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The system design and assemble for the high resolution telescope system with segmented aperture

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ABSTRACT

A design method along with its results, for a space optical system with high resolution and wide field of view, is described. Such optical systems can be used in the infrared as well as visible configurations. The proposed design is based on an on-axis Ritchey–Chrétien system with corrected lens element while the primary mirror is a segmented aperture. Here the on-axis concept allows wide-field enabling a variety of observations designed for the multi-object spectrometer instruments, optimized for low scattering and low emission of light. The use of segmented mirrors in the optical system allows adopting any method for its fabrication purposes. Segment results are discussed and the image quality of the design based on these results is evaluated in this paper.

1. Introduction

In recent years, the requirement of a high resolution and flat image plane for the space field has made the two-mirror systems to be developed rapidly. Thus, the Ritchey–Chrétien (R–C) system and its advanced types still need improvements. Large aperture optical systems are significant in astronomy research for their increased light gathering capability and angular resolution in the object space. For the large aperture optical systems, the refraction should be free of secondary spectrum. Special optical materials (for some or all components of optical systems) are used or complex structures are adopted. The catadioptric system has many advantages as compared to the refraction systems. First, it can correct the chromatic aberration with a fewer lens elements and allows larger aperture. Secondly, it is easily lightened and has many merits in heat tolerance. Thirdly, it contains all on-axis elements which are easy to fabricate. But there are intrinsic limits for the diameter of an optical instrument with monolithic mirrors. These limits include cost, weight, atmospheric turbulence and thermal equilibrium problems [1–3].

A variety of new technologies have been developed to resolve these problems, including lightweight reflective panels [4], large deployable reflector (LDR) [5] and the precision segmented reflectors (PSR) [6,7]. The PSR consists of a series of sub-mirrors (segments) but there arise some other problems regarding their assemblies such as mounting errors, diffractive effects caused by the intersegment gap, etc. Thereby these segments need to be put together (with high precision positioning) to form a primary mirror [8–10].

This paper presents the method to design a long focal length system with the complex-aperture. First a mathematical model is designed and then the system results based on this model are provided.

2. Complex aperture modeling

Based on the analysis of different types, we have selected some models to present here. Results are shown in Fig. 1

2.1. Primary mirror after segmentation

For the type 1a and 1b, the aperture is divided by several same sub-apertures but all of them are connected in such a way that the gaps between them are very small. This arrangement has very small influence on the diffraction limited image quality. But for the type 1c and 1d, the gap dimensions between the consecutive apertures are kept larger as compared to the previous case. In this case the quality will be decreased significantly. Whereas, in types 1e and 1f,

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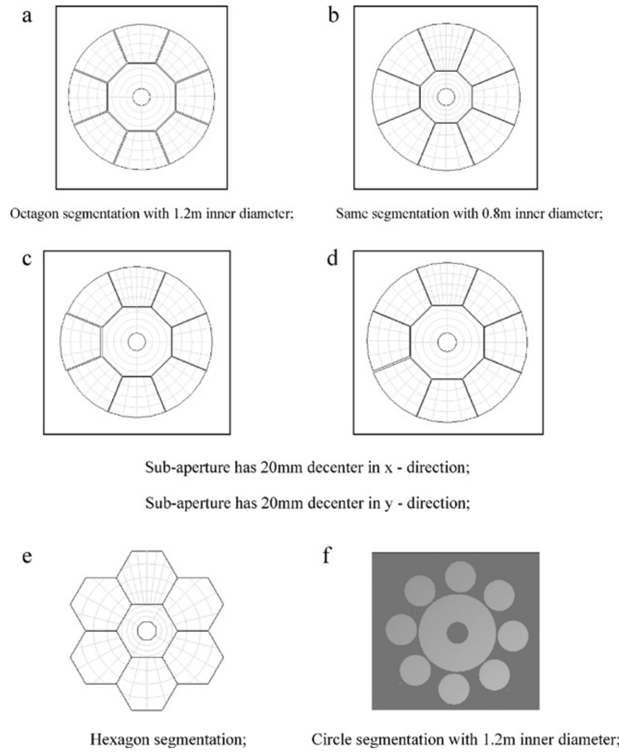

Fig. 1. Typical segmentation results (all the gaps are set equal to 10 mm).

the image quality has been influenced largely and hence the energy loss is observed.

