OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 1, No. 11, November 2007, p. 554 - 557

Designing of a large field of view and large aperture optical system for IR sensor

JUN CHANG*, ZHI-CHENG WENG, XIAO-JIE CONG, M. M. TALHA, HUI-LIN JIANG[a]
Beijing institute of Technology, School of Information Science, Beijing, 100081; Changchun, China
Institute of optics and fine mechanics, physics, Chinese Academy of Sciences, Changchun 130022, China
[a]Changchun Institute of Technology, Changchun 130022, China

Here we just describe a design method and result for an infrared system. This optical system can be used in the dual band infrared and also can be used at visible wavelengths. The design is based on an off-axis three-mirror anastigmatic (TMA) system. The off-axis concept allows wide-field enabling a variety of observations designs for the Multi-Object Spectrometer instrument optimized for low scattered light and low emissivity. The large field of views available: 30 degrees in the IR and the visible, and the system large aperture is F/2.5-F/2. The final optical system is a three-mirror unobscured telescope with two off-axis segments. It achieves diffraction-limited imagery at visible and IR wavelengths. Achievements of computer technology of automated shaping of large-sized optical details with achieving of diffraction quality of the image permit to expand technological opportunities of the method on creation of aspherical off-axis mirrors of a complex configuration. Technical parameters of made off-axis aspherical mirrors are listed.

(Received September 26, 2007; accepted October 31, 2007)

Keywords: IR system, Optical design, Off-axis aspherical mirror

1. Introduction

In recent years, the required for a compact and lightweight optical system with a wide ground cover, high resolution and flat image plane for a large aperture IR system in the space field has made the three-mirror anastigmatic system (TMAS) be developed rapidly, it has made the three-mirror anastigmatic system (TMAS) get greatly improvement. TMAS has the following properties: it is unobscured, it is entirely reflective so it doesn’t produce the chromatic aberration and can allow larger aperture. Meanwhile it is easy to be lightened and has greater merits in heat tolerance and it can make system compact and lightweight with a flat image plane in the space field. For the TMAS design, it requires considerable trade-off between obscuration of the mirror by another, off-axis angle, and the third order aberrations.

The further development of optical instrument-making industry, in particular of te1escopes of space basing, requires creation of high-precision aspherical off-axis components for compound main mirrors, and consequently development and perfection of technologies of their manufacturing. Challenges in fabrication and testing have historically limited the choice of surfaces available for the design of reflective optical instruments. Spherical and conic mirrors are common, but, for future science instruments, more degrees of freedom will be necessary to meet performance and packaging requirements.

The compact TMAS presents in this paper has the large aperture value and its FOV is relatively wide (30^o by 5^o). The system is intended for use in an orbiting push-broom linear-array scanner for multi-spectrum earth observation or use in the multi-spectrum linear array experiment (MLA). This MLA also employees a series of linear detector arrays in the push-broom scanning mode.

2. The solution of optical system

There are two conditions for the TMA system forming the middle image. The first solution is using the primary mirror forming it; the second solution is using the primary mirror and the secondary mirror forming it. When the TMA system is made of three conic mirrors (Fig. 1), there are 7 variable ($a_1, a_2, \beta_2, \beta_3$) and three conic coefficients. After satisfying the focal length and correction Seidel aberrations (S_1, S_2, S_3, S_4), there are still enough variable values to satisfy the reduction of the central obscuration, working length and so on.
where:

$$a_1 = L_2/f_1' \approx D_2/D_1 \tag{1}$$

a_1 is the obscuration value of the primary mirror, D_1, D_2 are the diameter of the primary mirror and the secondary mirror, here the entrance pupil is located at the primary mirror;

$$a_2 = L_3/L_2' \approx D_3/D_2 \ , \tag{2}$$

a_2 is the obscuration value of the secondary mirror, D_3 is the diameter of the third mirror;

$$n_1=n_2'=n_3=1\ ;\ n_1'=n_2=n_3'=-1\ ;$$
$$\beta_2 = (n_2L_2')/(n_2'L_2)\ , \tag{3}$$
$$\beta_3=(n_3L_3')/(n_3'L_3),$$

β_2 is the magnetite of the secondary mirror, $\beta_3$is the magnetite of the third mirror;

d_1 is the distance between primary mirror to the secondary mirror,

d_2 is the distance between the secondary mirror to the third mirror.

