Active polishing technology for large aperture aspherical mirror and ultra thin mirror

Xiangqun Cui* Bilie Gao Xinnan Li

National Astronomical Observatories / Nanjing Institute of Astronomical Optics and Technology, CAS, Nanjing 210042, P.R. China

ABSTRACT

Some results on active polishing technology for large aperture aspherical mirrors and ultra thin mirrors, which have been developed in recent years in Nanjing Institute of Astronomical Optics and Technology, CAS, are presented in this paper. There are two polishing methods developed for the large aperture ultra thin mirrors with two different trial mirrors respectively. One is a hexagonal mirror with diagonal size of 1100mm, and thickness of 25mm by no-separate support method specially for polish the sub-mirror of Schmidt corrector of LAMOST, which is a national large scientific project of China. Another is a circular mirror with 1035mm in diameter and 26mm in thickness by active support method. The active stressed polishing technology developed for large aperture aspherical mirror with fast f ratio, and a paraboloidal mirror with a diameter of 910mm and an f ratio 2 as was successfully polished. The computer controlled polishing is also different from the normal way in the system. Some complicated aspects were added. The results showed the final surface accuracy of all these trial mirrors is better than expected requirements for normal application in astronomical telescopes.

Keywords: Active stress lap, Aspherical mirror polishing, Ultra thin mirror, Active polishing, Computer control polishing

1. INTRODUCTION

The enlargement in aperture makes astronomical telescope more powerful in capability of star-light collecting and more precise to identify detail. On the other hand, increasing the diameter at the limitation of same F ratio, the size of telescope tube will be prolongated, which will make telescope structure more complicated and more expensive. If we take much faster F ratio with increasing the diameter, the asphericities will be greatly increased. To obtain smooth surface, high surface accuracy and high polishing efficiency, it is necessary to develop new technique for manufacturing.

If we choose the mirror blank based on the traditional point of view, the thickness of mirror will be about 1/7 of its diameter. The larger of diameter is, the heavier of the mass is. Obviously the cost of telescope is proportional to the mass of primary. To decrease the expense, the technology for manufacturing the thin or ultra thin mirror needs to be developed. This technology will be very useful in both of the ground based large telescope and the space large telescope.

In the meantime of 1997 to 2004, several tentative experiments to explore the manufacturing technology of large deep aspheric mirror and large thin mirror are successfully carried out in Nanjing Institute of Astronomical optics and Technology, CAS (before 2001, it was called Nanjing Astronomical Instrument Research Center). Hereby some results are presented in below.

* xcui@niaot.ac.cn; phone 86 25 85482202; fax 86 25 85405562; niaot.ac.cn

2nd Intl. Symp. on Advanced Optical Manufacturing and Testing Technologies: Large Mirrors and Telescopes, edited by Yudong Zhang, Wenhan Jiang, Myung K. Cho, Proc. of SPIE Vol. 6148, 614803, (2006) · 0277-786X/06/$15 · doi: 10.1117/12.674037

2. ACTIVE STRESSED LAP POLISHING FOR LARGE APERTURE DEEP ASPHERIC OPTICS

Usually, aspheric optics is figured by means of small tools in a definite path across all different zones on mirror. The method is prone to introduce high spatial frequency error on the mirror and it is low in efficiency because of small tool. For active stressed lap polishing, the lap is large enough to avoid the introduction of high spatial frequency, to improve the polishing efficiency. In principle, the active stressed lap is varied in real time. The shape of the lap is actively adjusted to the form of the mirror where is covered by lap during polishing procedure. It makes polishing run much easy just like polishing a spherical mirror.

The Steward Observatory Mirror Laboratory of University of Arizona led to the development of a new deformable large-tool polishing technique (the active stressed-lap technique) that has had great success in the past years[1]. The stressed-lap technique has successfully polished several large deep primary mirrors. The optical laboratory of physics and astronomical physics department of UCL also developed this technology.

We have explored the active stressed polishing technique since 1997[2]. An F/2 parabolic mirror with diameter of 910mm was served as trail mirror (Fig.1). The stressed polishing technique needs to be solving following questions: the design of stressed lap, the relationship of lap deformation and active force, the relationship of lap movement and lap deformation, the relationship of lap position and polishing pressure, measuring method of lap shape and displacement sensor, computer servo system for stressed lap and numeric polishing machine.