3. System design with segmentation and analysis

The starting point for this design was an on axis R–C system with correct lens. This system was chosen particularly because of its compact configuration with good performance over wide fields of view. Some of the notable design points are shown in Table 1. The main advantage of choosing this kind of system as a starting point is that, such systems are composed of two mirrors with large power, small overall length, and compensable back focal length and it is easy to eliminate the color aberration. The specific design goal of this current work was to find out an optimized solution of the segment types to reduce the fabrication risks to the optics, while maintaining system performance, field of view, and *F*-number. The final solution evolves as a consequence of the design approach discussed above. The design and performance are shown in the following figures. Fig. 2 shows a 3D layout of the system. Figs. 3 and 4 show MTF and the diffraction energy curve of the designed system, Fig. 5 shows the spot diagram of it. From the above discussions we can conclude that the system quality approaches the diffraction limit.

To achieve the diffraction limit over the whole FOV, the primary and secondary mirrors are the on-axis aspherical elements, while the correction lenses are spherical elements. The primary mirror is a segmented aperture which has been fabricated using the traditional method; it is fabricated by mounting many small mirrors together and separated it later. The result shows in Fig. 6, we control the radius tolerance not more than 1 mm and the surface accuracy error not more than $\pm\lambda/30$. Now the optical lens elements and the building system are assembled now, as show in Figs. 6 and 7.

Table 1
R–C system optical parameters.

Focal length	3–4 m
Field of view	$2 \times 0.05^{\circ}$
F-number	8–10
Spectral bands	0.486–0.7 micron
Total length of system	3–4 m
Average MTF (100 LP/mm)	0.3 (MTF diffraction limit 0.32)

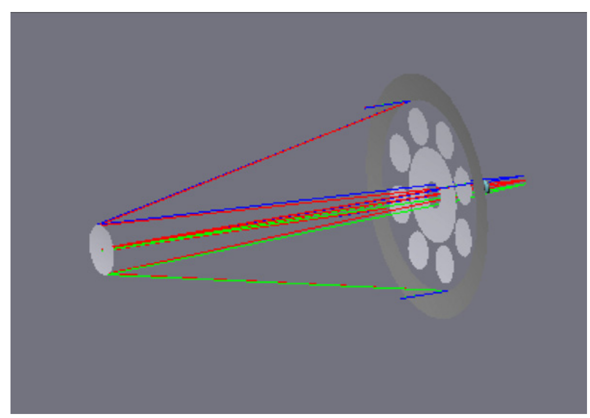

Fig. 2. The 3D layout of the system.

4. System stray light analysis

The analysis of stray light suppression is the study of all unwanted sources that reduce contrast or image quality. The sources can be divided for three kinds, the first source is the radiant ray from the outside system, such as the sun light; the second source is the infrared radiant from the inner system, and the third source is the objective ray pass through the un-normal surface reaching the sensor.

