The LAMOST Multi-object Spectrographs with Aspherized Gratings

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ABSTRACT

LAMOST is a powerful spectra survey telescope with 4 meter aperture and 5 degree FOV. It's focal plate with 1.75 meter diameter can accommodate 4000 fibers in which feeds 16 multi-object spectrographs.

In the last conference of astronomical telescope and instrumentation hold in Munich, Germany in April, 2000, preliminary design for LAMOST multi-object spectrographs based on plane reflective gratings and Schmidt camera with refractive corrector has been reported[1]. Here, use aspherized reflective grating instead of the plane reflective grating and need for refractive corrector plate is avoided. Compared to previous design using a refractive plate for correcting aberrations from both collimator and camera mirror, use of aspherized grating has the achromaticity advantage as well as less asphericity, and minimizes the number of optical surface. This would improve the efficiency of spectrograph and allows much broader spectral coverage. In this paper, we present the current design of multi-object spectrographs for LAMOST project.

Keywords: Instrumentation – Spectrographs – Aspherical gratings

1. INTRODUCTION

LAMOST project has been granted for construction by the Chinese government. It is a meridian reflecting Schmidt telescope laid on the ground. Its optical axis is fixed in the meridian plane, tilted 25° to the horizontal and runs from south to north. The telescope has an aperture of 4m, f-ratio of 5, and a 5° field of view. Its focal plane with 1.75m in diameter may accommodate as many as 4000 optical fibers. The optical fibers are positioned in the focal plane using a parallel controllable positioning system. The shape of the Schmidt corrector has to change with different sky area and with tracking process. This is done by active optics[2].

This telescope planned for first lights in 2004 – 2005 will use 16 Low Resolution Spectrographs (LRS) which together take 4000 simultaneous spectra. The wavelength range is 370 nm to 900nm and resolution is up 2000. Each spectrograph has a red and a blue channel, each with a 2048x2048 CCD.

Fundamental desired capabilities and design alternatives for LRS were reviewed in the end of 2000. At that time, two alternative designs were recommended, one based on plane reflective gratings and Schmidt camera with refractive corrector and another one based on pseudo- plane aspherized grating and need for refractive corrector plate is avoided. A prototype of LRS will use aspherized grating.

In a slit or objective spectrograph using a reflective grating, one of the difficulties is the obstruction of the incident beam by the camera optics. To avoid this, it is usually necessary to move all parts of the camera optics to a distance of several times the aperture from the grating. This lead to larger camera and more difficult to design. The introduction of larger optics is always expensive and greatly increases the aberrations.

With aspherized grating, LRS would increase the optical throughput because using less optical element, and decrease the cost since much less asphericity is required for aspherized reflective grating than the refractive corrector. Several spectrographs have been designed with reflective aspherised grating before. The first such instrument was designed for the prime focus of the Canada – France – Hawaii Telescope[3]. The MARLY spectrographs of the Haute – Provence and

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Nanjing Observatory and CARELEC spectrograph of the 2 m telescope of the Haute – Provence Observatory have been designed with aspherized gratings[4].

2. DESIRED PERFORMANCE

The principal scientific goal of spectrographs is to obtain 4000 spectras of galaxies as faint as 20.5 magnitude over five-degree field of the telescope in a single exposure. We outline the requirement bellow which drove the spectrograph design:

Resolution

The resolving power requirement has been set at $R=\lambda/\delta\lambda=1000$ with an optical fiber of diameter 3.3 arcsecond. A second goal permits use of a narrower slit or change grating to achieve R=2000.

Wavelenth coverage

Spectra wavelength coverage in single exposure is from 370nm to 900nm. Placing the blue limit at 370nm ensures that the emission lines of OII is observed even at zero redshift.

