrication scheme is adopted, and the sputtered DLC solid wear-resistant lubrication film is plated on the bearing raceway of 9Cr18 material by physical vapor deposition method, which can ensure that the bearing has less wear and smooth operation between the parts in the operation stage. The multi hold rubber cloth is used as the cage for oil storage.

4. Servo control system

4.1 System structure and control strategy

The control principle of telescope scanning system and half angle servo system is basically the same. The following is mainly about half angle servo system.

The half angle servo system is mainly composed of half angle control drive combination, half angle torque motor and photoelectric encoder. The half control drive combination is mainly composed of control module, power configuration module and motor.

The control principle block diagram of half angle servo system is shown in Figure 4. The servo system is controlled by DSP, the half angle control module complete the position closed-loop, speed closed-loop and current closed-loop according to the predetermined control strategy, and then generates the motor drive quantity. The PMSM signal with variable duty cycle is formed by FPGA and input it to the motor driver. The motor driver collects the angle information of the photoelectric encoder as the feedback input of the position loop, and uses the difference of the position information as the feedback input of the speed loop. At the same time, a current loop control circuit is formed in the motor driver.

The half angle servo system adopts the improved cross coupling control strategy, and the system control structure is shown in Figure 5. At the same time, the half angle tracking accuracy is improved. Compared with master-slave synchronization and master-slave synchronization, the tracking accuracy of the cross coupling synchronization control strategy can be significantly improved.

(1) Design of current regulator

PI control is used to correct the servo control into a type I system, so that the system’s current does not appear too much overshoot when the load is disturbed.
Where $K_i$ is the proportional coefficient of the current controller, and $\tau_i$ is the lead time constant of the current controller. In the half angle servo system, $K_i = 1$, $\tau_i = 0.01$

(2) Design of speed regulator

PI control is used to correct the speed loop into a type II system, the transfer function of the regulator is below:

$$W_{ASR}(s) = \frac{K_n(\tau_\alpha s + 1)}{\tau_\alpha s}$$

(2)

Where $K_n$ is the proportional coefficient of the speed controller and $\tau_\alpha$ is the lead time constant of the speed controller.

In the half angle servo system, $K_n = 1$, $\tau_\alpha = 0.1$

(3) Design of position regulator

Because of the forward channel of the control object has an integral link, and the tracking command is a constant velocity curve, so the position loop regulator adopts PI control, which can achieve steady-state error free. The transfer of the regulator is as follows.

$$W_{APR}(s) = \frac{K_p(\tau_\rho s + 1)}{\tau_\rho s}$$

(3)

In the half angle servo system, $K_p = 1$, $\tau_\rho = 1$

(4) Design of synchronous control regulator

The synchronous control regulator takes the half angle mirror position closed-loop transfer function as the object. The falling amplitude depends on the parameters of the synchronous regulator.

4.2 Control module design

The control module is the core of the servo control system. The module is mainly composed of DSP (TMS320C6701, TI company) and FPGA (AX2000, Actel company). DSP is used to calculate closed-loop algorithm. FPGA is used to realize data exchange, complete data acquisition of photoelectric encoder, calculate half angle servo error and output pulse width modulation signal to motor driver.

5. Test Result

The Physical diagram of the system is shown in Figure 6. Figure 6 shows the telescope scanning mechanism, half angle mechanism and a set of control system, which mainly includes the signal controller, related power supply, upper computer and simulator for debugging.

Fig.6 Physical diagram of mechanism and control system of two axis servo system

In order to test whether the two axis servo scanning system meets the technical requirements, Labview is used to build the upper computer interface to receive the real-time data of telescope and
half angle mirror sent by the serial port. The data utilization rate is 100us. The measured results are shown in Figure 7(a) and Figure 7(b).

![Fig.7(a) angle error of the telescope](image1)

![Fig.7(b) synchronization error of half angle mirror](image2)

It can be seen from Fig.7(a) that the angle error of the telescope is less than ±5″ every 10ms, and the synchronous of half angle mirror is less than ±15″, which meets the technical requirements.

6. Conclusion

In this paper, based on the development of space high precision two axis servo scanning system, the structure design and synchronous control are analyzed and designed. Using torque motor direct driver control mode, through full digital drive control circuit and high-precision photoelectric encoder, the speed stability of the telescope can reach 0.28% under the condition of large angle and friction torque disturbance, and the synchronous error can reach ±15″, which meets the requirements of high-precision control.

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