A New Design of Large Aperture Telescope Drive System

Li Xiaoyan, Zhang Zhenchao, and Wang Daxing

Abstract. The drive system used in large aperture astronomic telescope has some particular demands such as smooth operation, high accuracy, good repetitiveness, etc. Traditional friction or gear drive system has some nonlinear disturbs that are hard to be eliminated. A new drive control system based on a permanent magnetic alternating current motor integrates the motor and the load, that is to say, the transmission part between them is deleted. The motor is composed of several segment motors which assembled equispacedly and can work independently and synchronously. The actuating force acts on the whole structure, rather than only gear or master wheel. Muti-motor synchronizing and segment motor control method are discussed in the paper.

Keywords: drive system, permanent magnetic alternating current motor, segment motor, large aperture telescope, intelligent control method, Muti-motor synchronizing.

1 Introduction

In company with the development of astronomy, the astronomical telescope demands larger aperture and higher precision. In 1990's, a group of 8-10 meters ground-based optical/infrared telescopes were manufactured and brought into commission. In this decade, a new generation of 30-meter giant astronomical telescope is under development which represents the level of astronomical facilities in

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Z. Qian et al. (Eds.): Recent Advances in CSIE 2011, LNEE 129, pp. 345–353.
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the next 10-20 years. Chinese astronomical technical experts also carried out the research of key techniques in large astronomical telescope. Telescope drive control system is one of the key techniques.

The demands of large telescope drive system are big inertia force, low speed, and high precision. GTC (Gran Telescope CANARIAS in Spain) is a telescope with 10.4 meter aperture. The maximum moment of inertia of GTC azimuth is 1.2×10^7 Kgm^2. TMT (Thirty Meters Telescope) which is under development with 30 meters aperture has a moving mass of about 1430 metric tons and moment of inertia of about $2\times10^8 Kgm^2$.

Four motion modes of the telescope drive system are fast moving, positioning, guiding and tracking.

1) Fast moving. Aim to change the direction of the telescope tube. The maximum velocity is 1°~3°/sec. The period from still to the maximum velocity should not beyond 6 seconds. On emergency braking, the inertial motion of the telescope should not be over 2°。

2） Positioning. Aim to find the target object in the middle of the telescope field of view. Positioning velocity is about 2′/sec. The positioning precision (also called pointing precision) is under ±1″~2″.

3) Guiding. Aim to find the target object and keep the target in the middle of the telescope field of view. Guiding speed is about 0~±5″/sec or 0~±60″/sec. It depends on the telescope structure.

4) Tracking. Aim to keep the speed of the telescope as the same as the apparent speed of the target object and make the target stable in the field of view. Exact tracking request the error should not be over 0.1″in a period of 1minute and 0.2″in 8 minute. [1]

In the past, gear driving, worm driving and friction driving were adopted as drive system for small and medium telescope. The drive force acts on the gear or master friction wheel. About 10%-50% of the electric machine force power will be consumed. Some nonlinear factors such as gear clearance and frictional resistance etc. make it hard to enhance the transmission accuracy.

2 A New Design of Large Aperture Telescope Drive System

A new project is designed using mechanotronics technology and deleting mechanical decelerate part and taking the load of telescope directly as a part of the rotator of PM motor. The PM motor composed of multiple segment motors is a multi-functional combined machine. The actuating force act on the whole structure of the telescope.

Each segment drive motor can work independently and meet the demand of the system. These segment motors combine as a whole motor to drive the telescope. The system would not ruin when some segments were wrong or maintained, for the others could still work. In addition, multiple segment motors driving system can greatly reduce the thermal produced by the machine. It is beneficial to not only improve the efficiency of the motor but also keep the optical path more stable during the telescope operating.

Fig.1 shows the structure mode of the motor which is assembled with 12 segment motors. Fig.2 shows three of these motors are mounted.

