Study on distortion control technology of the active stressed lap polishing deeper aspherical mirror

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ABSTRACT

A special computer controlled polishing machine and a 450mm diameter active stressed lap have been developed in NIAOT,and the lap has been successfully applied on polishing a f/2, Φ910mm paraboloidal mirror. This paper briefly introduces the control structure of the polishing system. The deformation technology is an important part of the stressed lap. This paper puts emphases upon discussing the deformation technology .On the base of experiments on f/2 mirror, deformation experiments on f/1.5、f/1.2 have been done also . As the asphericity becomes faster, the dynamic response of the lap's deformation becomes slower and the error of shape becomes bigger .In order to solve this problem and improve deformation precision ,we analyse the reason for the error of the lap and discuss the dedormation emendating problem. In the end according to the result of deforming experiments, several considerations for optimization of mechanic-electric design of the stressed lap are given.

Key words: active stressed lap; deeper asphericity; deformation; high precision;

1.INTRODUCTION[1]

As the modern astronomy developing, the highly precision ambitious astronomical telescopes are required. It is a serious challenge for opticions to polish the bigger diameter, faster focus ratio and higher precision astronomical mirrors. Through several years of hard work, NIAOT has successfully developed the first polishing machine with the active stressed lap technology of China .The machine has been successfully applied to polishing a ϕ910mm,with F/2 paraboloidal mirror. The precision of the mirror reaches to RMS=$\frac{\lambda}{30}$. Figure 1 is a picture of the lap polishing a mirror. During the procedure of polishing, the active stressed lap can actively changed its shape and maintain an accurate fit to the mirror surface according to different lap position on mirror surface and different angle of lap Using the lap, a aspherical mirror can be polished just like a spherical mirror. The classical small polishing tool not only can get high frequency errors on the mirror surface but also has slow polishing speed .Compared with it, the active stressed lap has high polishing efficiency and natural smooth. Now, after being partial altered, the active stressed lap is being used to polish a testing mirror for LAMOST project. The precision target of the mirror is RMS $\leq \frac{\lambda}{40}$.

This article introduces the stressed lap system from the side of electric control. Section 2 briefly introduces the structure and functions of the whole control system. Section 3 introduces the deformation experiments of the F/2 mirror surface, and discusses the limitation of the lap when it is applied to polish faster aspherical mirrors, and discusses dynamic deforming experiments in the end. Section 4 analyzes the above experiments and puts forward some ideas for the improvement of the stressed lap.

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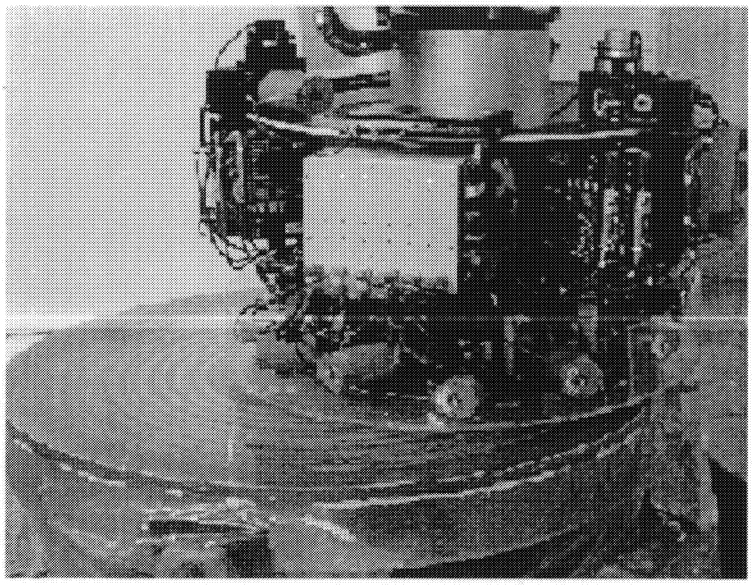

Fig. 1 a picture of the lap polishing a mirror

2.CONTROL STRUCTURE OF POLISHING SYSTEM [1][2][3]

The polishing controlling system consists of 3 parts: the polishing machine control, the active stressed lap control and the measuring deformation of the lap. Figure 2 is the sketch of electric control.

