A type of displacement actuator applied on LAMOST

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ABSTRACT

A type of displacement actuator used in active optics on Astronomical Telescope LAMOST was described in the paper. Now it have obtained success on the small LAMOST. Tests of the actuator using dual-frequency laser interferometer give some main parameters of them, and also give influence of condition varieties example for pull or push force. It show how do these conditons affect the actuator, and how to use the actuator to fit active optices. Finding out the characteristics after testing, these actuators were applied on the telescope. Some puzzles were encountered and solved all, which was showed in the paper. Finally we could control these actuators go forward or backward to several tens of nanometers accurately. By these technologic problems solved in the test and locations, these actuators could be applied on LAMOST or larger Astronomical Telescope.

Keywords: displacement actuator, LAMOST, active optics, nanometer

1. INTRODUCTION

Displacement actuator plays an important role in active optics, which is developing quickly with the advancing of large aperture telescope. Although general control system of displacement actuators for active optics on LAMOST have been published, how were the actuators applied on LAMOST is not been introduced in detail. Here a type of displacement actuator is tested in detail, giving characteristics of the actuator and how the conditions affect the actuator performance. Analyzing the data by test, we master that how does the actuator work. And then we design and adjust the strategy to control the actuator in active optics. We apply these actuators on the fixing process. By solving a great lot of difficulties, we could control actuators working well. As these actuators were applied successfully on the small LAMOST, there are hope that these actuators will be applied and controled better on whole LAMOST and other Astronomical Telescope.

2. TEST AND ANALYSIS OF THE ACTUATOR

The Displacement actuators could be divided two sorts, one applied on Mirror A(MA) of LAMOST, another applied on Mirror B(MB) of LAMOST.

2.1 Applied on MB

Based on technologic demand of LAMOST, MB displacement actuators should work accurately with no more than 30 nanometers RMS. We test the actuator using dual-frequency laser interferometer on the laboratory, and results and data are below.

We check linearity of the actuator. Let the actuator work at a certain speed several seconds and stop a few seconds, which forms a period. The actuator works periodically as above, and we observe variety of displacement by time. we could obtain figures as Figure 1, which could show the linearity of the actuator. Figure 1 shows a part of Stroke. We test linearity of the actuator at whole Stroke.

We let the actuator work similar to Figure 1 with given steps at a period, and then we could obtain data of test. Analyzing data by MATLAB at a long distance, we educe the resolution of the actuator(about 4.45 nanometers). Test again and again at several lengths, the results repeat, and std value of resolution is no more than 0.02 nanometer.

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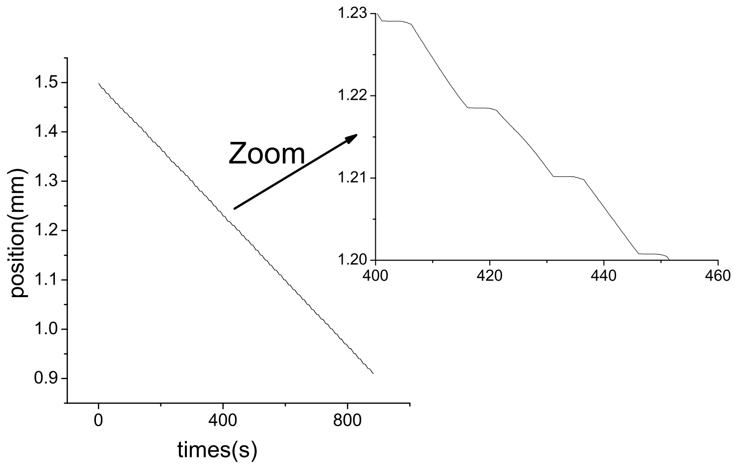

Figure 1. Test of linearity and resolution

If the actuator is applied on LAMOST, the actuator should fit the demand of load, here it should be pull force. We test the influence of the pull force loaded, and find that changing the pull force loaded affects design resolution weakly(could be ignored), but affects the backlash greatly.

