

Tip-Tilt Mirror, a Key part of the Stellar Interferometer

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ABSTRACT

The role of the tip-tilt mirror in the stellar interferometer is introduced. Tip-tilt mirror construction, work theory and mechanical design are discussed in detail. According to the facilities we already have had, we designed two sets of measurement system to measure two important parameters: tip-tilt mirror movement range and its frequency response. The result was given which shows good quality of this tip-tilt mirror we design.

Keywords: Stellar Interferometer Tip-Tilt Mirror PZT

1 INTRODUCTION

Stellar interferometry^[1, 2] is one of the key technologies for high resolution of astronomical observation. To a stellar interferometer, equal optical path and parallelity of the interference beams are two important points to get interference fringes and measurement result^[3, 4, 5].

Tip-tilt mirror system measures and controls the beam parallelity. Normally, two sets of tip-tilt mirror systems are arranged in the two arms. With this two mirror systems' self-adjustment, it keeps parallel $\leq 0.2''$. The tip-tilt wave front caused by the atmosphere disturbance is random. Maximum disturbance frequency would reach to 100 Hz, which leads to the tip-tilt mirror system's adjustment frequency by 100 Hz.

Tip-tilt mirror is an executive body of the tip-tilt mirror system which has many difficulties to design in order to acquire the wave front precise parallel and corrected frequency. This paper discusses the tip-tilt mirror construction, work theory, mechanical design and tip-tilt mirror character parameters measurement. The prototype of the stellar interferometer works well.

2 CONSTRUCTION AND WORK THEORY OF THE TIP-TILT MIRROR SYSTEM

Fig. 1 is the picture of the tip-tilt mirror. Fig. 2 is the theory schematic of the tip-tilt mirror system. It consists of tip-tilt mirror, 8098 controller, high voltage supply for PZT, sensor for beam direction. Starlight arrives at the circular mirror after the tip-tilt mirror. It passes through the circular mirror center, comes to the beam combiner and produces interference fringes. The part which concludes exterior of the circular mirror and its following facilities such as lens, quadrant prisms, photon counters is the beam direction sensor part. Part of the light reflected from exterior of the circular mirror is focused by the lens and comes to the quadrant prisms whose function is beam direction detector. Photon-electric multipliers get photons, 8098 controller collects photons and calculates the beam direction error. If the error is larger than a threshold, which is $\pm 25''$ in our system, it will be sent to the telescope in coarse adjustment. Otherwise, it will be sent to PZT in fine adjustment.

It should consider the fraction and inertia influence to design the tip-tilt mirror construction. Great efforts should be

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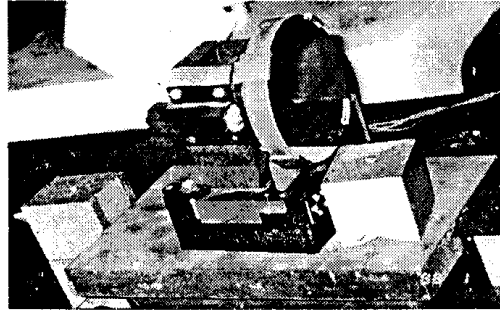


Fig.1 the picture of the tip-tilt mirror

made to get good mirror surface quality, mirror room and rotation point support design. PZT has the character of high frequency response and high movement resolution. It is selected as the executive part after non-linear correction.

With these effective steps, the tip-tilt mirror fulfills requirements of high movement resolution , high adjustment frequency and large tilt angle range.