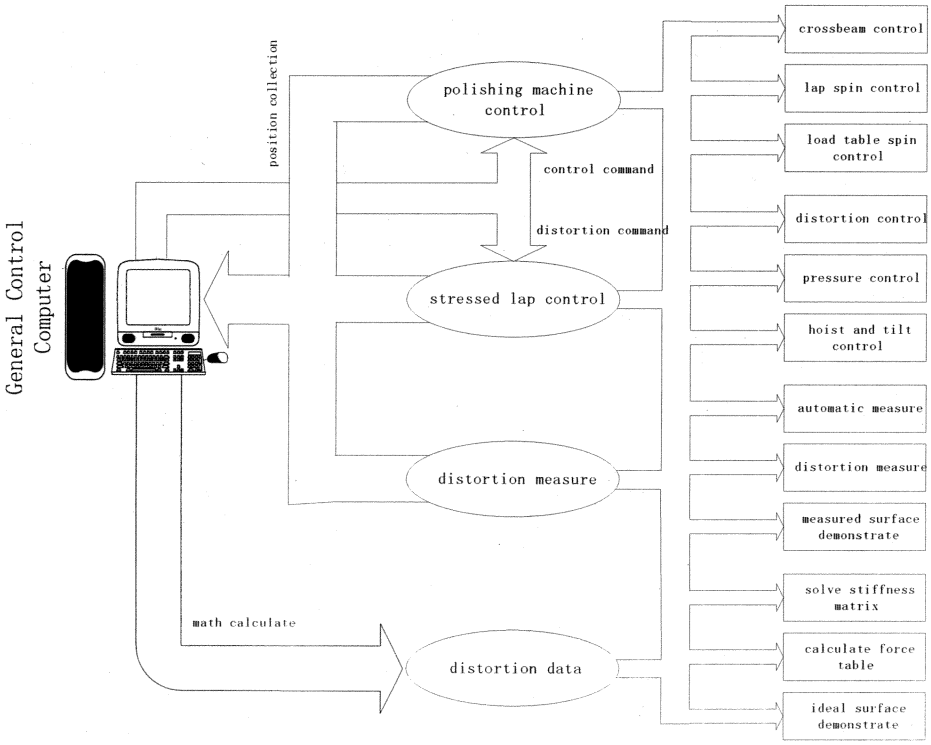

Fig. 2 sketch of electric control

The polishing machine controlling system adopts the computer-singlechip distributed controlling mode. The

computer delivers different commands in the different working patterns. There are 3 singlechips to control the driving movement along the crossbeam, the spin of stressed lap and the spin of load table respectively, which can run in the return mode in the defined scope. The system has the protection system to deal with the position restriction, over loading, over pressure and excessive speed, in this way the optic mirrors and the machine's security can be insured.

The main function of the stressed lap control is: to control deformation, to control of stressed lap's ascent and descent and tilt of the stressed lap, and to control the pressure that exerting on the mirror surface. Among them, the deformation control is very important. The change of the lap shape is accomplished by 12 actuators. The distortion of the lap is measured by 16 LVDT (linearly variable differential transducers). When the force on the actuators is changing, the change of the surface shape can be detected through LVDT. Thus, to control the surface shape is transformed to control force of 12 actuators.

3. TO MEASURE DEFORMATION OF STRESSED LAP

3.1 mathematical theory analyse[1]

In the elastic limit scope of the material of the stressed lap, there exists linear relationship between the force of actuators and the lap's deformation. Assuming actuators' variable is F_{12*1} and the lap's deformation is U_{16*1}, the relationship could be concluded as following

$$K_{16*12} \times F_{12*1} = U_{16*1} \qquad (1)$$

K_{16*12} is the measured stiffness matrix of the lap. According to K_{16*12} matrix, if using the least squares method is used to calculate it,therefore

$$F_{12*1} = (K_{16*12} \times K_{16*12}{}^{T})^{-1} \times K_{16*12}{}^{T} \times U_{16*1} \qquad (2)$$

The calculated force could be very large and overstep the scope of allowed. The damp least squares method could be used to correct them. Select a right damp factor and a set of force can be got. Apply calculated force to actual deforming framework and use LVDT to measure the shape of lap. Compare measure data and given data, the difference between them can be calculated. If difference can meet the requirement, the calculated force is thought right. If if can't, damp must be reselected. Until calculated force can yield the correct shape, we establish a look-up table to list force of 12 actuators of different position and orientation of the lap and save the table in general control computer.

