Progress and prospect of LAMOST project

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ABSTRACT

Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a meridian reflecting Schmidt telescope with an average clear aperture of 4-meter, a focal length of 20-meter and a field of view of 5-degree. It is a national large scientific project in China. The horizontal meridian reflecting Schmidt configuration and with an active Schmidt correcting plate to achieve the special telescope with both wide field of view and large aperture. There are 4000 optical fibers on the focal surface to transfer light of 4000 objects into 16 spectrographs. The project started in 1997. Now it steps into its assembly stage. The general status and progress of LAMOST project is presented in this paper: The key technologies of the project have been tested successfully; the design and manufacturing of the mechanical parts of the telescope have been completed; most segmented mirrors (sub-mirrors) have been polished. Also the first spectrograph, the first three sub-mirrors of Ma (Schmidt plate) with their complete support system, and the first three sub-mirror of the primary mirror are ready for being integrated on the telescope structure

Keywords: Astronomical telescope, Active optics, Multi-fiber spectroscopy

1. INTRODUCTION

The Chinese national large scientific project Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) is a meridian reflecting Schmidt telescope with an average clear aperture of 4-meter, a focal length of 20-meter and a field of view of 5-degree, and 4000 optical fibers on its focal plan to feed the light into 16 spectrographs[1, 2, 3]. It is laid down on the ground with its optical axis fixed in the meridian plane, with its optical axis tilted by an angle of 25° to the horizon for the sky coverage. The declination of observable sky area ranges from -10° to +90°. LAMOST consists of a reflecting Schmidt corrector M_A at the northern end, a spherical primary mirror M_B at the southern end and a focal surface in between. Both the primary mirror and the focal surface are fixed on their ground bases, and the reflecting corrector tracks the motion of celestial objects. Celestial objects are observed around their meridian passages.

The M_A is located at the center of curvature of the primary mirror. Its size is 5.72m×4.40m, which consists of 24 hexagonal plane sub-mirrors. Each sub-mirror of M_A has a diagonal of 1.1m and a thickness of 25mm, and will be actively deformed into required off axis aspherical shape to form a 4m active reflecting Schmidt corrector during the observation. The M_B has a size of 6.67m×6.05m with a radius of curvature of 40m, which consists of 37 hexagonal spherical sub-mirrors, each of them having a diagonal of 1.1m and a thickness of 75mm.

The image quality of LAMOST degrades with the increasing of the incident angle θ. To obtain a good image quality, the angular diameter of FOV is taken as 5° for the sky area of $-10°\leq\delta\leq+60°$ which corresponding to a sky area of 19.6 square degrees and a linear diameter of 1.75m. For the sky area of $+60°\leq\delta\leq+90°$, the angular diameter of FOV is taken as 3°, and it is noticed that this sky area is only 11.4% of the total observing sky area. For whole observing sky area and field of view, the image quality is 1.91 arc seconds for 100% energy concentration with image displacement due to differential atmospheric refraction[4].

The technical challenges of LAMOST are:

- Active optics

  Both thin mirror and segmented mirror active optics in M_A

  segmented mirror active optics in M_B

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- Optical fiber positioning for 4000 fibers
- Elimination of the air turbulence on 40m optical path
- Support system and wind protection for thin mirrors
- Mirror polishing and testing
- Accurate tracking and driving
- Computer control and diagnosis
- Huge amount of data processing

Until the end of 2004, all key technologies are successfully tested in laboratories. The assembly and installation on site commenced in autumn of 2005. The following presentation is the progress in recent years and expected achievements in 2006 and 2007 for LAMOST.

2. RECENT PROGRESS

2.1 Optics

The sub-mirror of M_A is a very thin hexagonal mirror. There are 14 sub-mirror of M_A have been successfully polished in the Mirror Laboratory of Nanjing Institute of Astronomical Optics and Technology until January of 2006. The RMS surface errors of all these M_A sub-mirrors are between 20-70nm before active correction and 9.5-18nm after active correction. The best case after active correction is shown in Fig.1.