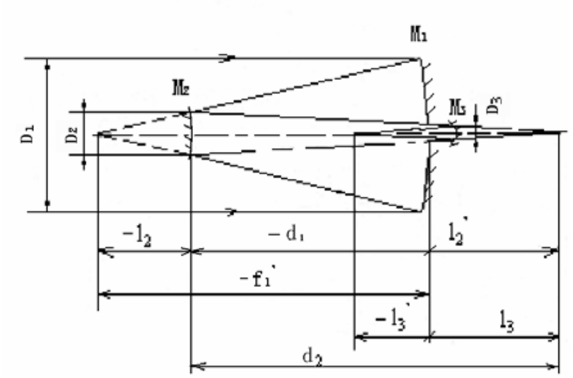

Fig. 1. Three mirrors layout.

In order to solve the equations of the seidel aberrations, the three unequal equations such as $d_1<0$, $d_2>0$ and $L_3'<0$ should be satisfied:

$$\begin{cases} (1-a_1)\cdot f_1' < 0 \\ a_1\cdot(a_2-1)\cdot\beta_2\cdot f_1' > 0 \\ a_1\cdot a_2\cdot\beta_2\cdot\beta_3\cdot f_1' < 0 \end{cases} \tag{4}$$

For the no-middle image forming by the primary, we can get this formulas:

$$\begin{cases} d_1\cdot f_1' < 0 \\ \left|f_1'\right| > \left|d_1\right| \end{cases} \tag{5}$$

Connected the unequal equation (4) and (5), we can get the four different solve conditions.

$$\begin{cases} f_1' < 0\ ,\ -1 < a_1 < 0\ ,\ a_2 < 1\ ,\ \beta_2 < 0\ ,\ \beta_3 > 0 & \text{(6a)} \\ f_1' < 0\ ,\ a_1 < -1\ ,\ a_2 > 1\ ,\ \beta_2 > 0\ ,\ \beta_3 > 0 & \text{(6b)} \end{cases}$$

3. The system design result

The starting point for this design was an unobscured TMA. This system was chosen as a particularly compact configuration with good performance over wide fields of view. Its focal length is 80-100 mm and a relative aperture of f/2~f/2.5, FOV is $30^{o} \times 5^{o}$, Here we choose the a_1=-2.2, a_2=0.4, β_2=-3, just as formula (6a), after select the good layout such as every mirror power is just as negative-positive-positive and the advantage of this system is it makes the total length be shortened and the back focal length to be more compensate. The specific design goal of this current task was to reduce fabrication risks to the optics, while maintaining system performance, field of view, and f-number. The final solution evolves as a consequence of following the design approach discussed above. The solution did not come from a few third-order equations; some fancy plots and good intentions are developed. The design and performance are shown in the following figures. Fig. 2 shows a 3D layout of the system. Fig. 3 and Fig. 4 show MTF and the Diffraction Energy Curve of this system. Fig. 5 show the distortion and field curve over the field. Some of the notable design points are shown in Table 1.

Table 1. TMA system optical parameters.