In the polishing proceeding , the computer continuously reads the lap's position and orientation with respect to the mirror surface. So the stressed lap is deformed to the required shape.

3.2 deforming experiment on f/2[2]

Does the stiffness matrix really reflect the system's performance? Does the calculated deformation force could be used to get the required surface shape? We can only verify them by the real deformation test. Considering we need to polish a Φ910mm、f/2 paraboloidal mirror , in the deforming experiment, we assume the lap's apex is at 365mm from mirror center. Figure 3 is a set of calculated force and figure 4 is the corresponding deforming shape. The 12 lines in figure 3 represent force of 12 actuators. The 16 lines in figure 4 represent deforming shape on 16 LVDT positions. There are 72 points on each line which represent the 72 tested point when the lap spin one circle ,each interval is 5° .

When the damp factor is changed , the different error between them can be got. Table 1 lists the respective tested data.

Table1 difference between measured and given data, when adopting different damp factor

damp factor	1×10^{-8}	8×10^{-9}	4×10^{-9}	2×10^{-9}	1×10^{-9}
RMS(μ)	2.98	2.65	2.32	2.13	1.88

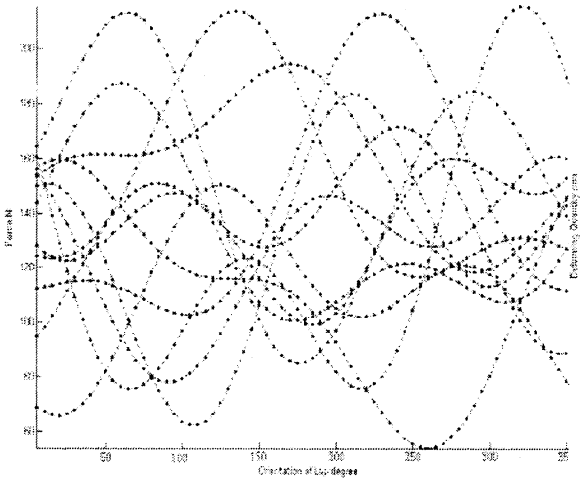

Fig. 3 forces of 12 actuators

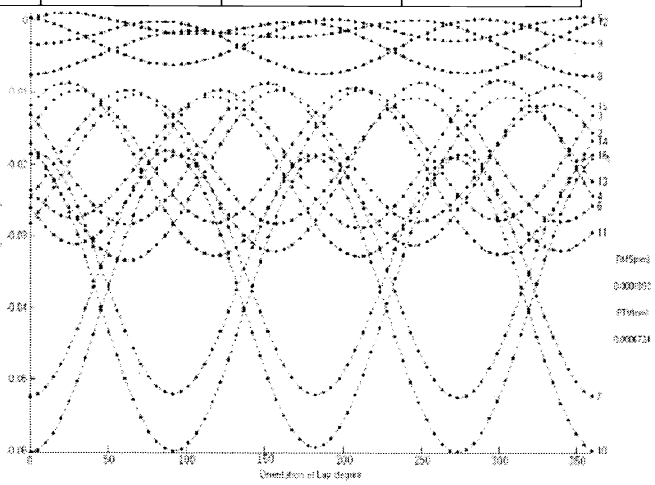

Fig. 4 measured shape on 16 LVDT position

3.3 primary discussion on faster aspherical surface

The first experimental object of the stressed lap is a Φ910mm,f/2 paraboloidal mirror. Can this lap be used to polish a faster focal ratios mirror? If it can't, we should find out its shortcomings. So we go on discussing the deforming problem for faster aspheric mirror. According to optical calculation, deforming quantity increases with asphericity which goes up dramatically with faster focal ratios. For example, the deforming quantity of f/2 is 0.07mm, f/1.5 is 0.16mm and f/1.2 is 0.32mm. Base f/2,calculated force are concentrated from 80N to 220N.Forces of actuators are designed between 50N and 400N. In this electro-mechanical structure, we choose f/1.5 and f/1.2 to perform deforming experiment. Table 2 lists deforming difference using different damp factors for f/1.5. Table 3 lists deforming difference using different damp factors for f/1.5.

