Design of the Wide-view Collimator Based on ZEMAX

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Abstract

As for the optical measurement, the longer the focal length of collimator is, the less the measurement error is. However, the longer the focal length is, the more difficult the optical design is. It's higher application value to design long focal length collimator with wide-view. The paper designs a collimator with 2000mm focal length, 4 degree field of view and its wavelength range is from 480nm to 750nm. The collimator is employed in the camera resolution detection system. It adopts the apochromatism three-piece-type structure and the secondary spectrum is corrected. The paper analyses the imaging quality of the optical system and the MTF curve is presented.

Keywords: Collimator, Apochromatism, Long focal length, Wide-view

1. Introduction

Collimator is an important apparatus for the optical experiments and measurements. It is a measurement base for the correction and imaging detection of the infinite conjugate imaging optical system (Ji, 2007, pp.36-40). In the camera resolution detection system, the objective of the collimator is required to image with apochromatism and flat view field to get high resolution imaging quality and which makes the design more difficult. In addition, the objective's structure is complex because of its characteristics (Zhou, 2004, pp.589-592). In the paper, the collimator used in the camera resolution detection system is designed.

2. The requirements of the system

The camera detection system is to detect the imaging resolution and evaluate the imaging quality. The camera detection system needs to simulate the infinity motion targets for the camera photography and detect the resolution with the photographed images. One of the important elements of the infinity motion target simulation system is the collimator. The camera imaging resolution can be estimated with the target resolution, simulated

flight height and the focal length of the camera. According to the related parameters, the requirements for the collimator are that the focal length is 2000mm, the view angle is 4 degrees and the wavelength range is from 480nm to 750nm.

3. The structure design

3.1 The key points of the design

The main design difficulties include the correction of the secondary spectrum and field curvature. The related dispersion of glasses is approach to get rid of the secondary spectrum. However, the Abbe constants of these glasses are different and which confines the materials selection. If the optical medium with special relative partial dispersion is adopted, it's difficult to correct the spherochromatic aberration. Because the refractivity and dispersion of the material are very low and the minus lens' refractivity and dispersion are not high too. Therefore, it needs to increase the lens to decrease the deflection angle and the structure of the objective is very complex to implement the apochromatism (Jerzy, 2001).

The field curvature is a difficult point for the long focal length collimator. When the focal power is very big, the field curvature is still severe although the view field is very small. The curvature extent is determined by the focal power of the lens not the lens' shape. Several thick meniscus lens and minus lens should be introduced to get rid of the curvature. Especially, the correction of the curvature and apochromatism are contradictory. Therefore, the material selection and lens' original structure should be considered to make the curvature and apochromatism perfect status.

3.2 The structure selection

There are three ordinary types for the apochromatic structure, telephoto-type, Petzval-type and three-piece-type. The lens of telephoto-type has big airspace and they are sensitive for the decentration. The lens of Petzval-type can get smaller secondary spectrum but larger curvature. And the minus lens is inserted before the image surface to correct the curvature. In this paper, three-piece-type structure is employed, because of its simple compact structure and easy assemblage (Xu, 2005, pp.57-59).

3.3 The material selection

The secondary spectrum formula is

$$\Delta L'_{CDF} = -f' \frac{P_{CF} - P_{CD}}{\nu_1 - \nu_2}$$

Where, $\Delta L'_{CDF}$ is the secondary spectrum aberration, f' is the focal length of the lens group, P_{CF} and P_{CD} are the relative partial dispersions and ν_1 and ν_2 are the Abbe constants of the two materials. Only the materials whose differences between the relative partial dispersions are narrow and between the Abbe constants are notable can correct the secondary spectrum.

The system adopts the lanthanum crown glass of LAK_{11}, heavy flint ZF_2 and flint glass of F_2, and their parameters are shown in Table 1. From Table 1, it's seen that the difference between the refractivity of the F_2 and that of the other two is notable and which can correct the spherochromatism of the centre wavelength and make the three focal planes coincident. The relative partial dispersion values of the material LAK_{11} and F_2 are very close and their Abbe constants are very different, which are favorable for correcting the secondary spectrum and they can be placed in the front as a doublet lens. However, the lens with wide-view is not easy to be glued and they can be separated for a gap (Wu, 2007, pp.34).

The principle of the glasses arrangement is that the positive lens group of large focal power with low refractivity and high Abbe constant is placed in the front, the negative lens group with high refractivity and medium Abbe constant is placed in the middle and the lens group of small focal power with high refractivity and low Abbe constant is placed in the last place (Thibault, 2004, pp.122-133). That is, the glass of LAK_{11} is in the front, then the glass of F_2 is in the middle and the glass of ZF_2 is in the last.