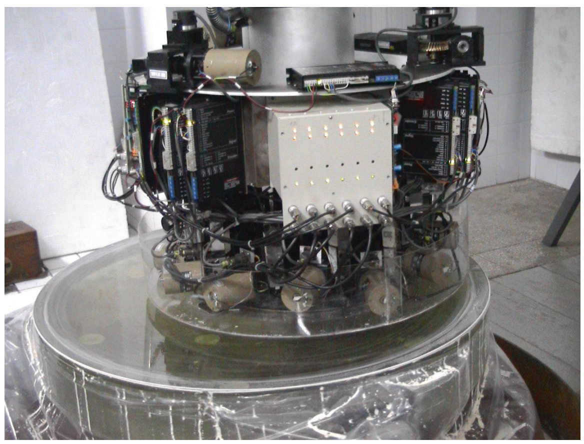

Fig. 1 Active stressed lap polishing forφ 910mm, F/2 paraboloid

The stressed lap is a deformable plate which figure can be actively adjusted by force actuators. It is same as thin–mirror active optics in principle. Even though the requirement of surface accuracy of stressed lap is less than the actively controlled thin mirror in telescope, but the update rate of active stressed lap is higher. A forging aluminium alloys base plate of stressed lap is 450mm in diameter. The working surface covered by pitch layer is 300mm in diameter, which is in the central area of base plate. There are 12 force actuators attached to the back of stressed lap. These actuators change the shape of base plate to fit the figure of any local area of paraboloid. The stressed lap updates itself at 6Hz, so the sampling frequency of 12 force actuator reach 100ms.

Based on the linear relationship in the range of elastic limitation, the force actuators are used to actively control the stressed lap to the desired off-axis shape real time during the polishing. The relationship of lap shape $\vec{w}$ and magnitude of force $\vec{f}$ given by

$$K\vec{f} = -\vec{w} \tag{1}$$

Where K is the stiffness matrix of the stressed lap.

The mode calibration method or the damp least square method can be applied to solve the active force of the stressed lap, just like the case in the thin mirror active optics. The solution of the mode calibration method is given by the numerical calculation or measuring the influence function of stressed lap. The solution of least square method is given by

$$\vec{f} = -(K^T K)^{-1} \cdot K^T \cdot \vec{w} \tag{2}$$

The application of the damp least square method was applied in the optical optimization design. It is been applied in active optics when the first active optics system in China was developed around 1990[3]. The objective is to solve the question that the influence function cannot be measured exactly. In the situation, calculated force is far away from original value and out of the range of force limitation. The solution is given by

$$\vec{f} = -(K^T K + pI)^{-1} \cdot K^T \cdot \vec{w} \tag{3}$$

Where, vector I is identity matrix, p is the damp factor which is tried and determined in force calculation. The proposition has proven by Ding-qiang Su and Yan-nan Wang[4]. That is, the damp least square method settles the non-linear question. Furthermore the answer is the best answer in an N-dimensional ellipsoidal space which surface is where the aggregate of answer located on and with the center in original point. The sum of square of residual difference is the least in formula (1). So when the measurement is not accurate enough, the damp least square method is a good solution to settle the question that the force large than the range of limitation (singularity).

The shape of the lap generated by 12 force actuators was measured by means of 16 displacement sensors. The result of static measurement has shown: (1)The deviation between desired shape and measuring result was less than 3μ rms. (2) The linearity of measurement was less than 0.9 microns, better than target of design. The result of dynamic measurement is about 1~2 microns, reaches the requirement of real application.

A lot of experiments shown that the repetition is well, namely the deformation and measurement error is about 1μ rms in the whole area of polishing lap.

The servo system of stressed lap and computer controlled machine is a distributing control system dominated by a singlechip computer. It issues command to realize following operations:

(1) To apply twisting and bending moment to the lap by 12 force actuators;

(2) To exert desired pressure between lap and mirror by using another 3 force actuators;

(3) To collect data by 15 force sensors;

(4) To control the rotate speed of stressed lap and table of machine;

(5) To control the movement and swing of stressed lap

Furthermore, all these operations must be harmonized enough and responded quickly.

The experimental result of stressed lap polishing

The interference fringe patterns acquired by SHACK cube shows that the surface accuracy less than λ /20 rms in whole aperture. If local non-symmetrical error are removed(not introduced by stressed lap), the surface accuracy less than λ /30 rms (Fig.2). At present, a F/2 paraboloid which requires ≤λ /40 rms is being polish.