Table 2 deforming difference using different damp factors for f/1.5

damp factor	4×10^{-8}	2×10^{-8}	1×10^{-8}	5×10^{-9}
difference(μ)	9.67	6.42	4.92	4.91
force(N)	120-210	90-250	75-290	60-370

Table 3 deforming difference using different damp factors for f/1.2

damp	4×10^{-8}	3×10^{-8}	2×10^{-8}	1.5×10^{-8}
difference(μ)	15.3	10.6	9.56	9.45
force(N)	120-220	90-270	65-340	50-390

From table 1 and 2,we can see that along with the damp factor decent, the precision of deformation is enhancing. But as the damp decent, the force scope is expanding and will exceed the designed limit. So using this lap is hard to polish higher precision, deeper aspherical mirrors, such as f/1.2. According to mathematic simulation, if the force scope could reach 0~800N, deforming difference of f/1.2 would be 3.42 μ and deforming difference of f/1.5would be 2.12 μ .So to enlarge the force range of actuators is a method to polish faster aspheric mirror. But it isn't a good method and can't solute its structure shortcoming ultimately.

3.4 dynamic deforming measurement

In section 3.2 and 3.3,all experimental results are got from static measurements. The actuators change force 1.5second. This frequency is sufficient for actuators to change, but in practical polishing proceeding it is too slow and would influence the rate and efficiency of polishing. On the base of static measurement, we continue doing dynamic measuring experiments. In experiments, we find as the frequency turns faster, precision of surface turns lower. In f/2 experiments, this problem is not very serious. As the asphericity turns faster ,the contradiction turns more serious. Table 4、5 、6 list difference with different asphere and frequency.

Table 4 dynamic experimental data of f/2

TIME(ms)	1000	800	400	200
difference(μ)	1.96	2.02	3.25	4.85

Table 5 dynamic experimental data of f/ 1.5

TIME(ms)	1500	1000	400	200
difference(μ)	4.72	4.96	7.25	11.2

Table 6 dynamic experimental data of f/1.2

TIME(ms)	2000	1000	400	200
difference(μ)	9.24	10.73	14.6	21.8

Figure 5 is a measured deformation with 1.5second interval time and figure 6 is a measured deformation with 0.2 second. Comparing with two figures, we can see amplitude change is small and phase is very stagnant.