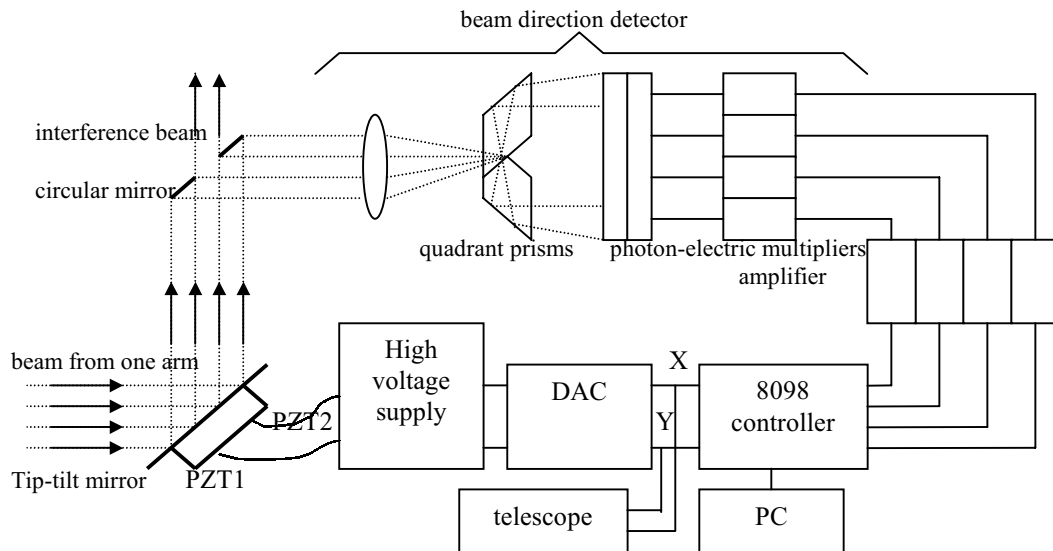


Fig.2 The theory schematic of the tip-tilt mirror system

3 TIP-TILT MIRROR SYSTEM DESIGN

3.1 8098 controller and high voltage support

The controller uses 8098 CPU on-slice to make up a control system. The TxD and RxD of the system interfaces with the series port of the computer. 8255 parallel port of the system is connected with the input of high voltage supply through DAC.

8098 controller generates 0v~10v controlling signal. This voltage is amplified to 30v~350v to drive PZT work. Fig. 3 is the theory schematic of the high voltage driver.

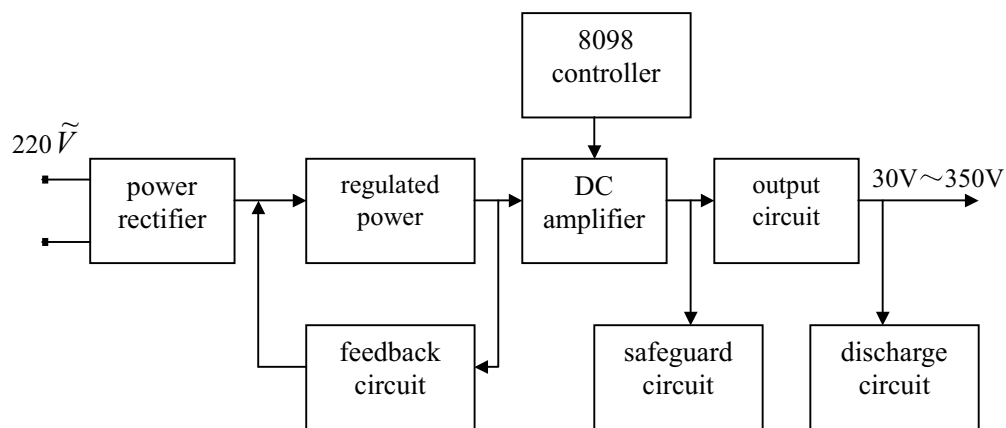


Fig. 3 theory schematic of the high voltage driver

The power rectifier and regulated power circuit turn the 220v AC into regulated DC which is the datum power supply for its following amplify circuit. Feedback circuit is adopted in this circuit design. DC voltage amplifier circuit is consisted of operational amplifier (such as LF 357) and large power tube. The control signal 0v ~ 10v from the controller is amplified to 30v ~ 350v through the amplified circuit. Safeguard circuit is adopted to insure work reliability. Output part of the circuit is the emitter style of the compound tube which functions as current amplifier and buffer. It can raise the circuit drive ability and cut off the effect to the preceding circuit. Discharge loop is the comparator composed by operational amplifier. It makes the triode conduct when the output voltage goes down. The power on the PZT drops quickly through the discharge loop and resets PZT rapidly.