Fibers

The design comfortably accommodates 4000 spectra per observation, using 16 identical spectrographs, each handling 250 fibres. Fiber core diameter 320μm(3.3 arcsecond)

3. OPTICAL DESIGN

For a grating spectrograph with resolution limited by the slit-width the principal design parameters are fully defined by the resolution-luminosity product [5,6], which can be given as

$$R\cdot\phi=\frac{2\sin\theta_b\cos\theta}{\cos\alpha}\cdot\xi\cdot\frac{D_c}{D_t} \tag{1}$$

This reduces, when $\theta=0$ (the Littrow), to

$$R\cdot\phi=2\xi\cdot\tan\theta_b\cdot\frac{D_c}{D_t} \tag{2}$$

Equation 1 can also be written in the form:

$$R\cdot\phi=2\sin\theta_b\cos\theta\cdot\frac{L}{D_t} \tag{3}$$

Which reduces, for the Littrow case , to

$$R\cdot\phi=2\sin\theta_b\cdot\frac{L}{D_t} \tag{4}$$

Where $R=\lambda/\delta\lambda$ is the spectral resolving power, ϕ is the angular width of the slit projected on the sky, D_c and D_t are the collimator and telescope apertures, L is the ruled length of the grating, θ_b is the blaze angle of the grating, θ is the off-Littrow angle $\alpha-\theta_b$, and α is the angle of incidence. For a fiber couple spectrograph, ϕ is the fiber diameter and ξ is focal ratio degradation of the fibers. There are only two free parameters: θ_b and D_c. To meet the resolution requirement of LAMOST-LRS, the value of $R\times\phi$ must be larger than 3300 arcsecond. The design parameters for the LAMOST-LRS are listed in Table 1, 2

Table 1. Design parameters of LAMOST-LRS for blue band.

Grating data		Units	const/var	Optical Parameters			Units	const/var
g/mm	720.0		constant	D_c (Collimator)		200.0	mm	constant
θ_b	10.44	deg	constant		f/	4.0		constant
θ	17.5	deg	constant	D_t (Telescope)		4.00	m	constant
γ	0.0	deg	constant		f/	5		constant
d	1.39	μm	computed	fiber size		0.32	mm	constant
α	27.94	deg	computed	Fiber degradation		0.8		computed
β	-7.06	deg	computed	Camera:	f	300.0	mm	constant
Order m	1.0		constant	$R\times\phi$		3228	arcsec	computed
λmin	370.0	nm	constant	Scaling Parameters				
λb	480.1	nm	computed	Slit projection factor		2.996	hor	computed
λmax	590.0	nm	constant					
CCD	2048×2048	pixels	constant	Image scale		30.895	(sec/mm)	computed
Pixel size	24.0	μm	constant					

Table 2. Design parameters of LAMOST-LRS for red band

Grating data		Units	const/var	Optical Parameters			Units	const/var
g/mm	480.0		constant	D_c (Collimator)		200.0	mm	constant
θ_b	10.66	deg	constant		f/	4.0		constant
θ	17.5	deg	constant	D_t (Telescope)		4.00	m	constant
γ	0.00	deg	constant		f/	5		constant
d	2.08	μm	computed	fiber size		0.32	mm	constant
α	28.16	deg	computed	Fiber degradation		0.8		computed
β	-6.84	deg	computed	Camera:	f	300.0	mm	constant
Order m	1.0		constant	$R\times\phi$		3302	arcsec	computed
λmin	570.0	nm	constant	Scaling Parameters				
λb	735.1	nm	computed	Slit projection factor		3.003	hor	computed
λmax	900.0	nm	constant					
CCD	2048×2048	pixels	constant	Image scale		30.972	(sec/mm)	computed
Pixel size	24.0	μm	constant					

The optical layout of the spectrographs is shown in figure 1. Light from the fiber (1) exits in an f/4 beam, expaned somewhat from the f/5 input beam of the telescope due to various processes collectively known as focal ration degradation. The beam encounters the spherical collimator mirror (2). The approximately collimated light returns from the mirror in a beam 200mm in diameter, passes the slit, and meets the dichroic beamsplitter (3). The blue light (370nm-590nm) is reflected while the red (570nm-900nm) light is transmitted. After the beamsplitter, the light incident upon asupherized gratings (4, 9 or 5, 10), which is mounted on the pupil position of the spectragraphs. The dispersed light exits from the aspherized gratings and then was focused onto 2048x2048 CCD by a spherical camera mirror. Optical parameters of these components are summarized in table 3.

