Wide-field telescopes with a Mangin mirror

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Abstract — Two all-spherical catadioptric optical systems with a Mangin mirror are described. The design A (aperture 500 mm, f/2.0) has flat field of view of 7° in diameter; the design B (aperture 1000 mm, f/1.7) has 10° flat field. Both designs show near-diffraction-limited images. The $D_{80}$ diameter for the design A in the integral waveband 0.45-0.85 mcm varies from 1′′.3 on the optical axis up to 2′′.2 at the edge of the field (6.2 – 10.7 µm); the corresponding range of the $D_{80}$ diameter for the design B is 1′′.5 – 1′′.9 (12.4 – 16.2 µm). The designs include simple glass types, mainly Schott N-BK7 and fused silica. In case of need, better images could be attained by a choice of other glass, aspherisation of some surfaces, etc.

Key words: Telescopes – Astronomical observing techniques

Introduction

The spherical meniscus with a reflective back surface is applied in astronomy since early investigations by W. Hamilton [1814], Mangin [1876], and Schupmann [1899]. One can find a number of such designs in the books by Maxwell [1972], Wilson [1996], Rutten and van Venrooij [1999], and in the cited there papers. The dual purpose of the present research is to substantially enlarge an angular field of view of a Mangin-based system and a telescope’s aperture, given spherical form of its surfaces.

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The basic features of the system A can be described as follows: 1) The all-spherical optics, 2) a remote aperture stop, 3) a large corrector lens used in the double-pass mode, 4) a Mangin mirror, 5) a two-lens exit corrector made of the simple glass. Let us discuss the features in brief.

As is well known, the all-spherical optics is not only cheaper at manufacturing, but also allows to make the surfaces very smooth. Latter property highly promotes increase of the image quality and mitigates tolerances.

The position of the aperture stop is important both for compensation of aberrations and for attaining low obscuration of light given such a field size – we have here only 23% of vignetted rays over all field. Even a more important role in providing low vignetting plays the fact that the large corrector lens works in a double-pass mode. The versions of the design A with less
field and a hole in the corrector lens were described by Ceravolo [2007] and Terebizh [2007] as the development of the original system of Hamilton [1814].

Table 1. Performance of the systems

| Parameter                        | Design A       | Design B       |
|----------------------------------|----------------|----------------|
| Entrance pupil diameter         | 500 mm         | 1000 mm        |
| Effective diameter              | 438 mm         | 853 mm         |
| Effective focal length          | 1000.0 mm      | 1724.1 mm      |
| Effective f-number              | 2.0            | 1.72           |
| Scale in the focal plane         | 4.848 µm/arcsec| 8.359 µm/arcsec|
| Angular field of view           | 7°.0           | 10°.0          |
| Linear field of view            | 123.0 mm       | 302.4 mm       |
| Image RMS-diameter               |                |                |
| center of field                  | 0''.68 (3.3 µm)| 0''.97 (8.1 µm)|
| edge                            | 1''.5 (7.2 µm) | 1''.4 (11.7 µm)|
| Image $D_{80}$ diameter          |                |                |
| center of field                  | 1''.3 (6.2 µm) | 1''.5 (12.4 µm)|
| edge                            | 2''.2 (10.7 µm)| 1''.9 (16.2 µm)|
| Maximum distortion              | 0.50%          | 0.23%          |
| Fraction of unvignetted rays     |                |                |
| center of field – edge           | 0.769 – 0.768  | 0.728 – 0.728  |
| Length of the optical system     | 974 mm         | 1704 mm        |

Aberrations of a Mangin mirror were repeatedly discussed in literature (see the above mentioned references), so we only note here that apprehensions connected with more severe tolerances of an internal mirror surface seem to be groundless. A version of the system A of slightly less size has been made recently in Sternberg Astronomical Institute, it shows the perfect images.

As to the glass types, the basic Schott glass N-BK7 has been used for the large optical elements, although fused silica is also allowable. There are a few attractive choices of glasses for two lenses of the exit corrector; we have preferred a pair N-BAK2 plus N-BASF64 to somewhat better combinations because of their presence in a renewed Schott catalogue and the low cost, only 2.0 and 3.0 relatively to N-BK7.

Let us consider the image quality of the design A. Fig. 2 depicts the corresponding spot diagrams. Since a point-like object produces images of
3.2 – 4.1 μm in diameter, when the wavelength varies from 0.65 μm up to 0.85 μm, one can see from Fig. 2 that the telescope provides nearly diffraction-limited images in the integral light. Naturally, using of the filters leads to better images.

**Design B**

Main difference of the design B from the considered above system consists in an additional large lens, which is also applied in a double-pass mode (Fig. 3, Tables 1 and A2). The double-lens entrance corrector has allowed us to reach twice larger aperture and 10°-field at nearly the same image quality as before.

The changes of secondary importance are the position of the aperture stop and the curved detector’s window. The stop remains far from the Mangin mirror to efficiently suppress its aberrations. Since linear size of the field of view is now more than 300 mm, there is good reason to believe that it is easier to make a slightly curved window lens than a strictly flat plate.

This time we prefer to use fused silica, instead of N-BK7, for the large optical elements. The latter glass is applied for the second lens of the exit
corrector, while Schott N-FK5 was chosen for the first lens. There are a number of pairs of glasses for the exit lens corrector ensuring the somewhat better image quality; N-FK5 and N-BK7 were chosen because these glasses are available now in the enough large blocks and are cheap (the relative cost of N-FK5 is 5.0).