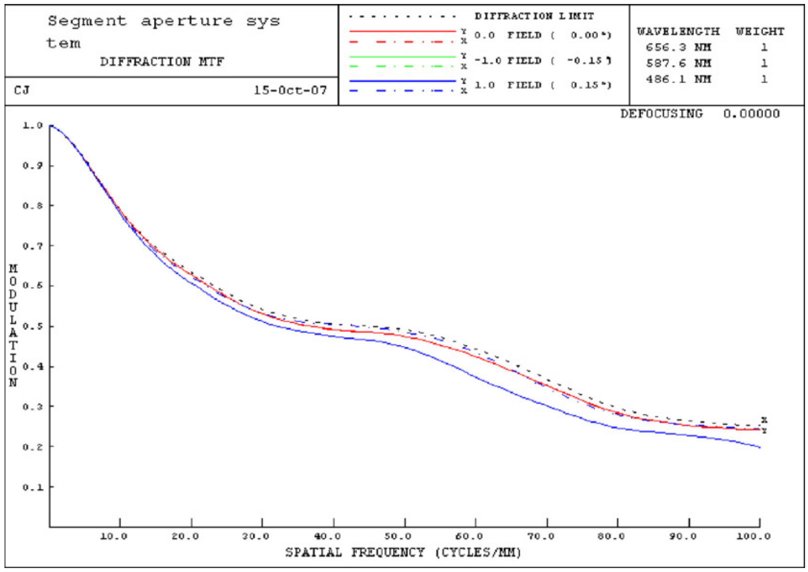

Fig. 3. MTF curvature of the system.

The energy of the stray light reaching the sensor was determined by this several factors [11,12]:

1. The power from the stray light source
2. The surface scatter characteristics of the source; these characteristics are defined by the bidirectional scatter distribution function (BSDF)
3. The geometrical relationship between the source and collector just like this formula:

$$\Phi_{\text{collector power}} = \Phi_{\text{source power}} \times \mathrm{BRDF}_{\mathrm{s}} \times \mathrm{GCF}_{\mathrm{s-c}} \times \pi$$

The creative use of aperture stops and field stops is an important part of any attempt to reduce the GCF term of the power transfer equation.

4.1. Stray light analyzing result

The optical system we use to analyze the stray light is the optical example discussed above. System worked in the visible wavelength. The fact this system is a R–C type imaging system, for this system it needs a long outlet baffle and a short inner baffle so that most direct scatter path is blocked. The small size of the field stop limits unwanted energy transmission; care was taken to make sure the object side of the aperture was not seen in reflection, because of the energy focused on it. Here we use the optical design software – LightTools to model and analyze it. The software is the product of American ORA Company; it can be used to model and analyze every kinds of stray light from every direction, Fig. 7 is the 2-D solid layout of system using the LightTools to model, the system was illuminated by the normal rays, the field of views were $(-0.5^\circ,0.5^\circ)$,$(0^\circ,0.5^\circ)$,$(0.5^\circ,0.5^\circ)$,$(0^\circ,-0.5^\circ)$.

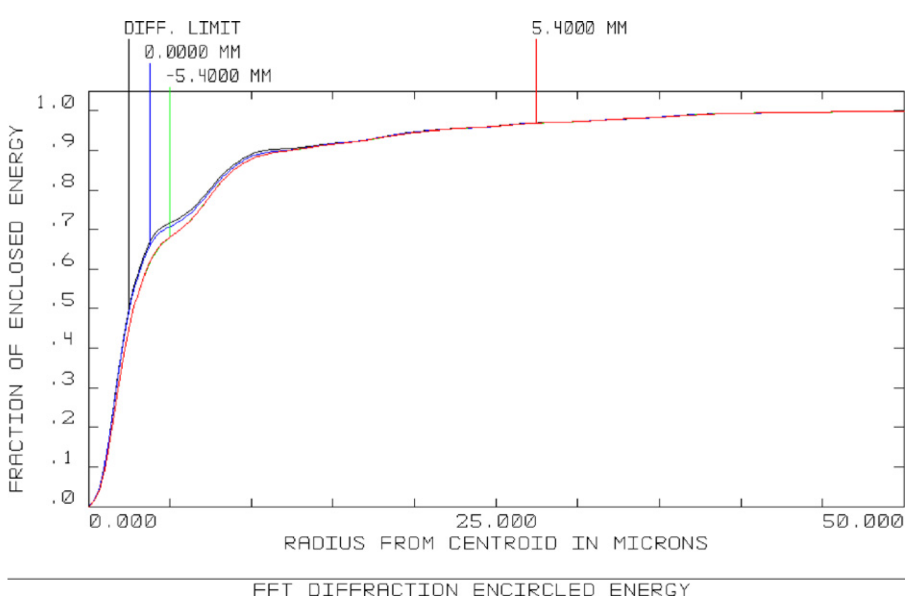

Fig. 4. The diffraction energy curve of the system.

