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Research on a new position actuator control technology for segmented primary mirror telescopes

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Research on A New Position Actuator Control Technology for Segmented Primary Mirror Telescopes

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Abstract: Active optical primary mirror segmented technology is one of the most critical core technologies for ground-based large optical infrared telescopes. The co-phase segment of mirror surfaces is the fundamental guarantee for giving full play to the optical performance of large primary mirrors. To achieve this goal, the performance of the position actuators presents a huge challenge. Considering the two key indicators of control accuracy and power consumption, we developed a new compound position actuator, which consists of a fine-tuning mechanism and an active offloading mechanism. For this new type of actuator, we have developed a high-performance control system based on the active disturbance rejection control algorithm. The experimental results show that the position actuator system we developed can achieve high-precision position tracking and position control，can meet the index requirements.

Keywords: Segmented mirror; Position actuator; Active optics; Voice motor; ADRC

1 Introduction

The emergence and development of active optics technology has greatly reduced the cost of telescopes, and at the same time, it has also provided technical reserves for the development of larger telescopes. With the maturity and continuous development of related technologies, scientists have focused their attention on the development of the next generation of very large optical telescopes. In order to meet the requirements of co-phase observation of segmented mirror telescopes, it is necessary to ensure that the relative displacement between the sub-mirrors is controlled at the level of ten nanometers. The influence of the mirror diameter is increasing, and in this case, higher demands are also placed on the dynamic performance of the position actuator. The currently applied position actuators all use the structure of a driving device plus a scaling mechanism. This type of position actuator converts the rotational angular displacement of the driving motor into a linear displacement, thereby realizing a linear

position output. This process will not only affect the dynamic performance, but also introduces nonlinear errors. At present, the thirty-meter telescope in the United States and the European Extremely Large Telescope are in full swing[1,2]. Among them, the displacement actuator is a key core component. Compared with the position actuator on the previous generation segmented mirror telescope, the structure and performance have been greatly improved. In terms of structure, the new position actuator adopts a composite design, which ensures the output accuracy under the premise of satisfying the large stroke. This paper describes a new type of compound position actuator that we have developed for the China Future Giant Telescope (CFGT). The schematic diagram is shown in Figure 1. The position actuator is divided into an offloading part and a driving part . The offloading part mainly bear most of the load of the segmented mirror, and the real-time dynamic response is not high. The driving part is used to finally ensure the output accuracy and real-time performance of the position actuator.
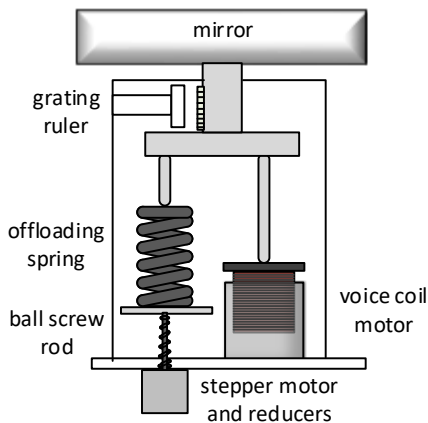

Fig. 1 Structural schematic diagram of compound position actuator

2 Indicators and Features

The design indicators of the current position actuator are as follows:

Table 1 design indicators of the current position actuator

Total stroke	＞45mm	
Load	150kg	
Mass	<15kg	
Lifespan	>5years	
Position control accuracy	Coarse part	1um
	Fine part	5nmRMS
Power consumption	<2W	operating mode

CFGT position actuator belong to soft actuator, and "hard" and "soft" refer to the stiffness of the actuator itself when the servo system of the position actuator is turned

off [3]. For a hard actuator, its own stiffness can effectively suppress low-frequency vibration, and the control system is mainly used to ensure the accurate output of the position. However, the output of the hard actuator in the high-frequency region will show low damping resonance, that requires increasing damping to suppress high-frequency vibration signals [4], and that will greatly increase the complexity of the position actuator design. During the tracking and observation process of the telescope, the equipment installed on the truss and the anti-focus platform is always in working state, and the high-frequency vibration signal generated by the work will be transmitted to the mirror surface through the hard actuator, thus affecting the segmented accuracy of the mirror surface. The frequencies of such interference signals are generally outside the control bandwidth and cannot be effectively suppressed. In the future, the large optical telescopes, such as TMT and ELT, plan to use position actuators based on voice coil motor, which is soft actuators.

