Mechanical design of the stressed- lap polishing tool

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ABSTRACT

We present an overview of the engineering design of stressed lap developed at Nanjing Institute of Astronomical Optics & Technology. Stressed lap consists of two parts: active deformable lap, driving-adjusting mechanism. The finite element model for active deformable lap is constructed, and the performance of lap deforming is discussed. Descriptions about mechanical structure of driving-adjusting mechanism are given. Now, stressed-lap polishing tool has been used to accomplish a fast parabolic mirror in Nanjing. The φ910mm F/2 parabolic mirror has been figured to an accuracy of 22 nm .

Keywords: Aspheric mirror polishing, Stressed lap, Finite Element Analysis

1. INTRODUCTION

Astronomical mirror become much more larger in size and much more deeper in asphericity as well as much more higher in accuracy in order to meet the demand of modern astronomical optical telescope, so the fabrication technology is required more and more demand. The reach effort at Nanjing Institute of Astronomical Optics & Technology (NIAOT) has led to the success of key project of National Natural Science Foundation of China "Fabrication technology of astronomical mirror with large aperture and high accuracy ". Stressed-lap is a new deformable large-tool polishing technique—its shape is actively changed as it moved across aspheric surface and it can maintain an accurate fit to an aspheric surface. Therefore, stressed-lap is applied to the manufacture of astronomical aspheric mirror with higher removal rate and lower level of surface errors than small tool. Stressed lap consists of two parts: active deformable lap, driving-adjusting mechanism.

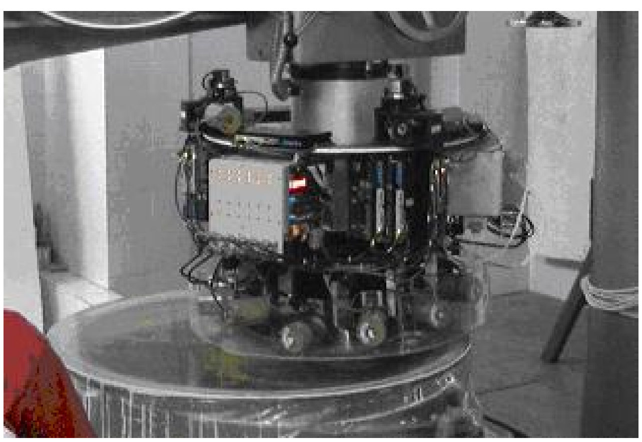

Figure 1. A photograph of Stressed-Lap polishing tool developed at Nanjing Institute of Astronomical Optics & Technology (NIAOT), CAS.

ICO20: Optical Devices and Instruments, edited by James C. Wyant, X. J. Zhang, Proc. of SPIE
Vol. 6024, 60241Y, (2005) · 0277-786X/05/$15 · doi: 10.1117/12.666942

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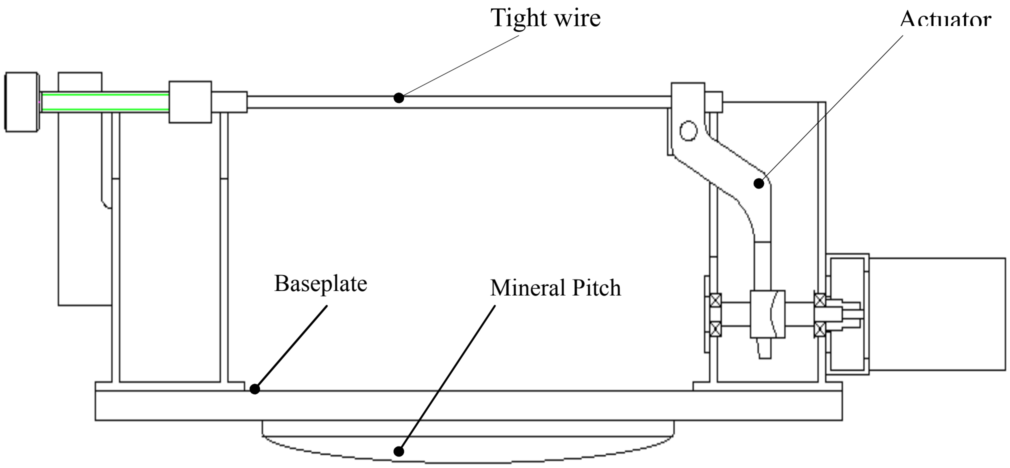

Figure 2. A side view of active deformable lap with one actuator and tight wire.