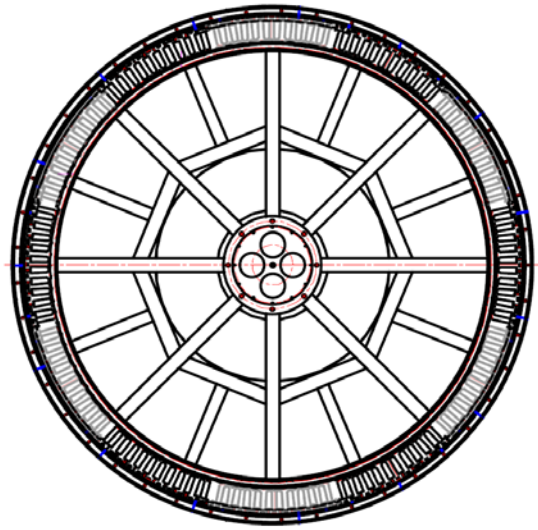

Fig. 1 Multi segment motor structure model

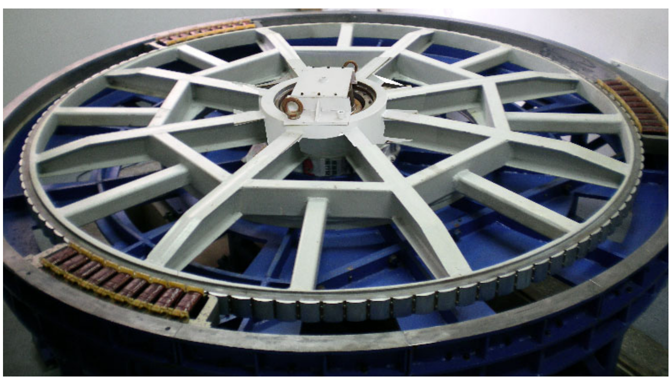

Fig. 2 Multi segment PM AC motor

- Segment motor control structure

Each segment motor can work independently, which has individual drive circuit and current feedback control element. Servo control system with current, position and velocity closed-loop is adopted to ensure the segment motor's performance.

Fig.3 shows the segment motor control system.

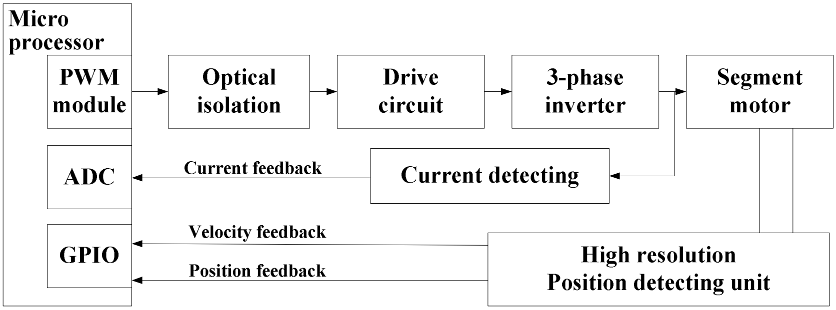

Fig. 3 Segment motor control system

Current correction is a control loop in the first level of the system. It can control the structure of inner loop and improve the speed of the system, suppress the disturbance in the current loop in time and limit the maximum current. In addition, the current control is advantage to ensure the system enough acceleration torque and safe operation.

The role of the speed correction is to inhibit the speed fluctuations and enhance the capacity of the system against load disturbances.

The main function of the position correction is to ensure the accuracy and tracking performance of the system. It is directly related to the performance of servo motor. Position servo system controller is required to have fast, non-overshoot response, and strong robustness.

Each segment motor has separate current sensors in its current loop. While all the segment motors share the same high-resolution position sensor. This sensor is an incremental encoder composed of the scan head, ruler carrier and ruler strip. The ruler strip is installed in the inner slot is shown as Fig.4.