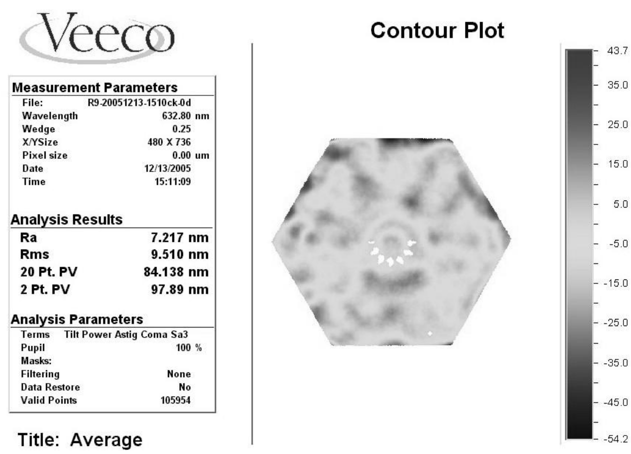


Fig. 1 The surface contour of a sub-mirror of M_A

Fig. 2 Two sub-mirrors of M_A

Each sub-mirror of M_A with its mirror cell and support system is going to be tested by a special test setup (Fig. 3) to get all information for the support system before to be installed in the telescope on site. This setup can simulate different altitude angles during observation. The first three have been integrated with their mirror cells and support systems, and are going to be tested soon.

All sub-mirrors of M_B are manufactured by LZOS in Russia. Until January of this year, polishing for 24 sub-mirrors of M_B have been completed and transported in Nanjing. The RMS surface errors of all these sub-mirrors are less than 15nm, and the consistency of all sub-mirrors is within 1.5mm for the 40m curvature radius of M_B. The first three sub-mirrors with their support systems (a whiffletree in axial and a center lateral support system) have been tested by a setup[5] shown in Fig. 4. The results are fitting with LAMOST requirements well.

In 2006, polishing for all 61 sub-mirrors of M_A and M_B will be completed. Before the end of 2006, at least 5 M_A sub-mirrors and 9 M_B sub-mirrors will be assembled with their mirror cells, and installed on the telescope structure.