2. ACTIVE DEFORMABLE LAP

Active deformable lap is a deformable plate mechanism under the action of bending actuator, which is applied the same principle as thin-mirror active optics. Active deformable lap consists of a solid circular aluminum baseplate with 12 actuators attached to the perimeter, and 12 tight wires are connected to the actuators respectively, as shown in figure 2. Computer-controlled actuators create bending and twisting moments at the edge of the plate by exerting pull to the ends of the tight wires and causes desired deformation on the plate to match the shape of mirror surface under it.

There are several problems should be considered during the design of the active deformable lap.

2.1. Available Deforming Area

Those 12 actuators are mounted at the periphery of baseplate, and this region become stiffening, so the active polishing area is constrained. According to the demand of fabrication technique of mirror, the active polishing area is 1/4~1/3 as the mirror in diameter. Therefore, we should find out the relationships between sizes of deforming area and mechanical parameters of a lap designed for one mirror. Aided by finite element analysis software, we construct a model with the parameters of a preliminary design.

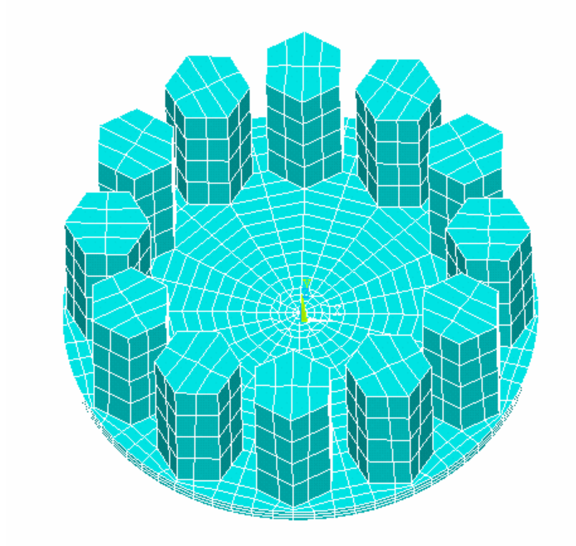

Figure 3. Finite element model of active deformable lap.