The voice coil motor is a special form of linear drive motor designed based on the Lorentz force principle[5,6]. In theory, voice coil motors have the advantages of zero hysteresis, high response, high precision, small size and infinitely small resolution, and are widely used in high-precision position control systems. The reason for choosing this type of "soft" actuator is that the new position actuator based on the voice coil motor acts as a low-pass filter and can better suppress the position actuators of this type currently in use. The frame vibrates at high frequency, however, for the interference at low frequency, a high-performance control system is required to suppress it by providing servo stiffness, thereby ensuring the high-precision output of its position.

3 overview of the current actuator design

The CFGT position actuator is divided into two parts, which adopts a series combination structure, as shown in the figure 2, a fine-tuning mechanism and a coarse-tuning mechanism. Among them, the fine part is composed of a voice coil motor and a high-precision grating ruler encoder. The coarse-tuning mechanism, also known as the offloading mechanism, is mainly composed of a stepper motor, a rotary encoder, a ball screw and a load spring, and bears most of the weight of the sub-mirror chamber (mirror and its supporting structure). Because the telescope in the observation process change the direction constantly, so the gravity acting on the axis of the actuator will also change accordingly. If the voice coil motor is used to compensate for this part of the change, it will need to increase the higher power, and at the same time will generate a lot of heat. Finally this will affect telescope observations.
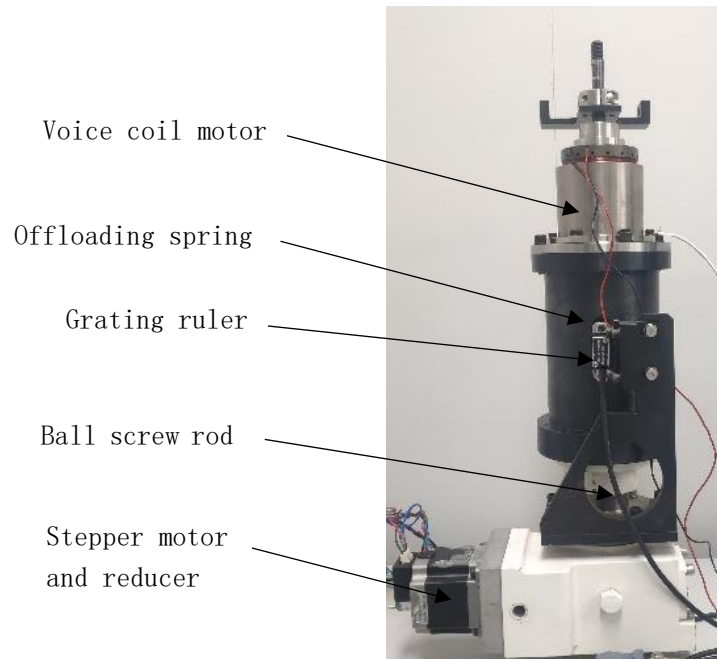
Fig. 2 CFGT position actuator structure diagram and physical diagram

The work flow is shown in the following figure 3: It is divided into two steps. First, judge according to the target stroke, and if the stroke of the fine-tuning mechanism is exceeded, the coarse-tuning mechanism starts to act. When the actual position enters the stroke range of the fine-tuning mechanism, the voice coil motor acts, and finally achieves nano-level position tracking.
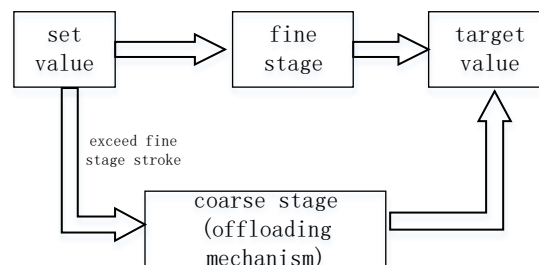

Fig. 3 CFGT displacement actuator working flow chart

4 Control system development and verification

4.1 coarse stage

For the coarse-tuning mechanism, we use mature PI control algorithm for control, and the rotary encoder measures the rotation angle of the stepper motor to ensure that the motor does not lose steps, and the position feedback is also obtained by measuring the grating sensor. The control accuracy of the coarse-tuning mechanism is shown in the