The focal power is assigned as the apochromatic conditions:

$$\begin{cases} \phi_1+\phi_2+\phi_3=\phi \\ \dfrac{\phi_1}{v_1}+\dfrac{\phi_2}{v_2}+\dfrac{\phi_3}{v_3}=0 \\ \dfrac{\phi_1}{v_1}P_1+\dfrac{\phi_2}{v_2}P_2+\dfrac{\phi_3}{v_3}P_3=0 \end{cases} \quad \text{and} \quad \begin{cases} LAK11: & \phi_1=0.507e^{-2} \\ ZF2: & \phi_2=0.437e^{-2} \\ F2: & \phi_3=-0.844e^{-2} \end{cases}$$

Where, φ is the focal power, v is the Abbe constant and P is the related dispersion.

From the results of the focal power equation, the negative focal power is bigger and it can not balance the senior aberration. Therefore, the negative group should be divided into two lenses and the former one needs respond more focal power.

The meniscus-type thick lens is introduced in the system as the former piece to balance aberration. The bending minus lens can bend the light to the lens cell direction and the field curvature can be reduced. Here, the glass of F_5 is selected as the thick lens material.

The structure of the collimator is shown in Figure1.

3.4 Majorized design

The software of ZEMAX is developed by Focus Software Inc. in the USA and it is a synthetically optical design and simulation software, widely used in the optical design. The assignment of the focal power is optimized by the software of ZEMAX and the final design result is obtained. The surface data is shown in Table 2. From the Table.2, we can see the selected glasses and their diameters. The optical path figure is shown in Figure 2.

3.5 design of the reticule

The reticule is located in the focal plane of the collimator. The infinity paralleled lights will be imaged in the focal plane through the collimator and the pattern of the reticule is the images of the infinity lights. The reticule with special length is designed to synchronize the camera and infinity motion target simulation system. The length of the reticule is 300mm, the width is 24mm and the pattern is followed the standard of JB/T 9238-1999. The pattern is duplicated and jointed.

4. The imaging quality evaluation of the collimator

The imaging quality evaluation can be seen from Figure 3, Figure 4 and Figure5.

The spot diagram, as shown in Figure 3, is that many rays sent from a point can not be focused on the focal point after the optical system, because of the aberration. The spot diagram ignored the diffraction effect (Zhang, 2010, pp.32-35). In the spot diagram, the full curve stands for the Airy disc and the confusion discs formed by the objectives are all included in the Airy disc, which means no blur imaging.

The spherochromatic aberration is shown in Figure 4 and the secondary spectrum is 0.1mm. Therefore, the focal depth is:

$$\Delta L'_K=\frac{\lambda}{\sin^2 u}=\frac{0.587\times10^{-3}}{\sin^2 2.5}\approx 0.3\text{mm}$$

From the above computation, the secondary spectrum is less than focal depth and it meets the apochromatism requirement.

The modulation transfer function (MTF) curve of the optical system is shown in Figure 4. The horizontal axis and the vertical axis stand for the space frequency of the imaging surface and the MTF of the optical system individually. The top curve is the diffraction limiting curve. The MTF curve can not overpass the limiting curve. From Figure 5, the MTF curve is very close to the limiting. Therefore, the imaging effect is very good.

5. Conclusion

The paper designs a kind of collimator with long focal length and wide-view based on the technique requirements of the system to measure the camera resolution. From the imaging quality analyzing figures, it's proved that the aberration is corrected and the precision meets the requirements. The design scheme is correct and can be implemented.

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Table 1. The parameters of the selected glasses

parameters / glass	n_0	v	P_{DF}
LAK11	1.664500	54.6015	0.71076
ZF2	1.672520	32.2300	0.71740
F2	1.612800	36.9500	0.71470

The selected glasses' parameters are presented in the table.

Table 2. The surface data from the ZEMAX

SURFACE DATA SUMMARY:					
Surf	Type	Radius	Thickness	Glass	Diameter
OBJ	STANDARD	Infinity	Infinity		0
1	STANDARD	Infinity	0		200
STO	STANDARD	567.2428	40	F5_CN	200.6244
3	STANDARD	997.3189	159.219		197.2395
4	STANDARD	515.4698	34.512	LAK11_CN	192.4086
5	STANDARD	-307.7645	2.225		190.6726
6	STANDARD	-298.0649	30	F2_CN	189.0659
7	STANDARD	340.1111	70.087		178.2551
8	STANDARD	-236.1184	31.085	ZF2_CN	179.2369
9	STANDARD	-533.7789	9.657		192.0161
10	STANDARD	-1135.33	30	ZF2_CN	196.1236
11	STANDARD	-316.042	1736.498		200.5148
IMA	STANDARD	Infinity			139.7285