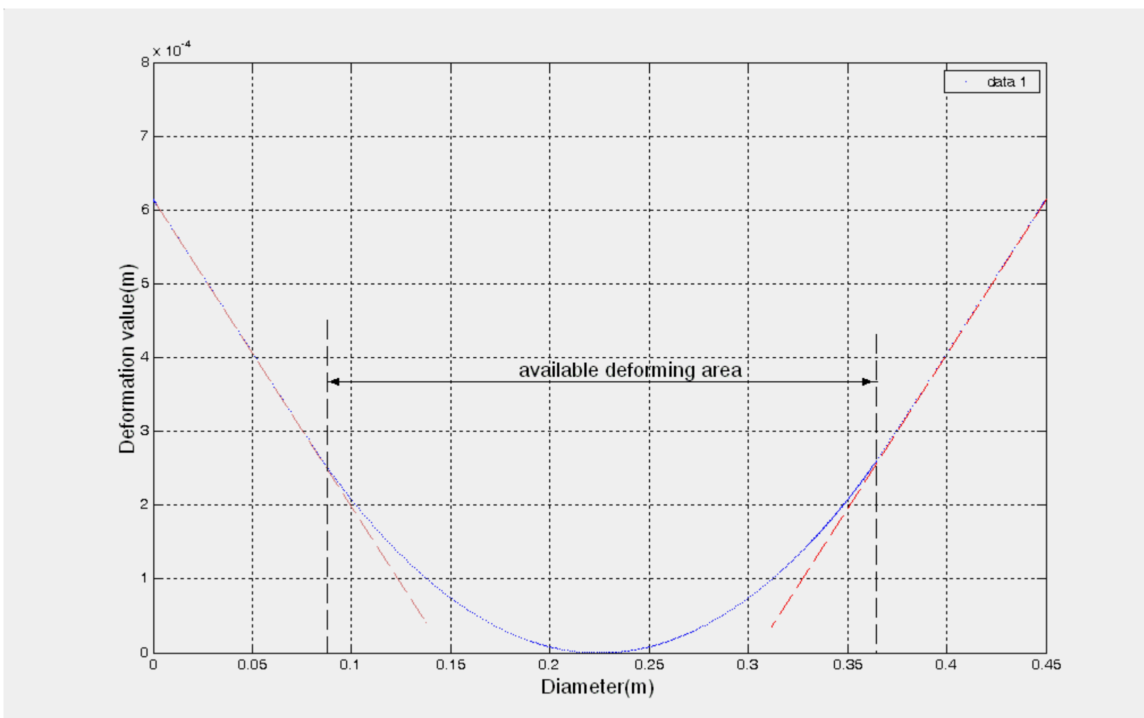

Figure 4. The deformation value of lap as function of baseplate diameter sizes. We plot the curve with the deformation data on the line which through the plate center. The solid line is the deformation curve of lap; the dash line is reference line.

The lap deformation analysis under the action of actuators is done and deformation data was obtained. Obviously, as shown in figure 4, the outer in the curve has become into straight line. This indicates that the lap periphery is stiffened and the desired deformation can't be created. By measuring and calculating, the active deforming area is constrained to be the inner 70% diameter of the baseplate. This result is proved by experiment test. From the result of finite element analysis, the position on which actuators mounted baseplate and thickness of baseplate are changed, the available deforming area and the maximum deformation value will be changed correspondingly.

2.2. Dynamic Response Frequency

The deformation value must be obtained during the mechanical design for polishing one mirror. To match the demand of fabrication technology of mirror, the deeper in asphericity one mirror with, the higher the deformation value needed for lap. Further more, the dynamic response frequency of lap deforming, which associated with whether the shape of lap fit to the surface of mirror, must be satisfied under precondition of meeting the deforming needed for lap. This agent affects the accuracy of mirror fabricated by lap. We use transient dynamic analysis to determine the dynamic response frequency of deforming, i.e., the number of the available deformation of lap creating under action of actuators per unit time. Preload and operation load is applied successively to the finite element model for analysis. Preload is applied firstly and then operation load is applied in succession, which simulates the practical process of lap operation. Since the application of preload, the backlash among the components of actuators will be eliminated and the range of applying operating-load will be decreased. In this way, the accuracy of loading is improved.

During the analysis, we obtain a series of dynamic deformation data by changing the load periodic. Clearly, dynamic deformation value always deviate from static deformation value by comparing dynamic data with the static data. Table 1 gives the list of compare result. As shown in figure 5, the deflection increases rapidly and is greater than 1%. Therefore, the dynamic response frequency of lap deforming can reach 25Hz while deformation precision is satisfied. However, the practical dynamic response frequency is less than 25Hz result from backlash among the components of one actuator, the elastic of tight wire and the hysteresis of servo system.

Table 1. Comparison of dynamic data and static data. We select one data got from the same position on the lap to compare.

Load periodic(s)	Dynamic deformation value (mm)	Static deformation value (mm)	Deflection (%)
1.5	0.0780991	0.078058	0.05
1	0.0780641		0.01
0.5	0.0780103		0.06
0.25	0.0779322		0.16
0.125	0.0782772		0.28
0.05	0.0783536		0.038
0.04	0.0780162		0.05
0.036	0.080229		2.78
0.0355	0.0804235		3.03
0.035	0.079945		2.42