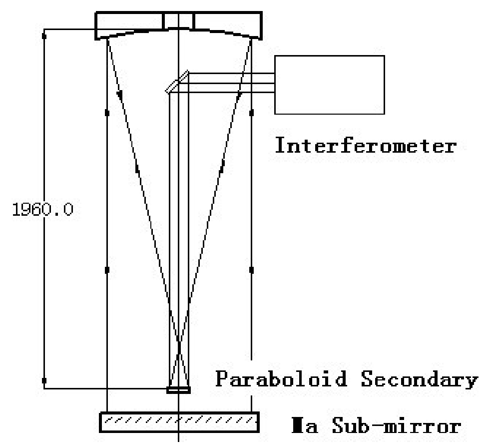


Fig. 3. Test setup for M_A sub-mirror assembly

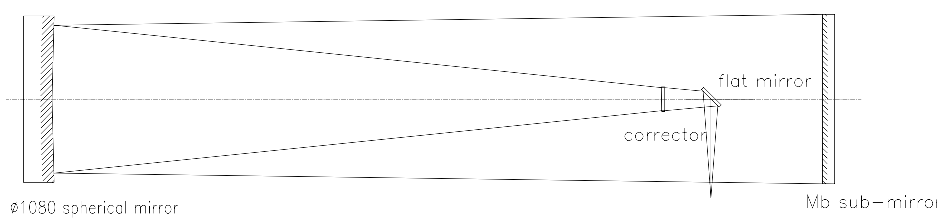


Fig. 4 Test setup for M_B sub-mirror assembly

2.2 Active Optics

The active optics in LAMOST is not only a combination of segmented mirror active optics and thin deformable mirror active optics on the reflecting corrector M_A, but also has two large segmented mirrors needed to be actively controlled in the same time in the telescope. The segmented mirrors active optics of LAMOST will be used to control the 24 sub-mirrors (M_A) and the 37 sub-mirrors (M_B) to keep co-focus. The thin deformable mirror active optics will be used to form by real time the 24 sub-mirrors into required aspherical surface shape to eliminate the 3rd order spherical aberration of the primary mirror M_B. This is a very special application of active optics. In addition, the thin deformable mirror active optics will also be used to correct the manufacturing errors, the gravity deformation and the thermo deformation of the 24 sub-mirrors of M_A. There are two correction modes in the thin deformable mirror active optics of M_A: (i) the open loop control is to correct the spherical aberration mainly during observation, and correct the gravitational deformation while observation sky area is changed that makes a large elevation change of M_A; (ii) the close loop control is to correct the thermo deformation and all other low time frequency random errors to calibrate the initial surface of each sub-mirror before each observation.

Active forces and displacements to produce the surface shape of sub-mirror of M_A:

A new calculation method of active forces and displacements, which is used specially for no round mirror shape, developed in LAMOST during last two years[6,7].

The original shape of the reflecting correcting surface is plane. There are 34 force actuators and 3 displacement actuators at the back of each sub-mirror of M_A. All these actuators are used for obtaining the required surface shape of M_A. The maximum required deformation of surface shape of sub-mirrors of M_A is about 10μm. During the observation, the fastest shape and displacement changing interval of M_A is two minutes.

For certain sky area during observation, from the M_A surface shape in reference paper 1, we can obtain the surface shape formula (1) and (2) as below:

$$s = a_1y^4 + a_2y^3 z + a_3y^2 z^2 + a_4yz^3 + a_5z^4 + a_6y^3 + a_7y^2 z + a_8yz^2 + a_9z^3 + \\ + a_{10}y^2 + + a_{11}yz + a_{12}z^2 + a_{13}y + a_{14}z + a_{15} \quad (1)$$

(All coefficients $a_1, a_2, \ldots, a_{15}$ are known)

$$\mathbf{s} = C\,\mathbf{l} \quad (2)$$

l expresses a vector its components are all forces of force actuators and all displacements of displacement actuators of this sub-mirror: **l** $(f_1, f_2, \ldots, f_{34}, d_1, d_2, d_3)$, and **s** $(s_1, s_2, \ldots, s_m)$, in which $s_1, s_2, \ldots, s_m$ are the shape of reflecting correcting surface to be calculated from (1). We can use the least square method (formula (3)) or the damp least square method (formula (4)) to obtain the forces and displacements.

$$\mathbf{l} = (C^TC)^{-1} C^T \mathbf{s} \quad (3)$$

$$\mathbf{l} = (C^TC + PI)^{-1} C^T \mathbf{s} \quad (4)$$

We can also using the pre-calibration method to obtain the forces and displacements.

$$\mathbf{l} = a_1\,\mathbf{l_1} + a_2\,\mathbf{l_2} + \ldots + a_{14}\,\mathbf{l_{14}} + a_{15}\,\mathbf{l_{15}} \quad (5)$$

Where

$$\mathbf{l} = a_1 (C^TC)^{-1} C^T \mathbf{s_1} + a_2 (C^TC)^{-1} C^T \mathbf{s_2} + \ldots + a_{14} (C^TC)^{-1} C^T \mathbf{s_{14}} + a_{15} (C^TC)^{-1} C^T \mathbf{s_{15}} \quad (6)$$

Giving hour angle and declination (t, δ) we can obtain all coefficients $a_1, a_2, \ldots, a_{14}, a_{15}$, then by using (5) the all forces and three displacements for a sub-mirror are obtained.

There are some advantages in this pre-calibration method: (i) It can be used not only for the circular mirror but also for the mirror with any shape, such as hexagonal; (ii) It can obtain active forces and displacements in one calculation; (iii) The shape of sub-mirror is not expressed by a fixed polynomial, but it is derived from formula (1) in reference paper 1 which is with high accurate; (iv)It is easier to obtain all coefficients than a fixed polynomial; (v) The solution of pre-calibration method (5) is same strict as the least square solution (3).