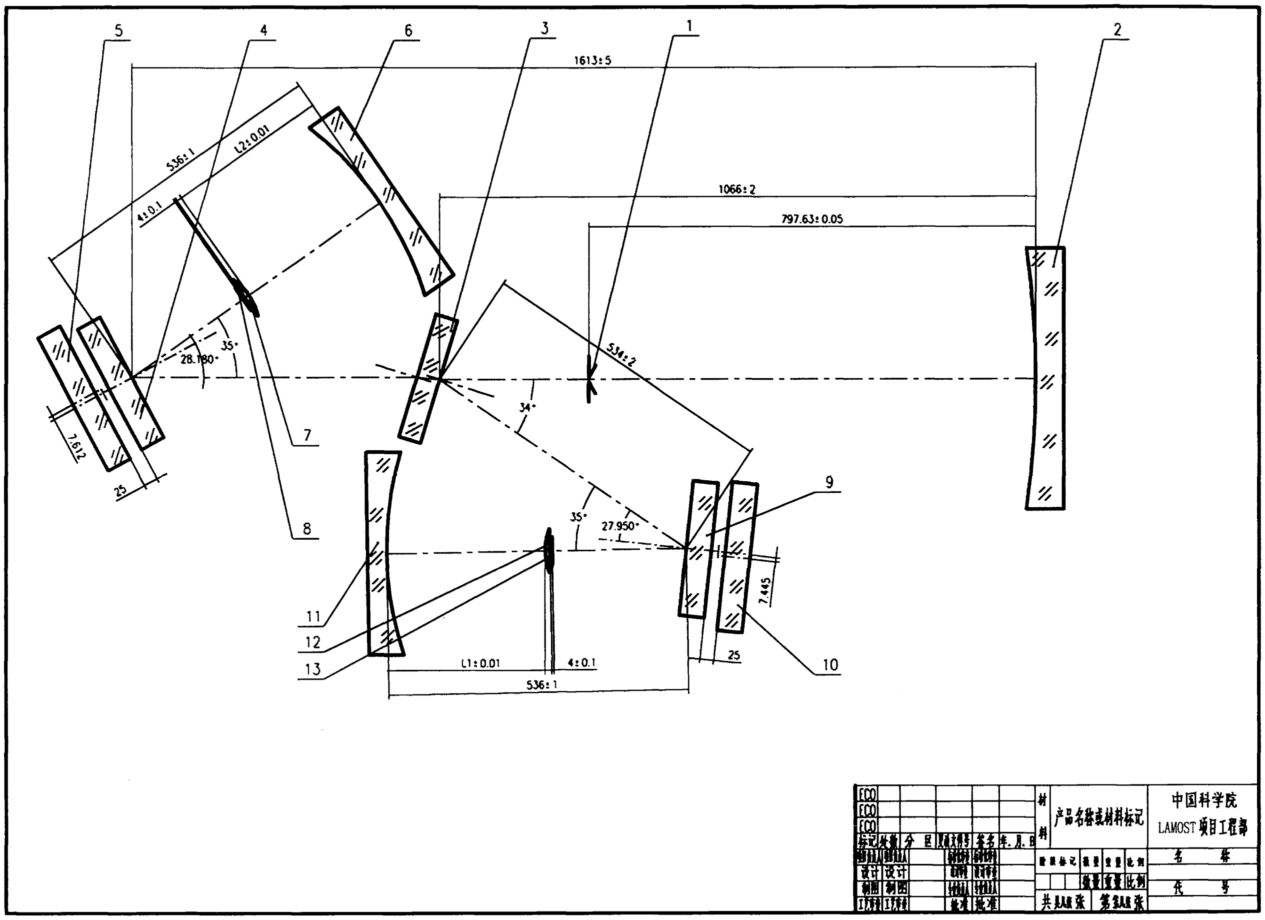

Figure 1. Optical layout of LAMOST-LRS

Table 3. SURFACE DATA SUMMARY:

Surf	Type	Radius	Thickness	Glass	Diameter
Slithead	Spheric	-800	797.626		130
Collimator	Spheric	-1600	-1066	MIRROR	453.5583
Dichroic	Flat	Infinity	534	MIRROR	283.4371
Grating *	Aspheric	Infinity	-536	MIRROR	225.6262
Camera	Spheric	600	282.9504	MIRROR	331.171
Flattener , front	Spheric	105	9	F_SILICA	75.3591
Flattener , back	Spheric	-3240	4		73.77393
Image	Tilt				

Collimator

The collimator mirror is a spherical figure with 200 mm x 454 mm clear aperture. The substrate will be a zero thermal expansion material, Chinese VO_2.

Beamsplitter

The beamsplitter, which divides the collimated beam into blue and red channels, will be made of fused silica. This material has excellent transmission and low dispersion in our wavelength coverange.

Aspherized grating

Grating is ruled grating on aspherical surface with sag defined gy equation:

$$Z = a\,(X^2+k^2Y^2) + b(X^2+k^2Y^2)^2 + c\,(X^2+k^2Y^2)^3 + d\,(X^2+k^2Y^2)^4$$

The grating lines are parallel to the local X-axial. The sag equation parameters, a, b, c, d and k, should be variable when do optimization. Optimization results show that grating aspherical substrate having a biaxial symmetry gives a better aberration corrections than those having a rotational symmetry. In our case, the incident angle α, diffraction angle β and blaze angle of the gratings are very close in blue and red channels, so that one can also expect to carry out optimizations with same grating figures for both blue and red. Parameters of aspherized substrate for grating as follows:

k= 0.986786=COS9.324885°

a= 0.19927e-4

b= -0.6014608e-9

c= -0.2483097e-14

d= 0.1303439e-19

In these results, all of the grating coefficients are identical for red and blue. This reduces drastically the cost of the submasters to replica aspherical grating.

Camera mirror

The camera mirror is a spherical figure with 600 mm radius. The substrate will be a zero thermal expansion material, Chinese VO_2.

Field flattener

Actual detectors are only available with flat sensitive surfaces. The addition of a positive single lens before the detector allows to achieve flat field design. The lens with 9 mm thickness, made of fused silica, use as a cryostat window of detector.

Image quality

Spot diagrams are given for each of the seven field position in five different wavelengths. Wavelength units are microns. Figure 2 shows spot diagram of blue band and Figure 3 shows spot diagram of red band. The RMS value of spot diameter is about the 12~30μm.

4. CURRENT STATUS

A prototype of LRS is to be finished in 2003. In the current moment, the prototype of LRSs is near to it's module manufacture.

LRS components are at an advanced stage, all the hardware components have passed the final design review and are in the manufacture phase.

The contract for the optics has been issued, and the mechanics will follow soon; Elasticity design of active optics submasters for aspherized grating is to be designed;