Focal length		100-200 mm
Field of view		30 × 5 Deg
F-number		2~2.5
Spectral bands		3~5 microns 8~12 microns
Total length of system		230 mm
Average MTF (20 LP/mm)		0.62 (MTF diffraction limit 0.7)
Aspherics	Primary	Conic, k=-4.2; 4th order, 6th order
	Secondary	Conic, k=-1.83; 6th order
	Tertiary	Conic, k=-2.91; no high order
Maximum Aspheric Departure	Primary	0. 4 mm
	Secondary	0. 23 mm
	Tertiary	0.045 mm
Dimension	Primary	281*230 (mm)
	Secondary	R60 (mm)
	Tertiary	220*180 (mm)

To achieve the diffraction limit over the whole FOV, the primary and tertiary are off-axis aspheres, cutting them from the parent mirror, the parent mirror is polished in a conventional manner, finished by hand touch-up or computer controlled polishing and then the off-axis segments are cut out. And for this system it also can be used diamond-machining processes, it allows conic or general aspheric surface contours to be placed on elements allowing superior image correction over an all-aspherical system of the same number of elements. In this method can be obtained two segments in the same time with exactly the same aspherical parameters.

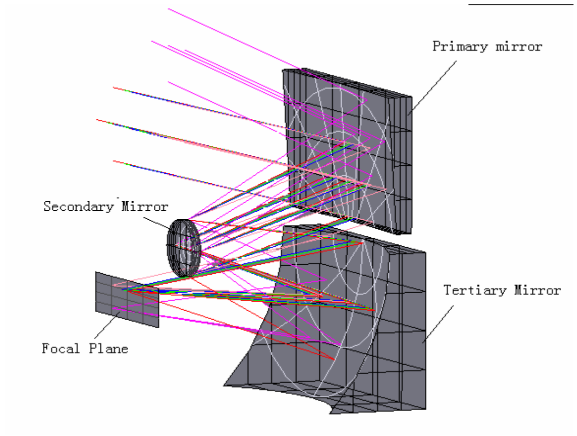

Fig. 2. The system 3D layout.

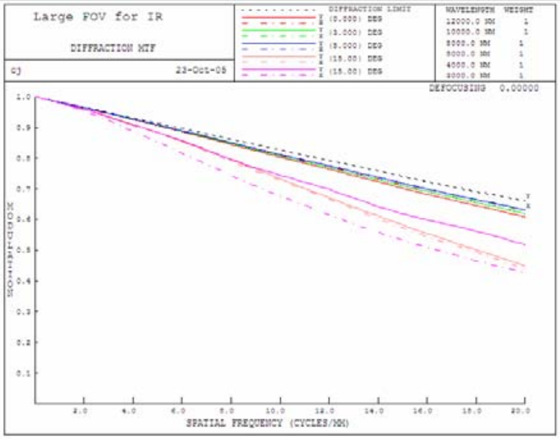

Fig. 3. Modulation transfer function curve.

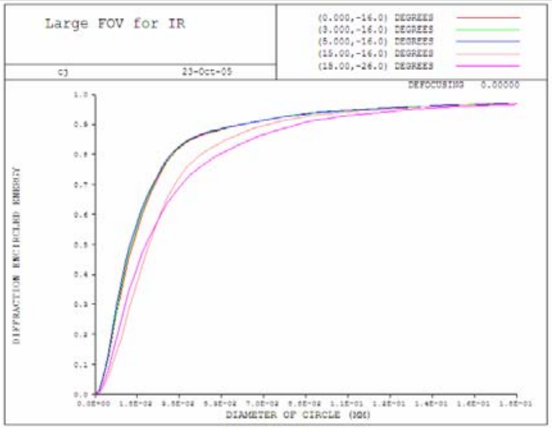

Fig. 4. Diffraction energy curve.