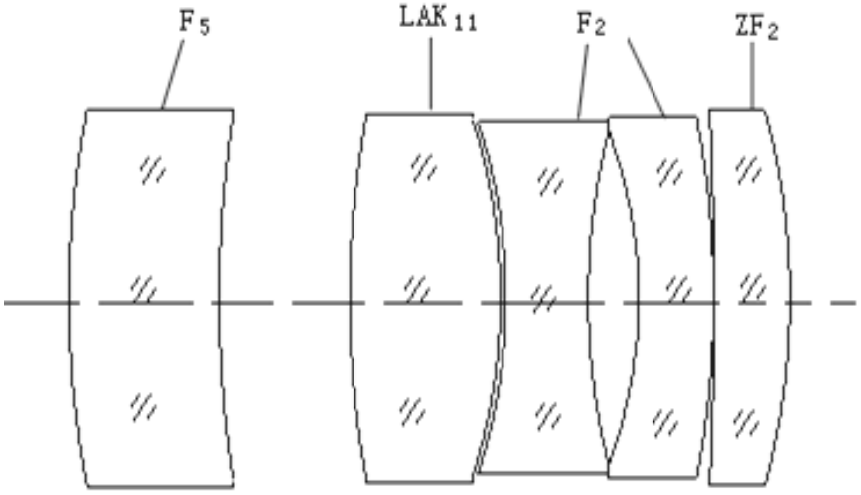

Figure 1. The Structure of the Collimator Objective

The collimator objective is composed of five pieces of glass.

Figure 2. The System Optical Path Figure

The optical rays' transmission path is shown in the figure.