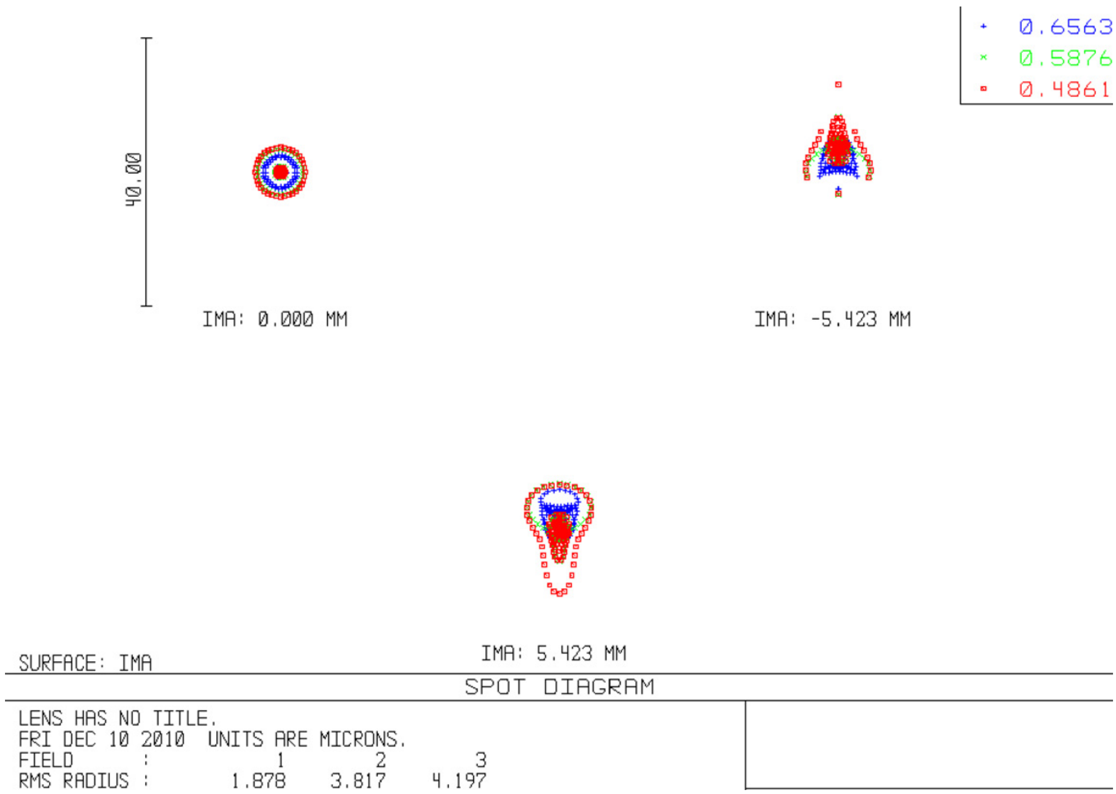

Fig. 5. The spot diagram of the system.

Fig. 6. The reality element of the primary mirror.

In this system these processes were used to control the stray light:

(1) The long outlet baffle and inner baffle were put here to block the straight ray from the sun, moon and so on, and the aperture stop was placed on the secondary mirror;
(2) The vanes placed on the inner system were made black to reduce the diffuse coefficient;

The length of inner baffle	The diameter of central baffle	The energy ratio of the stray light	The energy for the lose
250	40	0.003	0.029
300	40	0.002	0.018
350	40	0.002	0.0058

Based on the above second methods we have analyzed the energy at the imaging surface for different dimensions of the baffle, and we can get good result to block the stray light efficiently.

Fig. 7. The assemble background for this special system. The system layout for the stray light incident from different angles.

5. Conclusion

In this article we make use of the circle field of view. It is suitable to different detectors including the TDI-CCD. This system is also suitably used in the field of Space to Earth remote sensing and the space photographically recorded imagery. Due to its large aperture, it is expected to use in space telescope in future. Here, we have analyzed several kinds of segment models and also provided a sample model based on the proposed principle, and the stray light was analyzed here to make the best method blocking it.

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