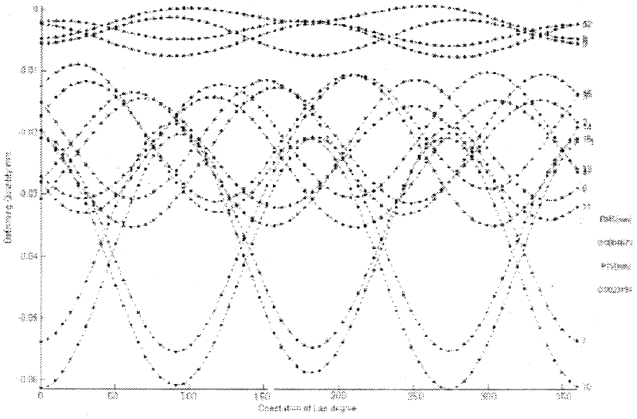

Fig. 5 f/1.5,1500ms

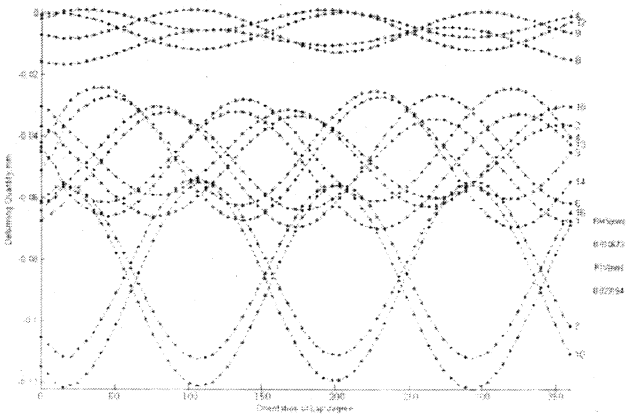

Fig. 6 f/1.5,200ms

4. CONSIDERATIONS FOR THE LAP'S IMPROVEMENT

4.1 deforming precision

To date, the error of deformation has been less than 2μ (RMS),which is sufficient to polish the mirror. An experiment has been done to test the error of measuring system. Keep forces of actuators invariable and read the changing value of 16 LVDT, in ideal condition, the changing value must be zero. But in practice, it's not. The experiment is performed 5 times and the respective data is listed in table 7.

Table 7 errors when force is unchanging

times	1	2	3	4	5
changing value(μ)	0.74	0.53	0.68	0.61	0.63

The average of data in table 7 is o.64.Error is caused by sensors、amplifying circuit 、A/D collecting card and so on. The stiffness matrix is got by measuring experiments, so it can't completely reflect the performance of the lap. The error of the stiffness matrix directly influences the precision of the calculated force and the deformation of the lap. Thereby it's hard to continuing improving precision that has been limited by the precision of the system.

In order to improve precision ,we must redesigned measuring system. Now the performance of LVDT that being used is not very good. We are considering change them for high precision eddy current NCDT (Non-Contacting Displacement Transducers). Only when the high precision measuring system has been chosen, the deforming precision can be improved and high precision mirrors can be polished.

4.2 dynamic response

In dynamic measuring experiment, errors of deformation become bigger under the higher deforming frequency. In order to minish errors of dynamic measurement, the method of phase emendation is adopted. Advance force according to different frequency and the precision of deformation will be improved. Table 8 lists difference of before and after advance force. Experimental data show the method is very effective but it can not completely get rid of errors caused by fast frequency.

Table 8 difference of before and after advance force

	f/2	f/1.5	f/1.2
difference before advance force(μ)	4.85	11.2	21.8
Difference after advance force(μ)	2.34	5.42	12.1

The basic reason causing errors when frequency is quickened is that the response rate of the control system can't keep up with the changing rate of force. It is a simple control problem to solve. But in the initial stages of design, we were not clear about the target of the system and paid no emphasis on this problem. Figure 7 is the existing deforming control structure. The step response is tested and drawn as the dot line in Figure 8. The dot line shows that the response rate is slow for sure. In Figure 7,the rate adjuster has been designed a PI controller and the force adjuster has been designed a P controller. This problem is caused by force adjuster. When the portion is a big value, the control system will be unstable. In order to keep the stability of the system, the portion is designed a relatively small value which causes the slow response rate of distortion control. In the redesign of the stressed lap, the force adjuster will be designed a PI or PID controller. When the integral function is added to the system, the portion can be properly augmented and can't do harm to the stability of system. In this way, the response rate will be quickened. The solid line in Figure 8 is a simulated step response of the system in which the force adjuster is altered for a right PI controller. On the base of step response experiment, the sine response is tested. In Figure 9, there are 3 lines. The solid line represents the perfect sine response, the dot line represents the measured sine response and the dash line is the simulated response when the force

adjuster is adopted PI structure. If the differential coefficient is adopted, the response rate will be quickened more.

