

Optical Design for the Off Axis Telescope with Long Focal Length and Wide Field of View^{* *}

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Abstract: A kind of TMA was described, all the system surfaces are uncoaxis, avoid the affection of the central obstruction, the system is 15 m focal length, and $5.0^\circ \times 0.4^\circ$ field of view FOV, the total length of system is nearly $f/3.5 \sim f/3.0$, the evaluation shows that the image quality is nearly diffraction limit.

Key words: three mirror anastigmat (TMA); long focal length; optical design; telescope; off-axis

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长焦距、大视场、离轴望远系统的光学设计

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摘要: 设计了一种长焦距、大视场、离轴望远镜光学系统, 采用的 TMA (three mirror anastigmat) 系统 3 个反射面都是二次曲面, 将 3 块镜面都离轴和倾斜放置, 从而避免了中心遮拦的影响, 系统的视场为 $5.0^\circ \times 0.4^\circ$, 焦距为 15 m 和总长度为 $f/3.5 \sim f/3.0$, 像质达到了衍射极限。

关键词: TMA; 长焦距; 光学设计; 望远镜; 离轴

1 Introduction

Somehow, there is always a need for an optical system that has a larger field of view and high resolution, especially if such a system is also compact, achromatic, and has a flat field. The best kind of system with comparatively longer focal length is the three-mirrors anastigmat (TMA) telescope. It can fulfill these needs.

In the large aperture optical systems the refraction or catadioptric systems need to get rid of the secondary-order spectrum by using special optical materials for some or all of their components or adopting complex structure^[1]. The reflection system has many advantages that the refraction system hasn't.

Firstly, it doesn't produce the chromatic aberration and can allow larger aperture. Secondly, it is easy to be lightened and has greater merits in heat tolerance. On the other hand, mirror systems suffer from obscuration problems: the central obscuration make loss of modulation transfer function (MTF) even for a perfect design and, in eccentric systems, difficulty to obtain a large unvignetted bidimensional field of view (FOV). By making use of uncoaxis system we can rectify the aberration and make the structure simpler and easier and obtain fine image quality in the end. So for now some researchers who major in this field have done lots of work^[2~3]. For this system, the main trouble is that it also has large FOV and little space even if its focal length is long.

In order to solution the trouble, here a kind of

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TMA system is showed whose focal length is 15 meters. Its FOV can reach to $5.0^{\circ} \times 0.4^{\circ}$, the total length of system is nearly $f/3.5 \sim f/3.0$. It can cover a comparatively wide area and has short canister. The evaluation shows that the image quality has nearly reached the diffraction limit.

2 Optical system analysis

In the aberration-free system or when the aberration is small enough the highest resolution is decided by the diffraction limit caused by the aperture of the system. The diffraction has an effect on the resolution of the system and the effect is characterized by the diameter of the Airy disk

$$d = 2.44\lambda f/D \quad (1)$$

In the formula above, λ is wavelength, f is focal length, D is the dimension of the aperture. The best image quality is the diffraction limited.

The f is determined by the below formula

$$f \frac{s}{H} = \delta \quad (2)$$

Where H is the height of the planet orbit, s is the resolution to the ground, δ is the pixel dimension of detector.

The width of the ground covered

$$Q = 2H \tan(\omega) \quad (3)$$

In the above formula, ω is the semifield angle of view.

The space resolution is related to the relative aperture when the wavelength and the height of the planet are rooted. If the aperture can be confirmed to put into practice, based on the same orbital height, increasing the focal length can also increase the resolution to ground. At the same time, increasing the field of view can wide the width of the ground covered.

From the above analysis and demands we can see that large-aperture does a great deal of benefits to improve the capability of the space optical system. Because the refraction system and the catadioptric system are limited by the factors on materials and so on their practical use is correspondingly limited. While the total reflection system can allow larger aperture and doesn't produce chromatic aberration.

Of all the systems mentioned above the TMA has the simplest structure and can obtain ideal image quality. When the three mirrors of the system are quadratic surfaces the system has 8 variances (include three radii, and two intervals, and three conic aspherical coefficients). When the primary aberration is rectified and the total focal length is satisfied the residual variances can be used to satisfy the special needs of the central stop and the working distance and so on. And it also has several results.