Experiments for thin deformable mirror active optics of M_A

The outdoor experiment for M_A thin deformable mirror active optics has been carried out until 2004 with a special experiment system - a 1m small LAMOST[8]. In this active experiment system, a tunnel enclosure has been built. To improve the seeing, we installed cooling and ventilation system to blow cooled air with controlled temperature into the tunnel. Some experiments for the support system of M_A, modifying the seeing condition, and measurement of the seeing by Shack-Hartmann wave front sensor[9] have been done also.

(1) Results of close loop control active optics for M_A

The close loop control active optics means that the correction with the wave front measurement. There are two experiment modes for close loop correction: (i) Wave front measuring and active correction in autocollimation mode with artificial light source (the normal of M_A experiment mirror is fixed); (ii) Wave front measuring and active correction in real time mode during observing a star in sky (the normal of M_A experiment mirror is changing).

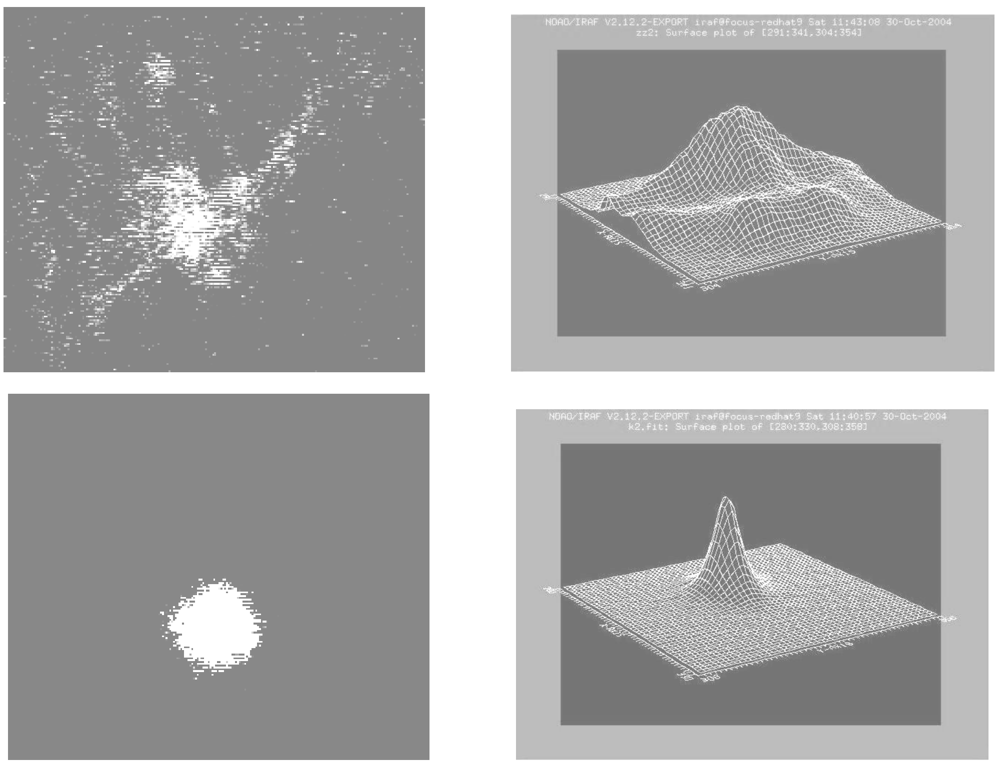
The result for real time mode in the experiment has shown that during 2 hours observation the average corrected image quality is less than1.5arcsec for 80% energy concentration.

(2) Results of open loop control active optics

The open loop control active optics means the active correction only depends on the theoretic calculation during tracking a star, but the initiate referent surface of M_A got by close loop active correction in autocollimation mode before telescope (or M_A) pointing at object.