We let the actuator work with demanded pull force, let it go forward and backward, and then test the backlash. For example from Figure 2 we could see the backlash by the zoom. The rising section is normal; If there is no backlash, the decline value should be almost the same as the rising value. By comparing rising value with decline value, the backlash was showed. Analyze the data, we gain the value of backlash. Decades periods like the zoom at Figure 2 shows that backlash stably retains a certain value, and std value is no more than 200 nanometers. That is very important for our backlash control(see Section 3.3). Between the whole test, we should be very carefully, because any fixing negligence on the test bed could bring friction or crowd or press, which could increase the backlash greatly, or affect the stability of backlash value, even destroy the actuator. For example While the actuator working at the test bed, friction could be decreased by working of actuator, then could decrease the backlash value tested at decades periods like the zoom at Figure 2. We should be carefully also because technologic demand of LAMOST is strict. The backlash of MB displacement actuator is no more than 2 microns at the test.

We test Min. step size. Min. step size is 30 nanometers. Here it means that error of control could be 15 nanometers. If the target should be move 0-15 nanometers, we don't drive it; If the target should be move 15-30 nanometers, we could drive the actuator moving to 30 nanometers, the error could be all along below 15 nanometers theoreticly.

2.2 Applied on MA

We test the MA displacement actuators similarly to MB ones, but some condition is not the same. First the load on MA displacement actuators should be push force. And then the Stroke of MA displacement actuators is more than that of MB, it could be about 25mm.

Because MA displacement actuators are fixed with lever, which can zoom out to the displacement of target. So the design resolution of MA displacement actuators could greater than MB(about 10.45 nanometers), and the test could be easier also.

3. APPLY THESE ACTUATORS ON LAMOST

After testing and analyzing these actuators, we eliminate the unqualified, and carry the qualified ones on to the fixing location. And then puzzles come round.

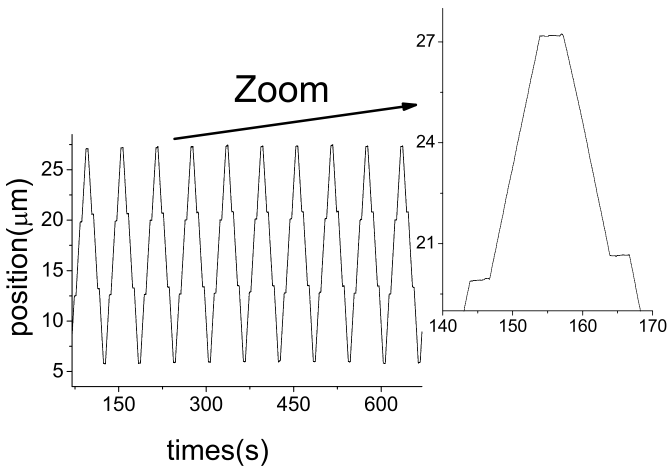

Figure 2. Test of backlash

3.1 Temperature distortion

Here we should known that three displacement actuators are fixed behind every piece of the mirror installed on LAMOST. The shape of the mirror is hexagon, and three actuators are fixed behind symmetrically. If temperature changes, the displacement actuators fixed on mirror will protract or shorten, and then corresponding position of the mirror is moving. That is forbidden. The length of displacement actuator is decades of millimeters. If temperature changes, it could protract or shorten several microns. But considering three actuators, the length of three actuators is almost the same. So if temperature changes, three actuators protract or shorten the same length, then it corresponds to moving the mirror parallel. And by observing about several nights, the temperature distortion could be ignored.