Concluding remarks

Both considered above systems represent base models intended to attain images about one-second-of-arc quality in a flat field up to 10° in diameter, given spherical optics and low obscuration of light. If the better images are necessary, one could apply further known means, in particular, aspherisation of some surfaces and sophisticated exit corrector. Since the basic designs deliberately were optimized for the spherical set of surfaces, the first of the mentioned ways is rather inefficient, while the second one is quite productive. For example, the use of a fluoro-crown (like N-FK51A) or phosphate crown (like N-PK52A) in a 3- or 4-lens exit corrector provides really sub-arcsecond images in a wide, as before, field.

It is worth to note also that both systems under consideration are well
Figure 4: *Spot diagrams for the system B in the integral light 0.45 – 0.85 µm. The field angles are 0, 1°.5, 2°.5, 3°.5, and 5°.0. The box width is 2'' (16.7 µm). protected from stray light.

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Appendix:
The complete description of the designs

| Number of the surface | Comments           | Curvature radius (mm) | Thickness (mm) | Glass  | Light diameter (mm) |
|-----------------------|--------------------|-----------------------|----------------|--------|--------------------|
| 1                     | Aperture stop      | ∞                     | 126.34         | —      | 500.0              |
| 2                     | Shield\(^a\)      | ∞                     | 129.15         | —      | 120.0              |
| 3                     | Lens 1             | 4803.36               | 41.34          | N-BK7  | 532.2              |
| 4                     |                    | −3999.98              | 768.16         | —      | 533.3              |
| 5                     | Mangin             | −1156.39              | 35.0           | N-BK7  | 531.3              |
| 6                     | Primary            | −2013.58              | −35.0          | Mirror | 538.8              |
| 7                     |                    | −1156.39              | −768.16        | —      | 520.8              |
| 8                     | Lens 1             | −3999.98              | −41.34         | N-BK7  | 264.7              |
| 9                     |                    | 4803.36               | −65.73         | —      | 255.5              |
| 10                    | Lens 2             | −351.86               | −47.89         | N-BAK2 | 220.7              |
| 11                    |                    | 955.57                | −0.383         | —      | 208.5              |
| 12                    | Lens 3             | 931.71                | −15.15         | N-BASF64 | 208.3          |
| 13                    | Filter             | ∞                     | −10.0          | N-BK7  | 199.6              |
| 14                    |                    | ∞                     | −34.03         | —      | 158.8              |
| 15                    | Window             | ∞                     | −5.0           | F-SILICA | 133.1          |
| 16                    |                    | ∞                     | −10.0          | —      | 130.6              |
| 17                    | Image              | ∞                     | −10.0          | —      | 123.0              |

\(^a\) Circular obscuration between radiuses 0.0 and 120.0 mm.
Table A2. Design B

| Number of the surface | Comments     | Curvature radius (mm) | Thickness (mm) | Glass     | Light diameter (mm) |
|-----------------------|--------------|-----------------------|----------------|-----------|---------------------|
| 1                     | Shield\(^a\) | ∞                     | 424.08         | —         | 520.0              |
| 2                     | Lens 1       | 3455.65               | 75.0           | F_SILICA | 1002.8             |
| 3                     | Aperture stop| −28574.4              | 0.25           | —         | 998.2              |
| 4                     | Lens 2       | −2719.94              | 65.0           | F_SILICA | 998.4              |
| 5                     | Mangin       | −2331.60              | 1032.82        | —         | 1005.9             |
| 6                     | Primary      | −1611.04              | −60.0          | Mirror    | 1020.5             |
| 7                     | Primary      | −1611.04              | −1032.82       | —         | 980.0              |
| 8                     | Lens 2       | −2331.60              | −65.0          | F_SILICA | 667.6              |
| 9                     | Primary      | −2719.94              | −46.58         | —         | 648.9              |
| 10                    | Stop position| ∞                    | −0.25          | —         | 639.7              |
| 11                    | Lens 1       | −28574.4              | −75.0          | F_SILICA | 639.0              |
| 12                    | Lens 2       | 3455.65               | −232.56        | —         | 625.1              |
| 13                    | Lens 3       | −646.65               | −119.97        | N-FK5     | 495.0              |
| 14                    | Lens 4       | 793.38                | −6.56          | —         | 475.7              |
| 15                    | Lens 4       | 740.69                | −65.0          | N-BK7     | 467.8              |
| 16                    | Lens 4       | 740.69                | −65.0          | N-BK7     | 467.8              |
| 17                    | Lens 4       | 740.69                | −65.0          | N-BK7     | 467.8              |
| 18                    | Filter       | ∞                     | −20.0          | N-BK7     | 385.7              |
| 19                    | Filter       | ∞                     | −75.06         | —         | 376.6              |
| 20                    | Window       | 2176.5                | −20.0          | N-BK7     | 326.8              |
| 21                    | Window       | 2176.5                | −20.0          | N-BK7     | 326.8              |
| 22                    | 901.89       | −8.0                  | —              | —         | 322.2              |
| 23                    | Image        | ∞                     | —              | —         | 302.5              |

\(^a\) Circular obscuration between radiuses 0.0 and 260.0 mm.