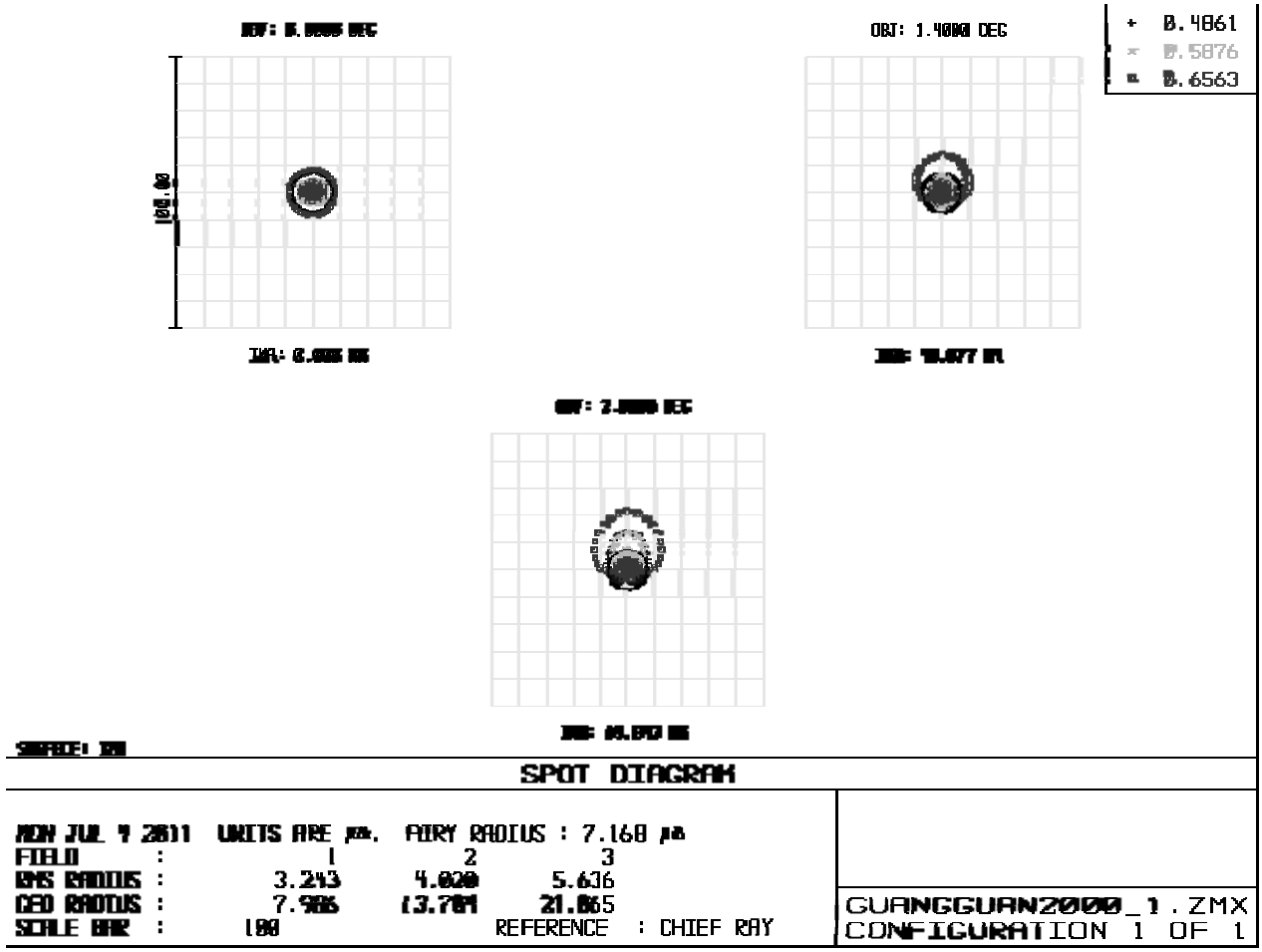

Figure 3. Spot Diagram of the Collimator

The imaging confusion discs of different wave lengths and the Airy disc are shown in the spot diagrams.

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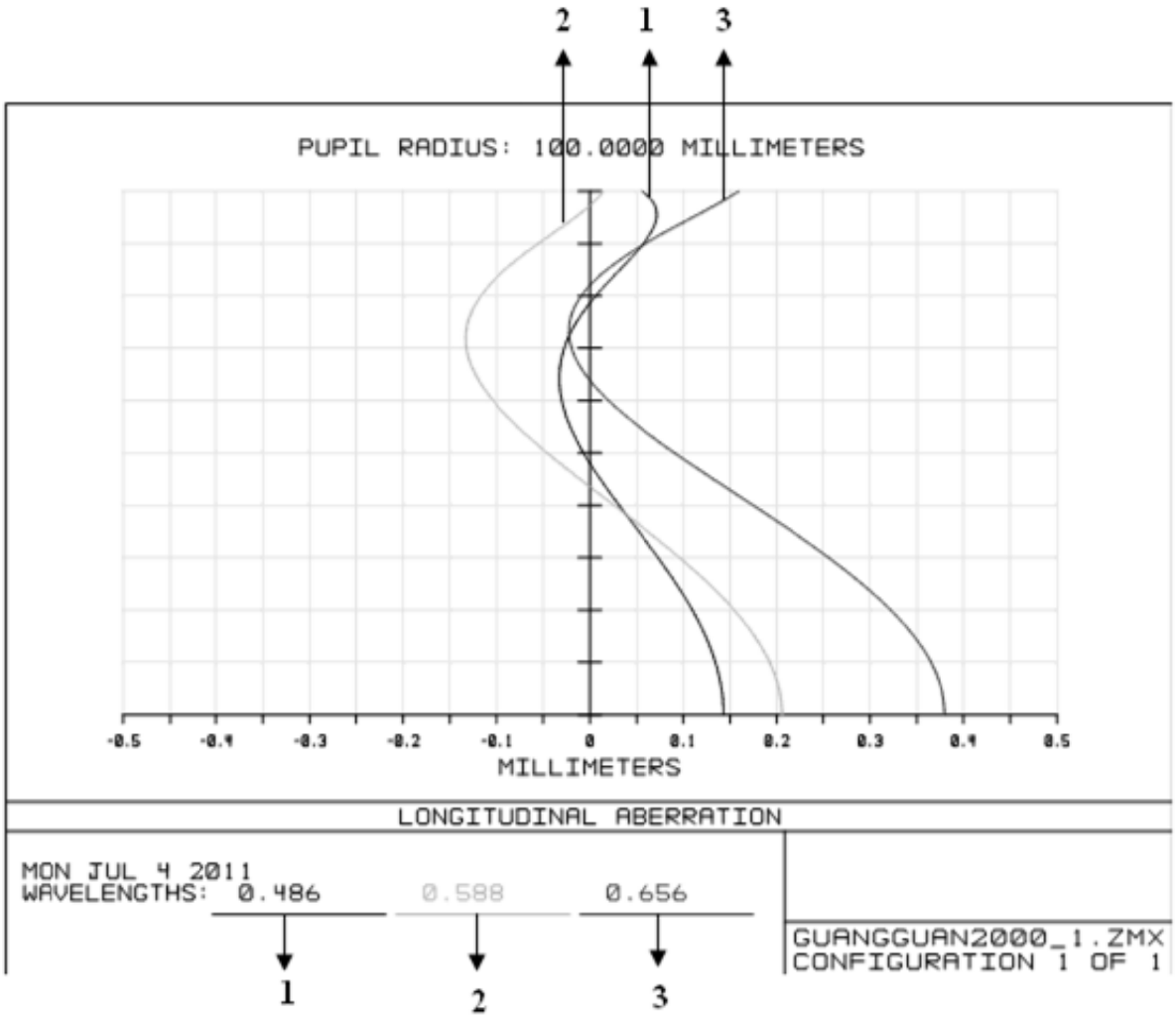

Figure 4. The Spherochromatic Curve of the Objective

The spherochromatic curves of different wave lengths are shown in the figure.