3.2 PZT

As the executive part of the tip-tilt mirror system, it should be considered to full about the atmosphere disturbance. The interference time is 10 ms. The atmosphere disturbance frequency can reach to 100 Hz. So the tip-tilt mirror should be able to work at least at 100 Hz. The frequency response of PZT is as high as 1000 Hz (it mechanical inertia and fraction moment should be as small as possible). We ask Nanjing University of Science and Technology to make PZT part. Its character parameters can be seen in Chart 1

3.3 Mechanical design for the tip-tilt mirror

There are several constructions for the tip-tilt mirror. Fig. 4 (a) is a general construction. It is long life, but the structure is complicated and requires large space. Its frequency response is very low, together with bearing friction and material inner friction. Fig. 4 (b) is the structure of German PI company's product. It is a simple and compact structure without exterior friction. Its inner friction occurs only when the material deforms. It has high frequency response, but it has unrational force link which is easy to be broken when the link suffer from high frequency force. It is short life. There is error between rotation center and mirror center, which will cause optical path difference along the adjustment direction.

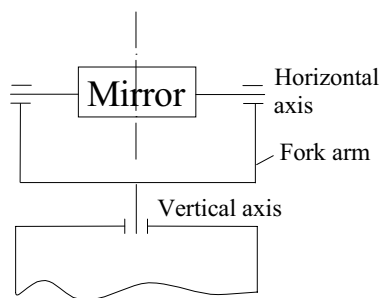


Fig. 4 (a) The general construction

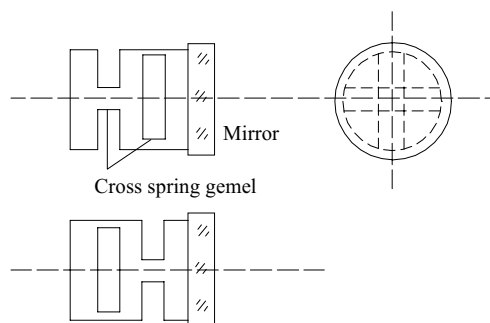


Fig. 4 (b) The PI product construction

In order to get high frequency response, high resolution, long life tip-tilt mirror, an original design for the system is introduced in our system. The basic principle of this method is to use axis ball to hold the mirror and the mirror room. A special structure will be used to push tightly against the mirror frame with a spring which has short range effect and makes a stable connection between the mirror and the axis ball. This structure becomes a two dimension rotation axes. Two PZTs force against the below and right side of the mirror frame back separately. When PZT elongates, the mirror frame rotates with the axis ball slightly, with a large force by the spring connected with the PZT to form a reverse torque. The advantages of this method are: small fraction damp, high response frequency, high resolution, long usage life, no special materials and manufacture technics. Its structure is compact and simple. Fig. 5 is the force system of this structure. P_1, P_2, P_3, P_4 stand for the force produced by the springs. Δ is the distance between P_1 (or P_2, P_3, P_4) and ball center. A stands for the force produced by the axis ball when it resists against P_1, P_2, P_3, P_4 . Q stands for the weight of the mirror movement part. D is the distance between the center of movement part and the ball center. F_x and F_y are the forces along the X and Y direction produced by PZT. l is the distance between PZT and the ball center. The relations between these series forces are the following formula:

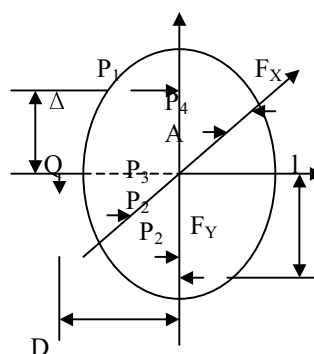


Fig. 5 Force system of the structure

$$\begin{aligned}\sum P_i &= A + F_x + F_y \\ P_1 \Delta + F_x l &= P_2 \Delta + QD \\ P_3 \Delta + F_x l &= P_4 \Delta\end{aligned}$$

4 TIP-TILT MIRROR CHARACTER MEASUREMENT

The tip-tilt mirror character parameter should be measured to see if it fulfills the work requirements. The parameters includes the mirror movement range, resolution and frequency response.