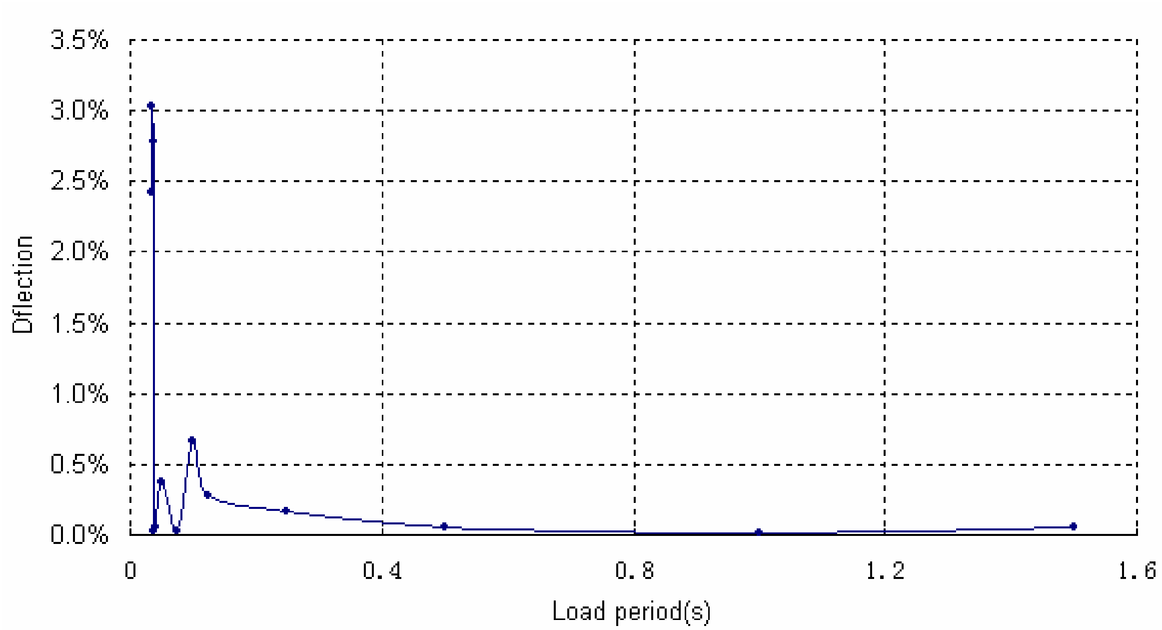

Figure 5. Deflection as function of load period. When the load period is less than 0.04s, the deflection increases rapidly and is greater than 1%.

We discuss the factors that affect the dynamic response frequency inherent in an active deformable lap with follow equation:

[M]{a}+[C]{v}+[K]{u}={F(t)}…. dynamic basic equation of motion (1)

[K]{u}={F}………………………. static basic equation (2)

Where:

[M] = Mass matrix

[C] = Damping matrix

[K] = Stiffness matrix

{a} = Acceleration vector

{v} = Velocity vector

{u} = Displacement vector

Comparing with static basic equation, as the existence of inertial force ([M]{a}) and damping force ([C]{v}), it causes the export hysteresis of lap deforming. Thus, reducing the inertial force and damping force is the effective ways to increase deformation frequency. Embodied to say, it's feasible to make the lap with a light and fit weight.

2.3. Stability

We think of active deformable lap as a linear system but it isn't so in actually, this affects the stability of deformation output. There are several factory affect the linearity, such as anisotropy of the plate-base material, unsymmetry of the active deformable lap on structure caused in assembling, backlash among components of one actuator, anisotropy of bends elastic, etc. During polishing, the lap is controlled without feedback and the shape of lap is not verified real time. Therefore, we should keep the isotropy of the material and the symmetry of the active deforming mechanism on structural.

3. DRIVING-ADJUSTING MECHANISM

Drive-adjusting mechanism is an important element of stressed lap, which transmit the rotation and motion of the spindle to the active deformable lap, and adjusts the attitude of lap and the pressure over mirror caused by lap continually.

During polishing, active deformable lap suspend across the mirror with a rotation around itself center and a radial motion continually, and maintain an accurate fit to mirror surface with desired pressure. Therefore, the ideal connection between the active deformable lap and polishing machine spindle contains the following ingredients. The drive force to move the lap should not cause unwanted gradient. The joint between lap and driving-adjusting mechanism should not constrain the deforming of lap. The pressure gradient should be adjusted to keep on constant and satisfy the requirements of figuring. The attitude of lap should be controlled to maintain an accurate fit to the mirror surface while the lap move across the mirror surface.

For the developing of driving-adjusting mechanism, we construct the model and simulate the motion of lap across the mirror surface aided by CAD software