3.2 Compensate error of lever

As MA displacement actuators are fixed on one port of a lever, while another port of the lever is fixed on target of the mirror, lever zoom out the displacement. And the gear ratio alters along with the movement of the MA displacement actuators. The lever could be described as follow:

$$D = \sqrt{B^2 - [M\cos(\alpha - \theta_1) - L]^2} + M\sin(\alpha - \theta_1) + E - B \tag{1}$$

$$d = -\sqrt{b^2 - [n\cos(\alpha + \theta_2) - l]^2} + n\sin(\alpha + \theta_2) - e + b \tag{2}$$

$$\frac{\partial D}{\partial d} = \frac{M}{n}\frac{\frac{[M\cos(\alpha-\theta_1)-L]\sin(\alpha-\theta_1)}{\sqrt{B^2-[M\cos(\alpha-\theta_1)-L]^2}} + cos(\alpha - \theta_1)}{-\frac{[n\cos(\alpha+\theta_2)-l]\sin(\alpha+\theta_2)}{\sqrt{b^2-[n\cos(\alpha+\theta_2)-l]^2}} + \cos(\alpha + \theta_2)} \tag{3}$$

Here D is the location of a MA displacement actuator. The Stroke of a MA displacement actuator is about 25mm, so value of D could be -12.5mm to 12.5mm. d is the location of target point of the mirror. $\frac{\partial D}{\partial d}$ is gear ratio of the lever. α is midder variable, and other sign parameters are certain constants. We couldn't find analytical resolution about $\frac{\partial D}{\partial d}$ VS D, but only numerical resolution(see points of Figure 3(a)). Generally input displacement, i.e. $\triangle D$ is few at a time, we could approximately consider that $\frac{\partial D}{\partial d}$ is linear along with D. We test every lever carefully, and gain some data of points of the lever, and then could linearly fit the relation approximately like Figure 3(b).

Optical image detection(Shark-Hartman sensor) could provide the displacement of target point of the mirror, i.e. $\triangle d$ at a time. Then we should calculate how much are corresponding displacements of the MA displacement actuators, i.e. $\triangle D$, and then drive the actuators to the demanded location as soon as possible.

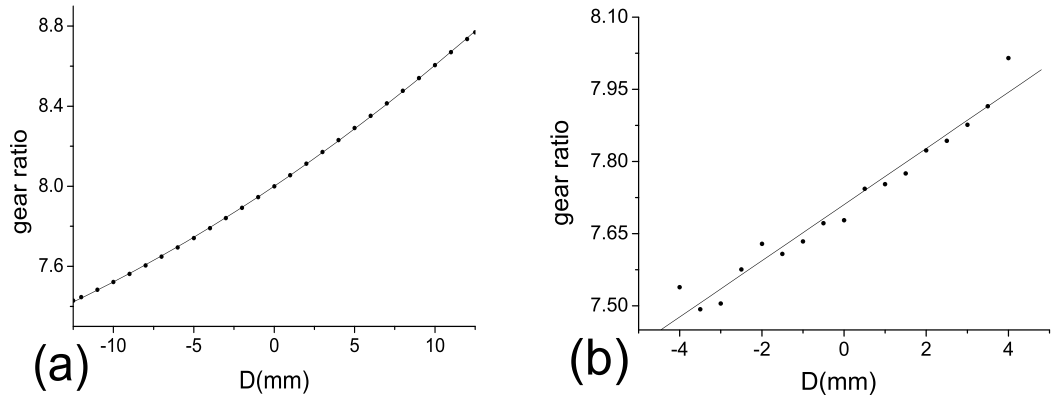

Figure 3. (a) Theoretic relation. (b)Test relation.

From test relation for example Figure 3(b), we could find

$$\frac{\partial D}{\partial d} = kD + b \tag{4}$$

here k and b are constant. As $\triangle d$ is given, so we could educe equation from equation (4):

$$\triangle D = (e^{\triangle d} - 1)(D + b/k) \tag{5}$$

3.3 Backlash control

Test results on the lab show that the average backlash of the displacement actuators is about several microns at proper load. Many factors could affect the backlash example for load variety, friction, improper press, and so on. LAMOST demands that displacement actuators should be control accurately with no more than 50 nanometers RMS. While the MB displacement actuators was fixed on LAMOST, the actual backlash of every one is more or less not the same with the test result. So how to set the actual value of backlash of fixed actuators? If the actual value is beyond or below tested value for about decades of nanometers, the several hexagon mirrors couldn't be confocal.