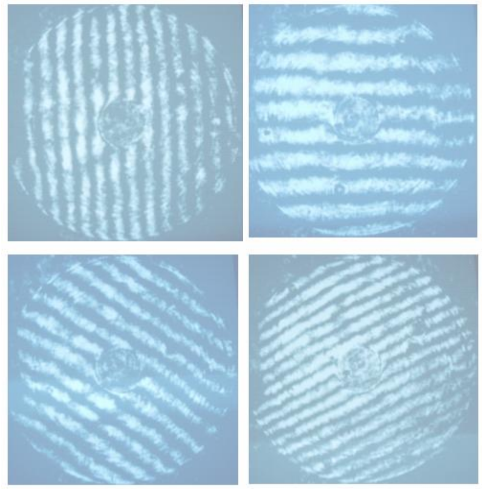

Fig. 2 The results of φ 910mm, F/2 paraboloid mirror by active stressed lap polishing (RMS surface accuracy ≤λ/30)

3. POLISHING TECHNOLOGY FOR LARGE APERTURE THIN AND ULTRA-THIN MIRROR

The application of thin mirror is supported by active optics technology. The thin mirror system is light in area density. So it is suitable to large-scale mirror, especially for large primary mirror of astronomical telescope. The typical examples are VLT primary (8.2-meter in diameter, 175-mm in thickness) of ESO, SUBARU primary (8.3-meter in diameter, 175-mm in thickness) of Japanese and GEMINI primary (8.4-meter in diameter, 200-mm in thickness). In the resent years, the applications have spread to space telescope. A model mirror has been successfully manufactured in the Optical Science Center of University of Arizona[5]. It is 2-meter in diameter, 2mm in thickness. The area density is only $13kg/m^2$, including the mirror, supporting base and actuators.

To polish large thin mirror, the most important factor need to be noticed is to avoid the high spatial frequency error. Because such mirror is small in thickness, weak in rigidity, the high spatial frequency is tending to be introduced during polishing run. Several pieces of ultra-thin mirror were polished for exploring the method of manufacturing in resent years. The mirrors are 1-meter class in diameter. Their aspect ratio is great than 40. Two kinds of supporting method for ultra-thin mirror are studied. One is non-rigid connection method; the other is computer controlled closed-loop active supporting method.

The non-rigid connection supporting system was applied in the manufacturing process of a hexagonal plane which is used for national large scientific project of China, the LAMOST project[6, 7]. The results showed that the mirror surface has reached the PTV = 0.23 wavelength, RMS = 0.046 wavelength in any circular area with 220mm in diameter. Two local interference patterns are showed in fig.3. There are 24 sub-mirrors in LAMOST MA. Its diagonal is 1.1 meter. Its thickness is 25mm. The requirement of surface error is less than 20nm.

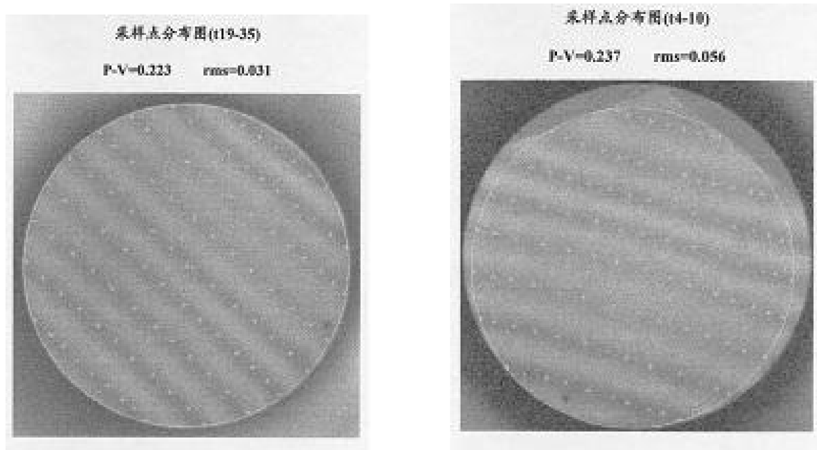

Fig. 3 The local interference patterns in the area of 200mm in diameter. Its tentative result