4.1 The tip-tilt mirror movement range and resolution measurement

Fig. 6 is the measurement system for the tip-tilt mirror movement range and resolution.

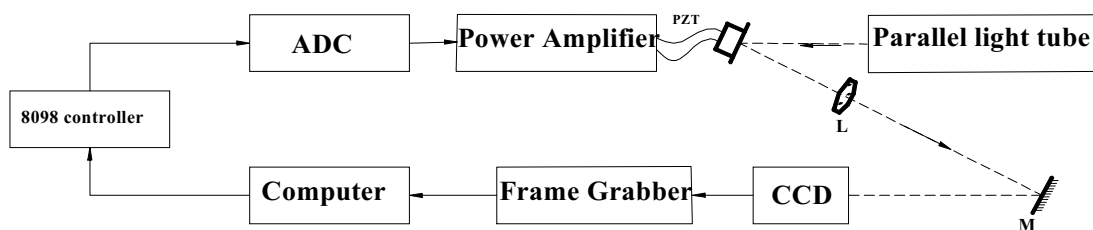


Fig. 6 Measurement system for the tip-tilt mirror movement range and resolution

There is a mask with a $50\text{ }\mu\text{m}$ hole at the output of the parallel light tube. This parallel light spot comes to the tip-tilt mirror, lens L and mirror M and arrives on the CCD camera. PC sends commands to 8098 controller so that PZT makes the tip-tilt mirror move step by step. The whole range is 512 steps. Each step the tip-tilt mirror rotates, CCD will take a picture of the light source (a small spot). The computer calculates the spot weight position. Each time PZT moves a step by the computer commands, the system will measure the spot weight position and get the tip-tilt mirror measurement. PZT parameters are shown in Chart 1.

Chart 1 The character parameters of PZTs

No.	The maximum extension μm	nonlinear
1 #	5.51	4.5 %
2 #	5.63	4.3 %

Chart 2 The theory rotation range of the tip-tilt mirror

No.	Rotation angle range "	Resolution of the rotation angle
1 #	28.4(56.8)	0.11
2 #	29.03(58.1)	0.11

PZT is installed 40 mm away from the tip-tilt mirror center. So, the tip-tilt mirror's theory rotation range is in Chart 2. The lens' focus length in Fig. 6 is 2400 mm. CCD size is $7.96 \times 6.45\text{ mm}^2$ with pixels of 795×596 . Each pixel size is $0.01 \times 0.0108\text{ mm}^2$ which is $0.8594''$ and $0.9428''$ according to the horizontal and vertical angle rotation. Chart 3 is the tip-tilt mirror measurement result.

Chart 3 The measurement result of the tip-tilt mirror

PZT No.	mirror movement range	resolution	rms of resolutuion
1#	$57''.2$	$0''.112$	0.117
2#	$50''.4$	$0''.098$	0.117

The measurement result shows the movement range and resolution of tip-tilt mirror's two axes fulfills the design requirement.

4.2 Frequency response measurement for the tip-tilt mirror

Frequency response is another key parameter of the tip-tilt mirror. As is discussed above, the frequency of atmosphere disturbance can be up to 100 Hz. The tip-tilt mirror frequency response shouldn't be lower than 100 Hz. PZT has the advantage of high response frequency itself. Of course it can response 100 Hz frequency control signal. But after PZT and other parts are setup to become the tip-tilt mirror, considering other parts influence between PZT and its mechanical-electrical connection, whether the tip-tilt mirror can reach this frequency response or not, we can know only after a through measurement.