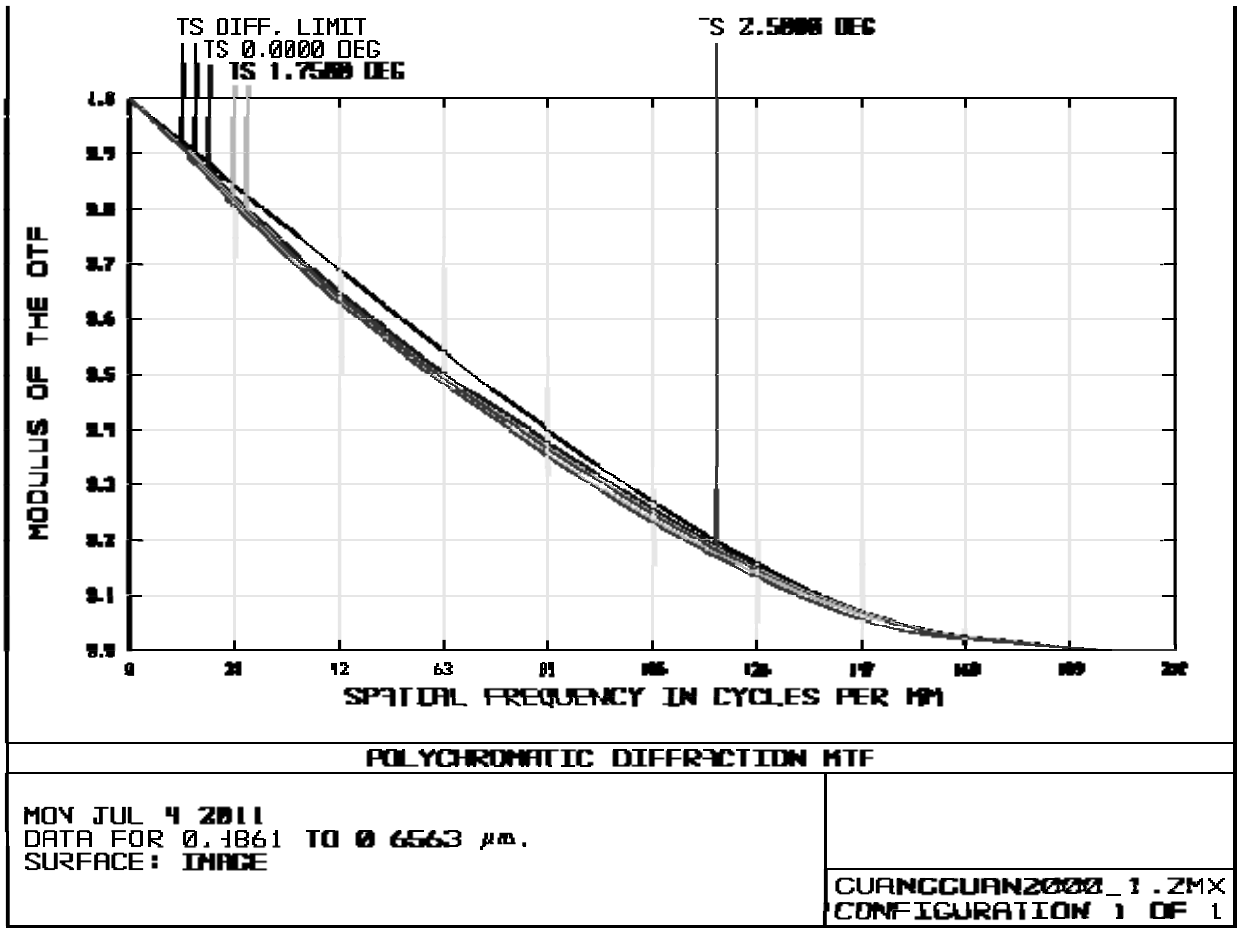

Figure 5. The MTF Curve of the Objective

The MTF curve is shown in the figure.