figure 4. The picture shows the control accuracy of the coarse-tuning mechanism measured by the laser interferometer, and its value is less than 1um.
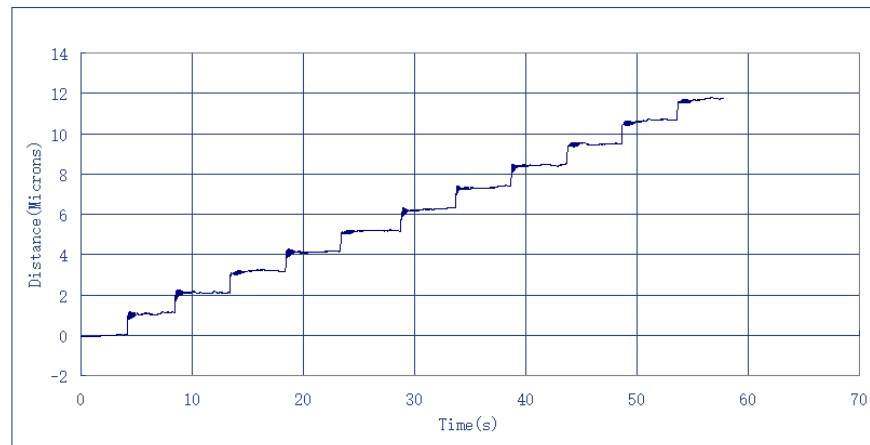

Fig. 4 control accuracy of the coarse-tuning mechanism

4.2 fine stage

In the design process of the control system, we simplified the fine-tuning part into a mathematical model based on mass-spring-damping, according to the voltage balance equation of the voice coil motor and the mechanical balance equation of the position actuator, ignoring the influence of the coil inductance of the voice coil motor[7]. The system is simplified to a second-order system, and the mathematical model of the fine-tuning part of the position actuator is constructed. After Laplace transformation, the transfer function of the system is obtained as:

$$\frac{x(s)}{E(s)} = \frac{K_a}{RMs^2 + (LK_s + K_aK_c)s + RK_s}$$

The linear active disturbance rejection algorithm proposed by Professor Gao is used to design the controller[8,9]. First, the system transfer function is transformed into the form of state equation, and the linear expansion state observer is used to observe the system state in real time, and then design the control law. Simplify the system to a double integral system. Finally, the PD controller is used for position control

The control algorithm of the whole system is realized on the STM32F407 chip, and the upper computer is responsible for sending instructions and data collection, display and storage. Relevant testing work is currently underway and some progress has been made, as the picture shows.
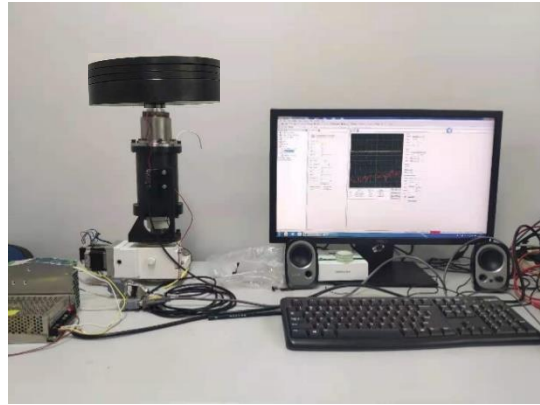
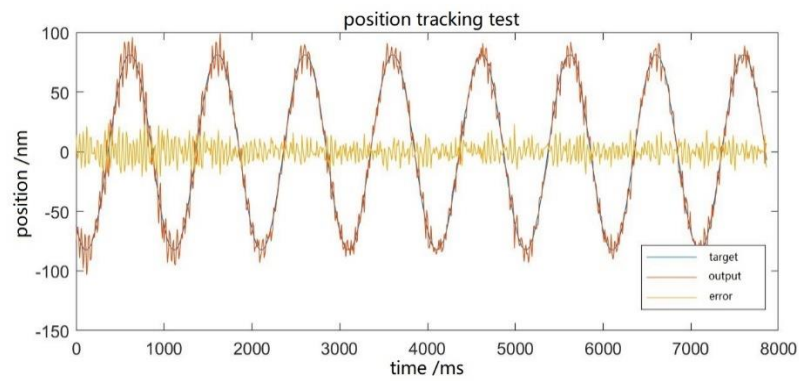Fig.5 position actuator test system