There are many methods for it. Here, we design a very simple, opto-diode measurement system which is shown in Fig. 7

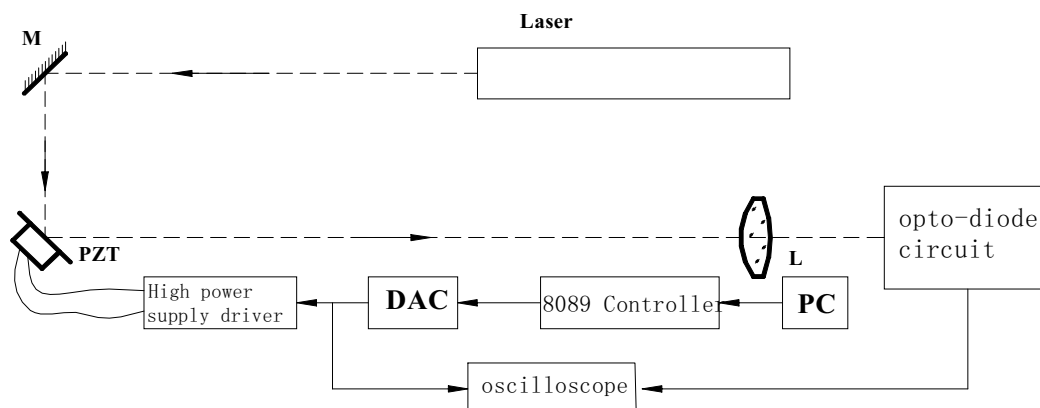


Fig. 7 Measurement system for the tip-tilt mirror frequency response

In the Fig. 7, the laser is a 3 mW He-Ne laser. The light passes through M, tip-tilt mirror, lens L, the tiny laser point will locate at the opto-diode circuit. The signal produced by the circuit will be one input of the oscilloscope. 8098 controller controlled by the PC can produce a series of different frequency signals. These signals will be sent to DAC and power supply driver to drive PZT, at the same time, these signals will be another input of the oscilloscope. We compare the two input signals' time difference and can get the result of tip-tilt mirror frequency response ability.

Normally, to measure one system frequency response ability, there are two kinds of input test signal: one is successive signal, another is a pulse signal. To use pulse signal to test the system frequency response character: The measurement can reach the whole frequency region, but the energy is very tiny distributed to each frequency point. Its advantage is that it has a high measurement speed. To use different frequency successive test signals to measure the tip-tilt mirror frequency character. Its advantage is high accuracy, because each frequency signal point has large energy. To our system, it only need to measure if the tip-tilt mirror can work on the condition of 100 Hz frequency or higher than 100 Hz. So, here, we use different frequency successive signals for the system testing.

In the frequency response ability measurement, we use 65 Hz, 125 Hz and 250 Hz triangle wave signals to measure the tip-tilt mirror frequency response. From the oscilloscope, we find that the signal received from the opto-diode circuit is about 1ms later than the original test signal if we don't consider the eye observing error. From Fig. 8, the original 250 Hz testing continuous signal for the system measurement and the system output are shown in the picture. In this picture, the waveform upside is the original 250 Hz signal produced by PC and 8098 controller, the waveform below is the measured signal output from opto-diode circuit. From this picture, we can see that the waves of the input and output signal of this measurement system are very good, it keeps the wave shape and there is no distortion which shows that this method is good. It also shows that the tip-tilt mirror can reach the requirement of stellar interferometer.

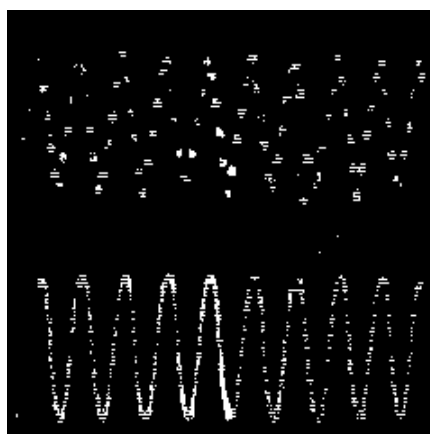


Fig. 8 Measurement result for the tip-tilt mirror frequency response

5 CONCLUSION

It details the original design of the tip-tilt mirror. With comparison, the general construction and PI product's construction are introduced. We also designed two sets of measurement system to measure its important parameters: frequency response, movement range and resolution. Two results are given which shows good quality we design.

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