for Schmidt plate of LAMOST project

Computer controlled closed-loop active supporting system is composed of a set of force actuators. These actuators are connected to the mirror and fixed to a rigid base (Fig.4). The alignments of actuators are carefully calculated. Such supporting system has been applied to the experiment of a 1-meter class meniscus thin mirror. The system is suitable for larger thin mirror, for example, 4 meter or 8meter. The procedure that adopts separated and active supporting system is integrated several important factors: testing device, computer added wave-front analysis, force actuator and computer controlled closed-loop active adjusting. The trial mirror is 1035mm in diameter and 26mm in central thickness. Its front surface is concave sphere with radius of curvature 3220mm. Its rear surface is convex sphere with radius of curvature 3120mm. 55 supporting points are adopted and distributed in 5 different rings. Based on calculation, the maximum deformation caused by gravitation is 15nm.

The active supporting system consists of 52 force actuators and their controller. A Shack-cube is used to measure wave-front of the mirror. During the polishing, the supporting force of force actuator keeps constant. After a polishing cycle, the surface shape can be adjusted. The variation of force actuator is based on the last measurement. Just like the controlling mode of active lap, the adjusting force is solved using least-square method. The final result is: the residual surface error RMS=λ/19, the local high spatial frequency error RMS=λ/27.

Fig. 4 The trial mirror with diameter of 1035mm and thickness of 26mm on it active support system for polishing

CONCLUSION

Some results on active polishing technology for large aperture aspherical mirrors and ultra thin mirrors, which have been developed in recent years in NIAOT, CAS, are presented in this paper

(1) The computer controlled active stressed lap has been developed. A paraboloid mirror with F-ratio 2 and 910mm in diameter has been polished to the surface accuracy of RMS≤ λ /30. The technology can be applied to manufacture off-axis aspheric optics also.

(2) A computer controlled machine which is equipped active stressed lap has been developed. It is ready for manufacturing large aperture, fast F-ratio aspheric optics.

(3) The computer controlled close-loop active mirror technology has been applied to the manufacturing procedure of 1-meter class ultra-thin mirror. To actively adjust the surface shape of the mirror, 52 high accuracy actuators integrated mechanism and electronics were employed. These actuators are used to measure and adjust the magnitude of supporting force. These works could become the base for manufacturing 4 to 8 meter large ultra-thin mirror in China.

(4) In recent year, several 1-meter class plano optics and meniscus thin mirrors have been polished to the surface accuracy of RMS≤ λ /20. One is large hexagonal thin mirror, a plane with 1100mm in diagonal and 44:1 in aspect ratio. It is served as a tentative mirror for LAMOST MA. The other is large thin meniscus with 1035mm in diameter and 26mm in thickness.

Active polishing technology is an advanced technology for large aperture aspherical mirror and ultra thin mirror. It is very useful in the manufacturing of large aperture telescope especially for new concept and extremely large telescopes.

REFERENCE

1. S. C. West, H. M. Martin, R. H. Nagel et al, Practical design and performance of the stressed-lap polishing tool, Applied Optics, Vol. 33, No. 34, 1994
2. Xiangqun Cui, Bilie Gao, Daxing Wang et al, A New Technology for Polishing Large Aperture Aspherical Astronomical Mirror, Acta Optica Sinica, 2005, Vol. 25, No.3, pp.402-407
3. Ding-qiang Su, Sheng-tao Jiang, Wei-yao Zou et al, Experiment system of thin- mirror active optics, Proceedings of SPIE Conference on Advanced Technology Optical Telescopes V(Ed. Stepp, L. M.)2199, 609-621,1994
4. Ding-qiang Su and Ya-nan Wang, Automatic correction of aberration in astro-optical systems, Acta Astronomica Sinica Vol.15, pp. 51-60, 1974
5. J.Burge etc. NGST Mirror System Demonstrator from the University of Arizona, proc.SPIE Vol.4451,2001
6. Shou-guan Wang，Ding-qiang Su, Yaoquan Chu, Ya-nan Wang, Xiangqun Cui, Special configuration of a very large Schmidt telescope for extensive astronomical spectroscopic observation, Applied Optics, Vol.35, No.25, 5155-5161, 1996
7. Xiangqun Cui, Xinan Li, Zhenchao Zhang et al, Tentative Fabrication Test for Large Aperture Thin Astronomical Mirror, Acta Optica Sinica, 2005, Vol. 25, No.7