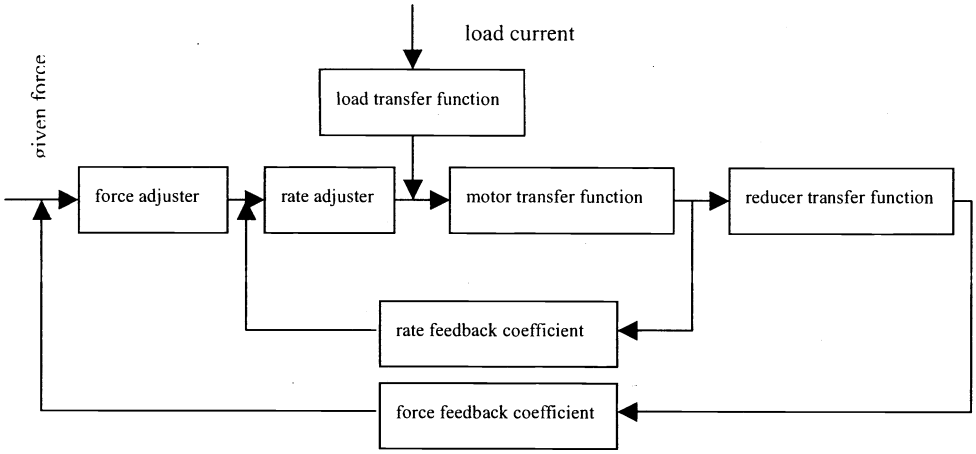

Fig. 7 the deforming control structure

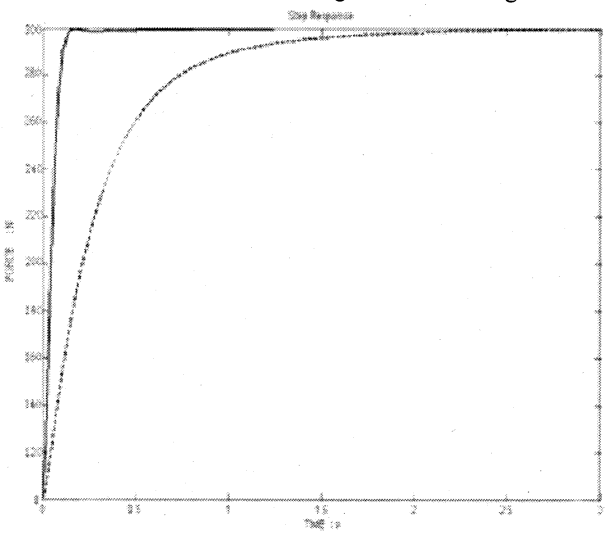

Fig.8 Step Response

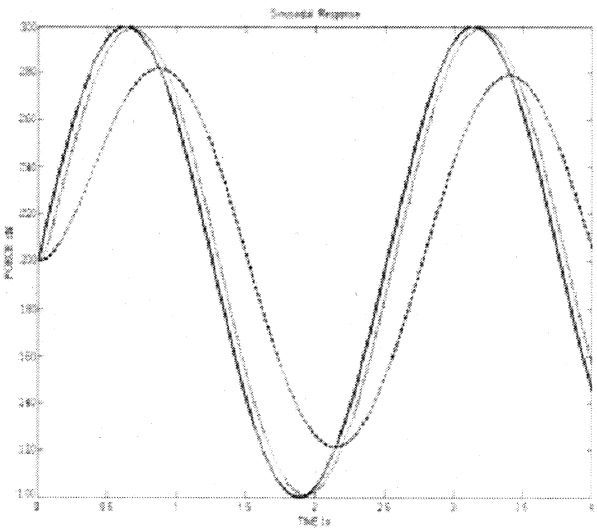

Fig.9 Sine Response

4.3 the problem for faster asphere

The active stressed lap must have the characteristic that exert the allowed maximal force on the lap and the deformation of the lap can exceed the needed deformation of the polishing mirror. In this way, the lap can be used to polish faster asphericity mirrors. The experiments of section 3.3 show the performance of the existing lap is lacked on this side. The force needed by ensuring the lowest precision has exceeded the allowed range. In order to polish the higher precision and faster asphericity mirrors, the basic method is to redesign the mechanic-electric structure. Lighten the weight of the lap(the weight is 50 kg now) and minish the volume of the lap. The stiffness matrix of the lap is changed. So the larger deformation can be got in the allowed force range, in this way the faster asphericity mirrors can be polished.

CONCLUSION

This is the first active stressed lap researched in NIAOT, so there is undoubtedly space to advance. On the other

hand ,we only apply the active stressed lap technology to the mirrors with 1m-diameter or so. On base of the first lap, we will develop a new active stressed lap to improve its performance. Later we will apply this technology to a 2.5meter polishing machine, thus bigger diameter and faster aspherical mirrors could be polished in the quicker and better way.

Anyway we will continually developed this technology of the active stressed lap, thus contribute to the development of the next generation's telescope and the development of astronomy.

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