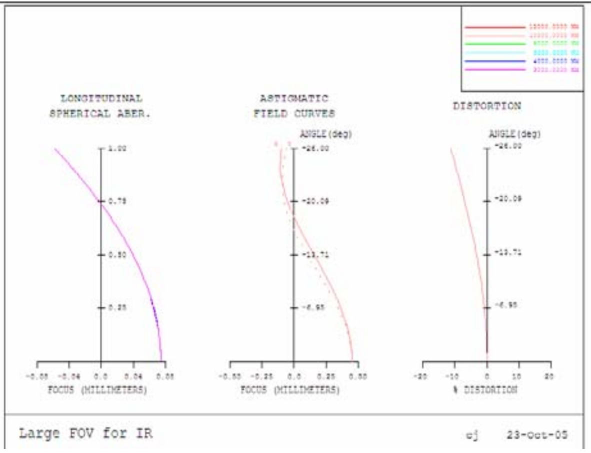

Fig. 5. The distortion and field curve.

4. Conclusions

Infrared optical systems pose multiple challenges for both the designer and the user. Infrared detectors are significantly more expensive than visible detectors. Materials are expensive, brittle, and sometimes opaque. Thermal sensitivity of infrared systems can be higher an order of magnitude or greater than similar visible systems.

In this article we make use of the rectangular field of view. It is suitable to linear array TDI-CCD receiver that obtains the image and is suitably used in the field of Space to Earth remote sensing and the space photographically recorded imagery. Meanwhile, we get rid of the MTF reduction reason due to the central shade and improve the image quality by using the uncoaxis TMAS.

Due to the unique advantages the TMAS has been widely used in the space photographically recorded imagery and paid much more attention at present. In the modern earth observation instruments use the push-broom concept with a linear FOV, perpendicular to the track on ground. This relaxes the problem and opens new ways for pure mirror optical systems used as light collector for advanced earth observation satellites.

With the improvement of CAM and the technique of alignment the uncoaxis TMA system will get much more widely used.

Reference

[1] Jiang huilin "On the Secondary Spectrum" ACTA Optical Sinica **2**(2), p 225-230.
[2] Warren J. Smith, "Modern Optical Engineering", Optical and Electro-Optical Engineering Series McFraw-Hill, Inc., 1990.
[3] Max J. Riedl, "Comments and guidelines for selecting IR objectives for focal plane arrays", SPIE Vol. **1970** Systems-Oriented Optical Design (1993).

[4] Andrew Bodkin, Compact multi-band (VIS/IR) zoom imager for high resolution long range surveillance, Fulop, Proc. of SPIE Vol. 5783.

[5] Y. Guimond1, Comparison of performances between GASIR moulded optics and existing IR optics, Proc. of SPIE Vol. 5406 (SPIE, Bellingham, WA, 2004).

[6] Muhammad Nadeem Akram, Design and Modelling of a Dual-Magnification Galilean IR Telescope and Associated Focusing Optics, Proceedings of SPIE Vol. **4832** (2002).

[7] K. H. Lee, First-Order Optics Computation for Re-Imaging IR Optical Systems, Proceedings of SPIE Vol. **5076** (2003).

[8] A. P. Semenov, J. Opt. Technol. **61,** 430-433 (1994).

[9] H. M. Martin, J. H. Burge, B. Cuerden, S. Miller, B. Smith, C. Zhao, “Manufacture of 8.4-m off-axis segments: a 1/5 scale demonstration”, Proc. SPIE Vol. **5494** (2004).

[10] C. Zhao, R. Zehnder, J. H. Burge, submitted to Optical Engineering (2005).

[11] J. W. MacKenty, M. A. Greenhouse, R. F. Green, L. M. Sparr, R. G. Ohl, R. S. Winsor, “IRMOS: An infrared multi-object spectrometer using a MEMS micro-mirror array,” Proc SPIE 4841, (2002).

[12] V. J. Chambers, R. G. Mink, R. G. Ohl, J. A. Connelly, L. M Sparr, J. E. Mentzell, S. M. Arnold, M. A. Greenhouse, R. S. Winsor, J. W. MacKenty, “Optical testing of diamond machined, aspheric mirrors for ground-based, near-IR astronomy,” Proc. SPIE 4841, (2002).

---

[*] Corresponding author: bitchang@bit.edu.cn