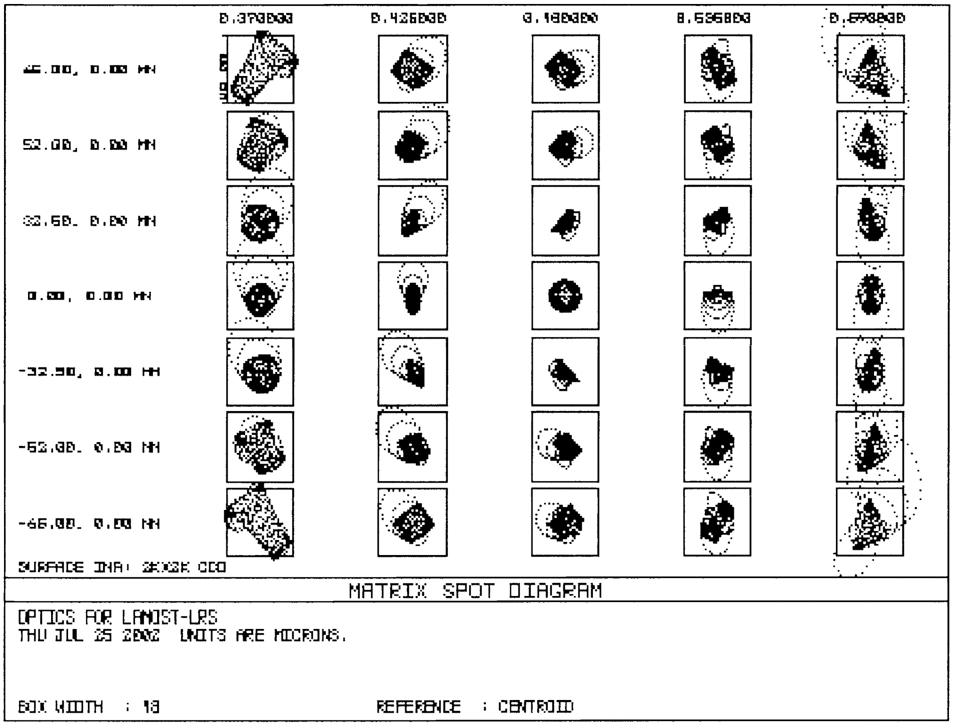

Figure 2. The spot diagram of blue band for LAMOST-LRS

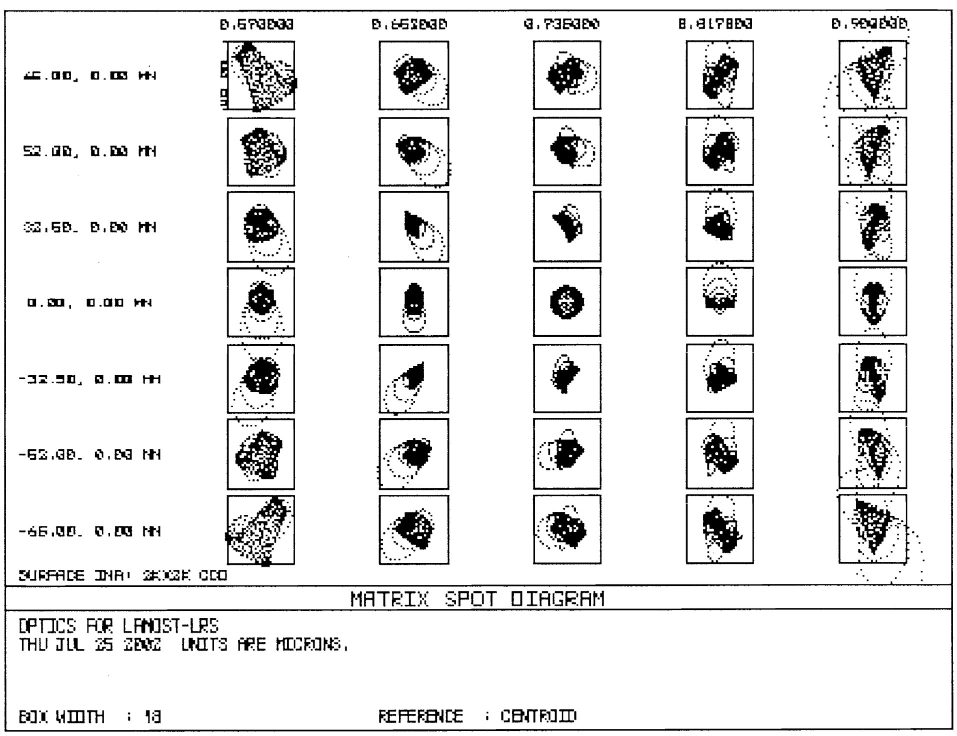

Figure 3. The spot diagram of red band for LAMOST-LRS

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