3 System examples and performance

Now here is an uncoaxis TMA system. The original structural parameters of the system is showed in the following tab. 1.

Tab. 1 TMA system optical parameters

System entrance pupil diameter/ mm		1 500
Focal length/ mm		15 000
FOV/ (°)		5×0.4
F-number		10
Spectral bands/ microm		0.486~0.700
Total length of system/ mm		5 000
Aspherics	Primary	Conic, $k = -1.44$
	Secondary	Conic, $k = -1.33$
	Tertiary	Conic, $k = -1.38$

It shows that the three mirrors are ellipsoidal mirrors. The aperture stop and the secondary mirror are superposed and it has no central image. To avoid the central shade we make all the lens tilt and eccentric. Fig. 1 is the TMA system's layout map. Making the system's components to be eccentricity and tilt, it will produce some new additional aberrations, which are mainly a certain amount of coma and astigmatism. Here we use the eccentricity produced by the third mirror to rectify them.

When we have finished the special optimization its image quality can reach to the extreme of the dif-

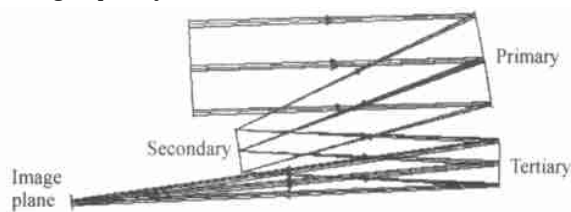


Fig. 1 System layout

fraction. Its optical MTF curve is showed in Fig. 2, the diffraction energy distribution curve is showed in Fig. 3. Its total length is $f/3.5 \sim f/3.0$.

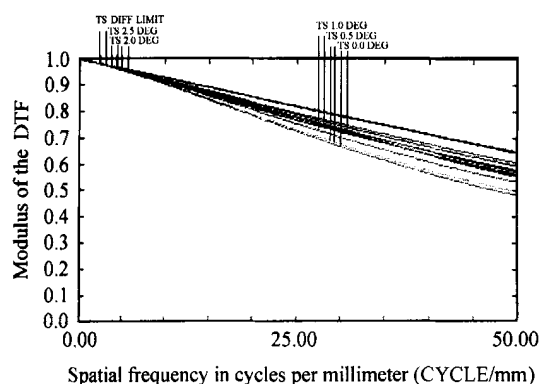


Fig. 2 MTF curve

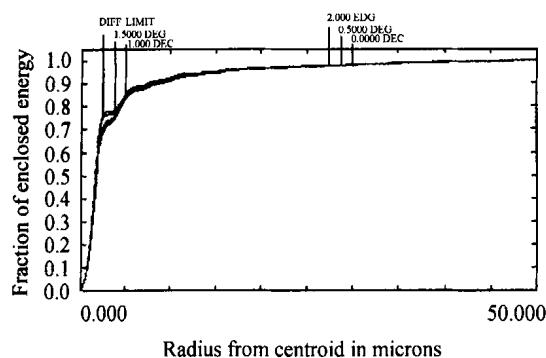


Fig. 3 Diffraction energy curve

4 Conclusion

The modern earth observation instruments use the push-broom concept with a linear FOV, perpendicular to the track on ground, recorded on the linear CCD during movement of the satellite. This relaxes the problem and opens new ways for pure mirror opti-

cal systems used as light collector for advanced earth observation satellites.

Due to the unique advantages of TMA it has been widely used in the space photographically recorded imagery and paid much more attention at present. The conventional two-mirror systems, like the TITCHEY-CHRETIEN telescopes cannot be appropriately used because they suffer from residual field curvature. In this article we make use of the rectangular field of view. It is suitable to linear array TDFCCD receiver that obtains the image by scanning and is suitably used in the field of space to earth remote sensing and the space photographically recorded imagery.

We get rid of the reduction due to the central shade and improve the image quality by using the un-coaxis TMA system. With the improvement of CAM and the technique of alignment the TMA system will get much more widely used.

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Biography :

CHANG Jun (1973 -), He received the Ph.D. degree from Changchun University of Science and Technology in 2002. Now he is a post doctor of Changchun Institute of Optics and Fine Mechanics, Physics, his current research interests concentrate primarily on optical design.