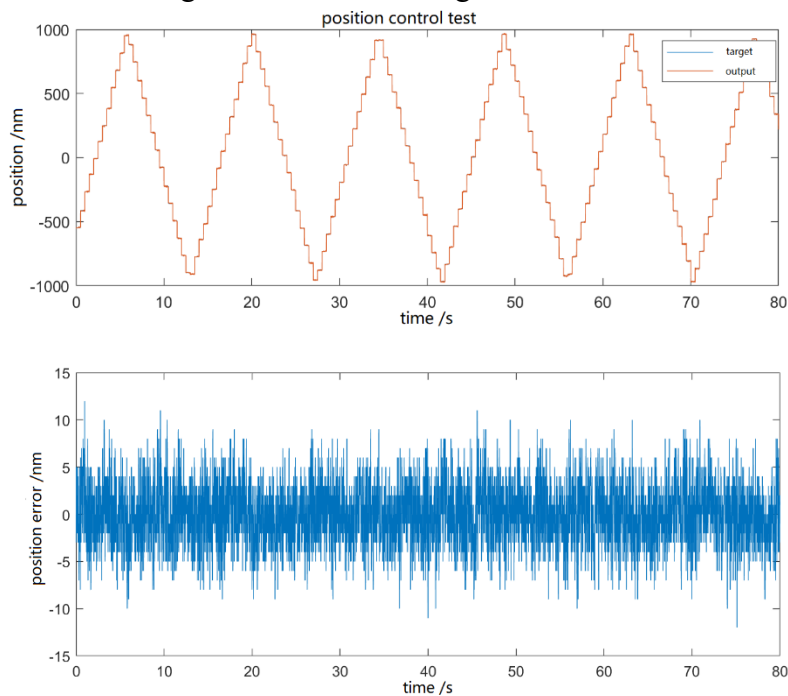Fig.6 sinusoidal tracking control at 1 Hz

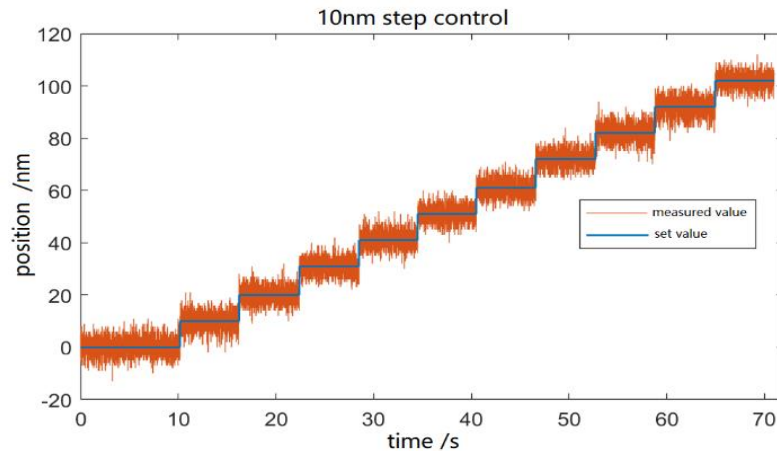Fig. 7 position control within a large travel range

Fig.8 tiny position control at 10 nm

We performed sinusoidal tracking control at 1 Hz, position control within a large travel range, and tiny position control at 10 nm, respectively. The experimental results show that the position control accuracy is 3.15nm (RMS), which is comparable to the control accuracy level of TMT and ELT. In terms of power consumption, in the tracking mode, the power consumption of the fine adjustment mechanism is 0.686W, which is almost the same as the power consumption of the position actuator of the ELT.

In the next step, we will carry out more detailed test work and improve the test content.

5. Acknowledgments

1   Schöck M, Els S, Riddle R, Skidmore W, et al. Thirty Meter Telescope Site Testing I: Overview. Publications of the Astronomical Society of the Pacific 2009, 121(878): 384-395.

2   Gilmozzi R. The European ELT: status, science, size, SPIE, vol. 6986. 2008.

3   Thompson PM, Macmynowski DG, Regehr MW, Colavita MM, Sirota MJ. Servo design and analysis for the Thirty Meter Telescope primary mirror actuators. Proceedings of SPIE - The International Society for Optical Engineering 2010, 7733(1): 77332F-77332F-77314.

4   Sedghi B, Dimmler M, Müller M, Kornweibel N. Improving E-ELT M1 prototype hard position actuators with active damping. vol 9906. SPIE, 2016

5   Zuo H, Li H, Zhou GH, et al. A prototype experiment of the adaptive deformable mirror based on voice coil and Eddy Current Sensor. Advances in Optical Astronomical Instrumentation 2019. SPIE, 2020, 11203: 37-38.

6   Li H, Hao HB, Zuo H. High precision shape control of large deformable mirrors for adaptive optics. Adaptive Optics Systems VII. SPIE, 2020, 11448: 1142-1145.

7   Li H, Zhang ZC, L GP, et al. Active disturbance rejection control of position actuator system for segmented mirror telescope. Infrared and Laser Engineering, 2019,48(02):186-193.

8   Han JQ. Auto-disturbance rejection controller and its applications. Control and Decision, vol. 13, Jan. 1998, pp. 19-23

9   Gao ZQ. Scaling and Bandwidth-Parameterization Based Controller Tuning. Proceedings of American Control Conference, 2003, pp. 4989-4996.