For open loop active control during 4 hours observation, with seeing condition 2arcsec(FWHM), the average result we got is 80% energy concentrated in 1.6arcsec.

A result of the open loop control experiment during tracking a real star is recorded by CCD camera showed in Fig.5.



(a)

(b)

Fig.5 The image quality obtained before (a) FWHM4.8arcsec and after (b) FWHM1.98arcsec

(Observing star with initiate position δ=49.9°, t=350°, θ=36°)

Experiment for segmented active optics of M_B

Considered about the feasibility, we choose M_B to do the experiment for co-focus segmented active optics. An experiment tunnel built specially in Nanjing for test the segmented active optics of M_B is shown in Fig. 6. Three sub-mirrors of M_B can be tested in this experiment system. The Shack-Hartmann wave front sensor is the same as described in the reference paper 10, which is located at the curvature center of M_B. With this experiment system, the support system of sub-mirrors, the control system of displacement actuators can be tested and modified. All 37 sub-mirrors of Mb are going to be tested in this experiment system before installed in LAMOST on site.

The test result for first three sub-mirrors shown: the accuracy of co-focus is about 0.1arcsec, and image quality is better than 0.42arcsec for 80% energy concentration (Fig. 7).

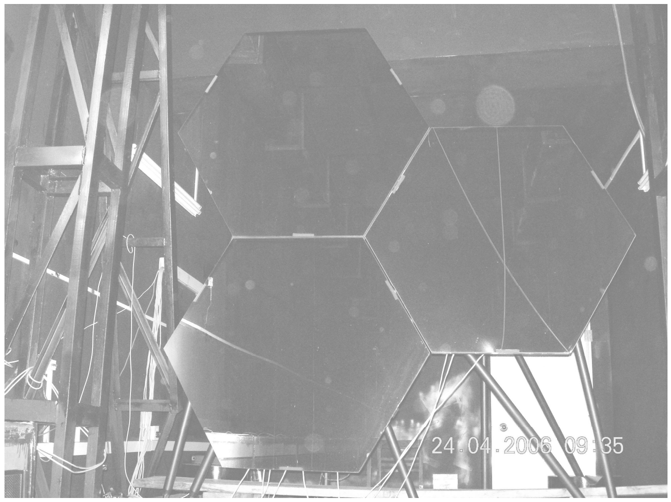


Fig.6 Three Sub-mirrors of M_B in co-focus test

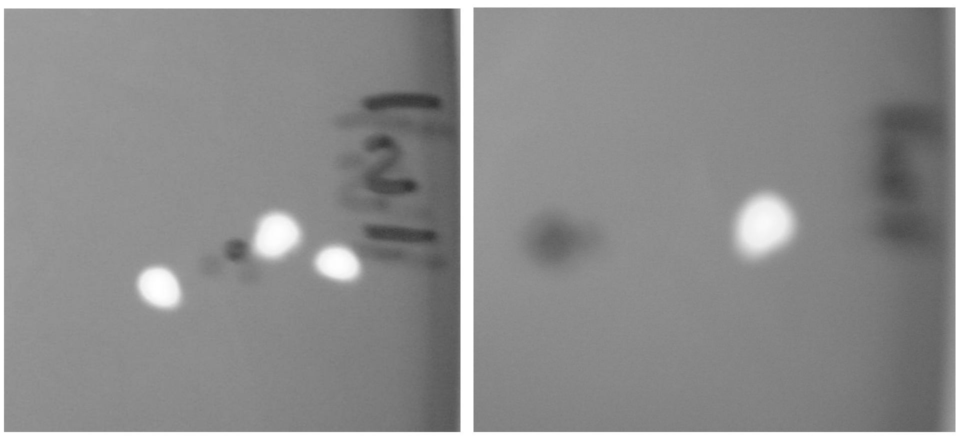


Fig. 7 Image before and after active co-focus correction in an experiment

2.3 Telescope Structure, Mounting and Control System

M_B truss structure is the largest piece in the telescope. After assembly, its size is 7.28m x 8.6m , used to support the primary mirror. M_B truss structure has been installed on its concrete pillar in last December.