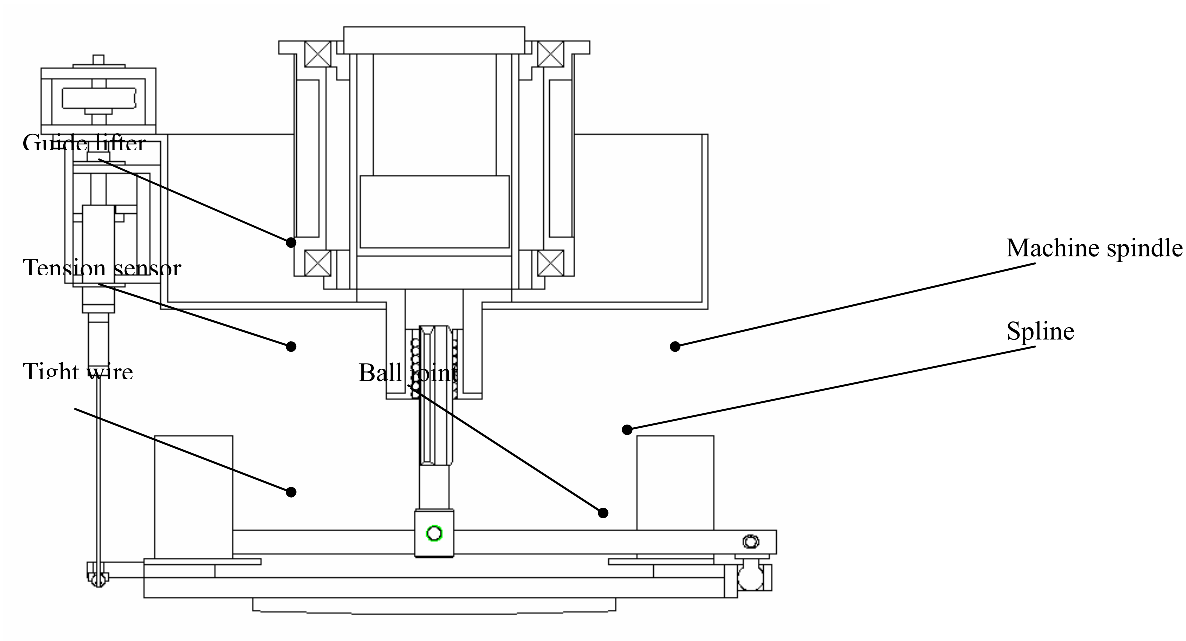

Figure 8. The side view of lap depicts the driving-adjusting mechanism, which is a combination of driving device and pressure-adjusting system.

3.1. Driving Device

Driving device consists of a ball joint with 3 deflector rods, a spline attached to the polishing machine spindle. The end of spline is connected to 3 deflector rods with a ball joint and can move along the spindle axis. At the end of each of deflector-rod have a ball joint connection to the periphery of lap. The driving force to rotating and moving the lap across surface of mirror acted on the rigid area at the periphery of lap. During polishing, as 3 deflector-rods rotate around the ball joint and keep paralleling with plate-base. In this way, driving force will parallel with base plat and don't cause undesired pressure gradient over the surface of mirror.

3.2. Pressure-adjusting System

There are 3 sets pressure-adjusting system, which is mounted symmetrically around the periphery of lap. Each of pressure-adjusting system consists of guide lifter, tension sensor, tight wire connected to the bottom of tension sensor and the periphery of plate-base. We assume that the weight of active deformable lap is G, three vertical lifting forces generated by guide lifter acting on the ball joint connected to tight wire and plate-base are P1 , P2, P3, supporting force generated by mirror is N, whose reaction force is the pressure generated by lap over the surface of mirror. All force acted on the lap are balance at vertical direction, thus

$$P1\times\cos\alpha + P2\times\cos\alpha + P3\cos\alpha + N = G\times\cos\alpha.$$

The stressed lap is designed for the polishing of aφ0.91m F/2 paraboloid, the angle α between plate-base and horizontal plane is less than 5°, the equation can be simplified under the condition that its deviation is less than 1%:

$$3P + N = G \text{ i.e. } N = G - 3P$$

Because the copulae between lap and mirror surface is mineral pitch that is of good elastic, the lifting force P increase while we raise the lap finely and the lifting force P decrease while we let down the lap finely. In this way, the pressure of polishing is changed to meet the figuring requirement.

3.3. Controlling Attitude

The tilt and piston are changed as the lap is moved over the surface of the mirror, we should adjust the attitude of lap to maintain an accurate fit to the surface of mirror. During polishing, some parts on the periphery of lap surface may be off the surface of the mirror, and the guide lifter will raise or let down the lap to change the title and piston of lap automatically. In this way, the attitude of lap is changed.

4. CONCLUSION

The preliminary design of stressed-lap had been down by referencing the design of stressed-lap polishing tools developed at the University of Arizona[1]. Nevertheless, we had encountered many difficulties, especially the driving of lap that interferes with the deforming of lap, during the testing for engineering prototype. We have solved the problem by the improving in design of driving-adjusting mechanism. Now, the stressed-lap has successfully polished aφ910mm F/2 parabolic mirror to batter than 22nm rms surface error[2].

ACKNOWLEDGMENTS

Authors would like to thank our colleague of this project for their help. This project was funded by NNSFC.

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