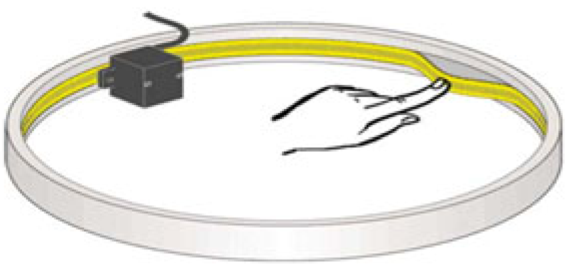

Fig. 4 High-resolution position 0073ensor installation

- Multi segment motors drive control system

The key point of Multi-motor synchronized driving system is to ensure all the segment motors have synchronic dynamic characteristics in operation, making the multi-motor system run as a single-motor system.

At present, there are mainly two multi-motor synchronized driving structures: coordinate control and master-slave cascade control. [6] If chosen the former all the segment motors share the signal from computer, so startup lag doesn't exist. While in the latter structure the master motor receives the given input signal and the other motors receive signals from the master motor, this structure is more flexible. In view of the telescope drive motor's feature of low speed, the effect of startup lag can be ignored, so master-slave cascade control method is chosen.

Multi-segment motors drive control system is shown as Fig.5.

Main computer communicates with the microprocessor of segment motor I which acts as master motor and specifies the position or speed. As a master control unit, the microprocessor calculates the position or speed and sends it to the appropriate microprocessor of motor II, III,…, N. When the master microprocessor communicates with others through GPIO port, tri-state data buffer enhances the power of signal.

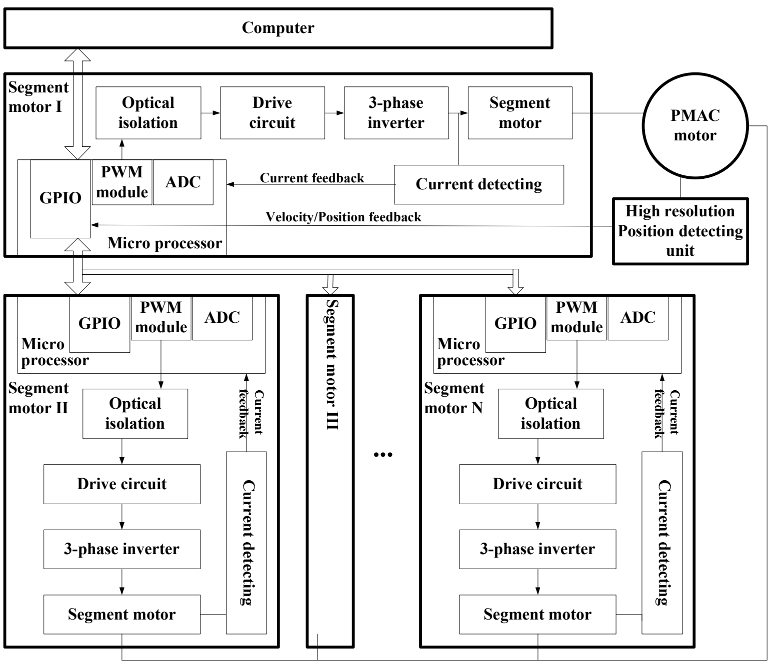

Fig. 5 Multi segment motors drive control system

- Servo control strategy

Common control strategies applicable to AC motor model include direct torque control and vector control. The main defection of the direct torque control is the torque ripple of low speed, so it is not suitable for telescope drive system. Vector control method is chosen in current servo control. The essential of id=0 vector control method is to regulate the current of PM AC motor. The principle of vector control was described in many literatures. [4][5]

Sliding mode variable structure is adopted in velocity and position servo control to meet the high performance and complexity of AC servo control system. This intelligent control method which is independent of the object model is a good strategy to control velocity and position.