The alt-az mounting of M_A and the focal mechanism have been tested in workshop before to be transported, and installed on their pillars on site in last October and December respectively.

The 8 meters diameter azimuth table of M_A mounting is the largest movable piece in LAMOST. The test result in workshop showed that the accuracy of the axis of the table in radial is less than 0.04mm, and in axial is less than 0.02mm. The repeat accuracy for rotation is less than 0.03arcsec.

Except the tracking for focal rotation and focusing, the focal mechanism is designed could be move aside while the Shack-Hartmann wave front sensor is in use for measuring co-focus of M_B. The test results in workshop are all reach the specification.

The control system of tracking is tested in workshop together with the alt-az mounting and driving system and focal mechanism.

2.4 Focal Instruments

A prototype of low resolution spectrograph (LRS) has been tested in 2004 (Fig.8). To fit the new plan of the science, the medium resolution is been added in the new design of the 16 spectrographs, and the Volume Phase Holographic (VPH) gratings is decided to be used to provide higher efficiency. Combined with the change the width of the slit, the low resolution are 1000 and 2000, and the medium resolution are 5000 and 10000. The wave bands are different between low and medium spectrographs:

- For Low, blue: 370—590nm, red: 570—900nm

- For Medium, blue: 510nm — 540nm, red: 830nm — 890nm

In this year, 34 E2V CCD chips are going to be delivered. The contracts for 34 CCD cameras are going to be signed soon in the first half of this year.

The fiber positioning system for 4000 fibers is with 4000 positioners on the focal plane. Each fiber is mounted on one positioner which is a double arm rotating mechanism. There are two step motors for control rotations of two arms respectively. It is developed in University of Science and Technology of China in Hefei. In 2004, a prototype with 19 positioners is developed in USTC successfully (Fig. 9). A smaller fiber positioning system with 250 fibers is going to be completed in 2006.

Each fiber will be about 230-30m long. In total the 4000 fibers should be about 14km. The first contract with Polymicro Technologies has been signed.

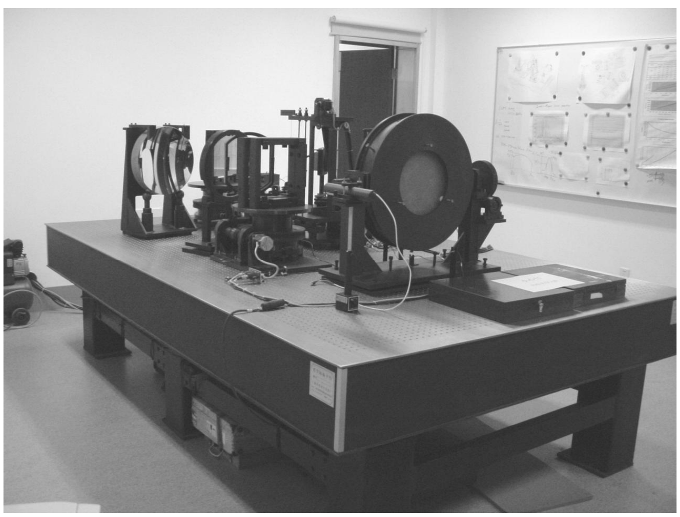


Fig.8 The prototype of LAMOST spectrographs

Fig.9 The prototype of the fiber positioning system

2.5 Enclosure and Site Building

The all three concrete pillars and building are ready for installation of the mounting of M_A, the focal mechanics and the truss structure of M_B in last October. Until now, the dome of M_A has been installed, and the enclosure for M_B and focus is going to be finished in May. The cooling system and ventilation system of the enclosure is going to be installed in the same time.

3. PROSPECT

The first light with the partial optical aperture of the telescope, which should be larger than 2m in diameter and one spectrograph with 250 fibers, is expected in spring of 2007. Complete the installation and alignment of the telescope with full aperture and 4000 fibers, and spectrographs should be in 2008.

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