Shark-Hartman sensor calculates the displacement value of every target point of mirror corresponding to actuator fixed, although the value is not very accurate because some environment factors. We drive the MB actuators following the given value, and then Shark-Hartman calculates again, we drive actuators again,...... until several mirrors are confocal(see Figure 4).

Because the actual value of backlash is not the same as test results, so every time when we drive these actuators, some actuators go forward more or backward more or less. It bring on that we couldn't control the actuators to work accurately. Here we could see the stability of the backlash is very important. We adopt two methods to do this. Firstly we record every value transferred by Shark-Hartman. We compare one group of displacement value to next group; estimate the error of backlash; set the new value of backlash which we estimate by the value transferred, and then experiment again. Until the value of backlash estimated is close to the actual value, we go to next step: If any of three given displacement values of actuators fixed on one mirror from Shark-Hartman is beyond 0.5 micron, we let three actuators drive according the given values; If the three given values are all less than 0.5 micron, we drive three actuators according shift values as table 1, corresponding move to mirrors parallelly base on three given values. And the actuators would not run reversely, so it would not bring on new backlash.

By the methods, we could see that the given displacement values of actuators from Shark-Hartman sensor are decreasing to below 50 nanometers, i.e. the mirrors are confocal after several times.

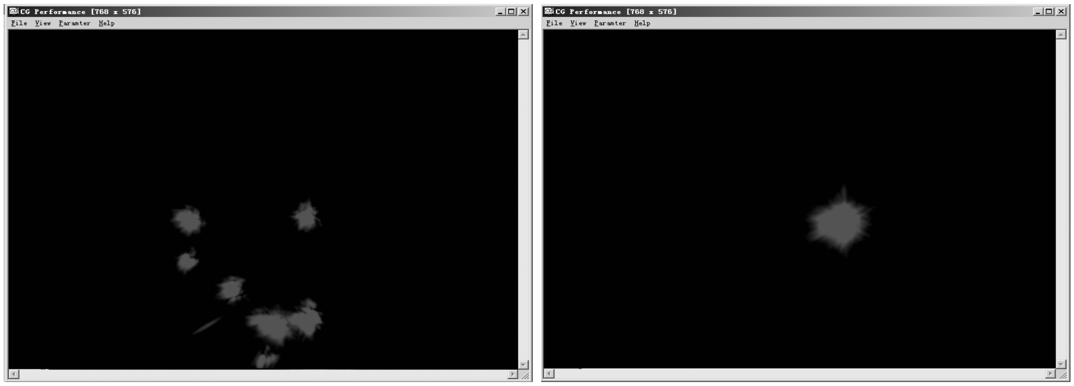

Figure 4. original to confocal

Table 1.

Given value	Shift value
0.41μm	0.69μm
-0.13μm	0.15μm
-0.28μm	0 μm

On Mirror A, every night we let MA displacement actuators run along one direction as above if the given values are all below certain microns, and so decreasing the infection of the backlash. When that experimentation in one night is over, we return every MA displacement actuator to original location.

Also we have encountered many other difficulties, we think and experiment, and finally solve them. Through hard working for several months, we could control these displacement actuators to content the demand of the small LAMOST.

4. CONCLUSION

A type of displacement actuator is tested on lab in detail, The tests give the stroke, linearity, design resolution, backlash and other characteristic parameters. Tests also announce the influence of force be loaded, or other variety of conditions. Based on the tests, we grope for how to control these actuators well. At this period, we solve many problems which we encountered on applying these actuators to the small LAMOST, and finally obtain success. We believe that these actuators could be applied better on LAMOST or future astronomical telescope, as long as our research is deeper.

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