Sliding mode control has many advantages such as strong robustness, not sensitive to the parameters etc. But the defection of it is that a precise mathematical model should be established while the telescope control system is nonlinear, strong coupled and time-varying.

Variable structure control system has better performance than fixed structure system by changing the structure of the controller itself.

So Sliding mode control and variable structure control are integrated to meet the high performance and high precision requirements of the telescope drive system. Fig.6 shows the sliding mode variable structure.

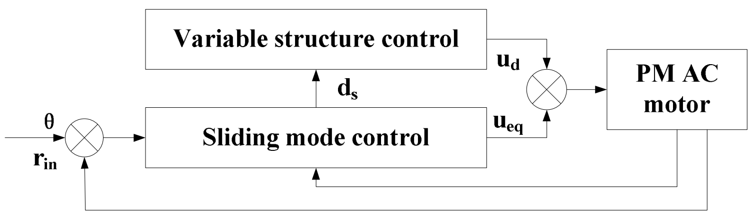

Fig. 6 Sliding mode variable structure

3 Software

The function of the drive system software is shown as below:

1. Current detection and correction of the segment motor.
2. Position detection and velocity calculation of the segment motor.
3. Calculating target position or velocity value of slave segment motor.
4. Power drive protection and other assistant module.

Several main modules routine processes are discussed in the following:

- Main routine flow process

The main routine is to initialize each sub-function module, open interrupt, enter into waiting loop routine and wait for interrupt. When interrupt occurs, interrupt service routine executes automatically. After that, the routine will be waiting for the next interrupt occurs.

Flow chart is shown as Fig.7:

- Interrupt service routine

Another important program is the interrupt service routine which implements close-loop control. The main function of the routine is acquiring current feedback, adjusting the current, coordinate transformation, reading position signal and producing PWM signal etc.

Fig.8 is a flow chart of the interrupt service routine:

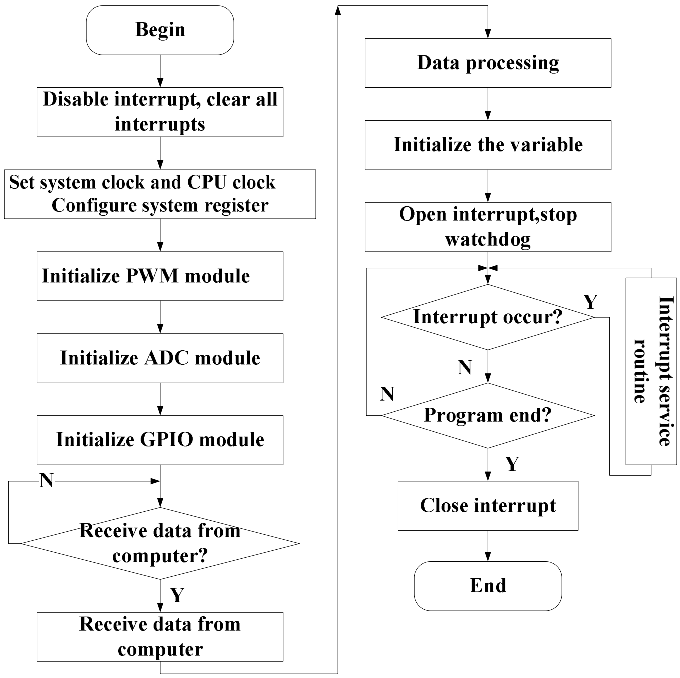

Fig. 7 Main routine flow chart

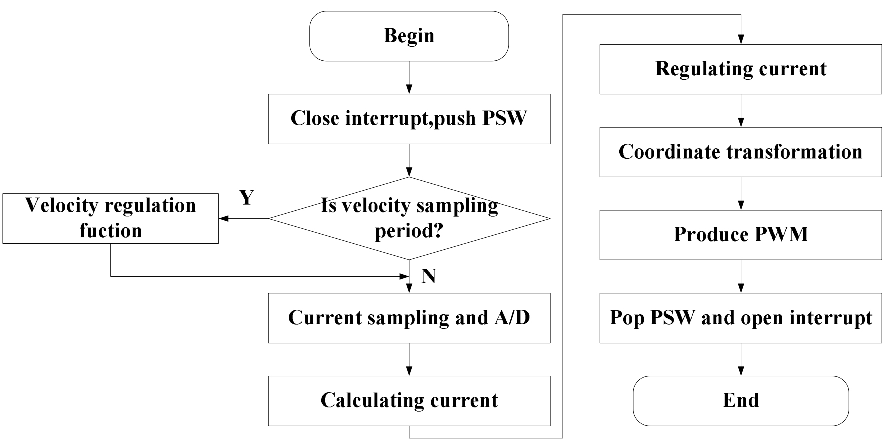

Fig. 8 Interrupt service routine

- Current sampling routine of segment motor

There are many methods to detect the current, such as resistor, current mutual inductance and hall effect current sensor etc. Hall current sensor has advantages of non-inertia, high accuracy and good isolation effect.

The maximum current ($-I_{Pmax} \sim +I_{Pmax}$) of hall current sensor is correspond to the output voltage ($V_{ol} \sim V_{oh}$). Before the output voltage is put into microprocessor, it is transformed by power amplifier circuit and voltage bias circuit.

The microprocessor converts the analog signal into digital signal by the A/D module. Assuming the digital signal have N bit, the number ($0 \sim 2^N-1$) is correspond to the input current ($-I_{Pmax} \sim +I_{Pmax}$).

- Velocity detecting and sliding mode variable structure velocity regulating subroutine

Rotor's position and velocity can be get by high-resolution photo-electric encoder. Then the value is sent to the microprocessor after optical isolation. Absolute number of pulses can be get by reading the relevant counters.

The relationship between rotor's position and speed is derivative. T method is the common speed detection method and the precision is high when the speed is low.

T method is counting m, the number of high-frequency clock pulse by measuring two adjacent pulse of quadrature encoder, in a pulse cycle output by the encoder. The velocity can get from the equation:

$$n=60f_0/(Pm)$$

f_0- the frequency of high-frequency clock pulse

P-the number of pulses generated by the encoder during a motor revolution time

Regulating the velocity should be done after the velocity is calculated. The flow chart is shown as Fig.9：

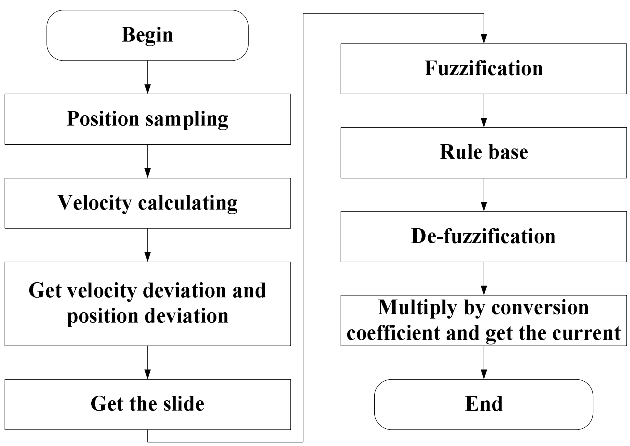

Fig. 9 Velocity regulating routine

4 Conclusion

In this paper, a new design of telescope drive control system is discussed. The telescope load is integrated with the AC motor which is composed of a number of segment motors. All segment motors synchronized adopt master-slave control method. Each segment motor can work independently. Sliding mode variable structure is chosen in the velocity and position regulating, while vector control method used in the current regulating.

A lot of work should be done to build a 30-meter diameter telescope. This paper is an exploratory experiment for the next step.

Acknowledgments. This paper is supported by the Knowledge Innovation Program of the Chinese Academy of Sciences, Grant No.KJCX2-YW-T17.

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