Comparison and analysis on Polarization aberration in Pehan prisms and the Telescope system including Pehan prisms

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Abstract

In this paper, using Free coordinate system and the Jones vector to analyse the discipline of polarization state when the light penetrates the confocal system, so obtains the distribution of the polarization state when a line polarized light penetrates the confocal system. Using the method of tracing ray obtains the distribution of the polarization state on the image surface when light penetrates the Pehan prisms system and the Telescope system with Pehan prisms—There are both elliptical polarized lights when light passes two roof planes of the Pehan prisms system and the telescope system with Pehan prisms respectively, of which the difference value between the azimuth angle and ellipticity angle is between ±1° on the supposition from the same roof planes. Do the experiment analysis using Stokes parameter measurement, then gets consistent result with theory. At last, clears the Polarization aberration effect of Telescope system with Pehan prisms results from the Pehan prisms.

Keywords: polarization aberration; Jones matrix; Pehan prisms; polarized light; polarization ray tracing

1. Introduction

The polarization aberrations that caused when the light got through the binocular system will affect the distribution of the electronic field on the image surface, telescope system is mainly composed by the lens and inversion prism. The previous articles research the polarization aberrations1,2 using by the intrinsic coordinate system when the light past the lens, but it is not convenient tracing the distribution of the polarization on the exit facet well using the Fresnel. This paper adopting both free coordinate system and Cartesian coordinate system to analyse the polarization aberrations when the linearly polarized light past through the confocal system. On the basis of the previous research about the polarization aberrations when the light past the Pehan prisms, this paper analyse by the theoretical and experimental which affect the telescope system’s polarization aberrations, in addition, the main factors to the telescope system’s polarization aberrations is the Pihan lens.

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2. The analysis about the exit pupil plane’s polarization of confocal system

Showing as Fig.1, the refraction angle and the angle of incidence can be solved by the light tracing method[3] when the light got through the lens under such conditions as the known structural parameters of lens, the aperture angle-\( u \) of the incident light and the height of the incident \( h_1 \). \( u \)-the incident aperture angle, \( h_1 \)-the incident point of the height relative to the optical axis, \( d \)-the center of the lens thickness, \( r_2 \)-the radius of curvature of the anterior surface of the lens, \( r_1 \)-the radius of curvature of the surface of the lens, \( n \)-the refractive index for the lens.

Known by the law of refraction:

\[
i_1 = u + a_2
\]

\[
i_2 = \arcsin\left(\frac{\sin(i_1)}{n}\right)
\]

\[
i_3 = (a_2 - i_2) + \arcsin\left(\frac{h_2}{r_1}\right)
\]

\[
i_4 = \arcsin(n \sin i_3)
\]

Fig.1. Schematic diagram of light got through a lens

Where:

\[
a_2 = \arcsin\left(\frac{h_1}{r_2}\right)
\]

\[
a = \tan(a_2 - i_2)
\]

\[
l_1 = r_2 - \sqrt{r_2^2 - h_1^2}
\]

\[
l_2 = r_1 - \sqrt{r_1^2 - h_2^2}
\]

\[
b = h_1 - (d - r_1 - l_1)a
\]

\[
h_2 = \frac{b \pm \sqrt{b^2 - (1 + a^2)(b^2 - r_1^2 a^2)}}{(1 + a^2)}
\]

Known by the Frensel law:
Shown in Fig.2. $\Phi$ is the angle between incident plane and xz plane. In the coordinate system, clockwise is the positive and anticlockwise is negative. The xy plane rotating $\Phi$ can coincide with the ps coordinate system, and x'y' plane rotating $\Phi$ can coincide with the p's' coordinate system. We can get the Jones vector of the lens' interface by adopting the Fresnel, and the final polarization state can get by multipling all the Jones vectors oppositely.

\[
\begin{bmatrix}
E_x \\
E_y
\end{bmatrix} =
\begin{bmatrix}
\cos \Phi & -\sin \Phi \\
\sin \Phi & \cos \Phi
\end{bmatrix}
\begin{bmatrix}
t_{p2} t_{p1} & 0 \\
0 & t_{s2} t_{s1}
\end{bmatrix}
\begin{bmatrix}
t_{p2} t_{p1} & 0 \\
0 & t_{s2} t_{s1}
\end{bmatrix}
\begin{bmatrix}
\cos \Phi & \sin \Phi \\
-\sin \Phi & \cos \Phi
\end{bmatrix}
\begin{bmatrix}
E_x \\
E_y
\end{bmatrix}
\]  

(9)

Fig.2. The coordinate system established when the collimated light got through confocal system

On the assumption that the Jones Vector of the incident light is \[
\begin{bmatrix}
E_{x0} \\
E_{y0}
\end{bmatrix} =
\begin{bmatrix}
1 \\
0
\end{bmatrix}
\], we can get the Jones Vector of the exit pupil plane:

\[
\begin{bmatrix}
E_x \\
E_y
\end{bmatrix} =
\begin{bmatrix}
t_{p2} t_{p1} t_{p2} t_{p1} \cos^2 \Phi + t_{s2} t_{s1} t_{s2} t_{s1} \sin^2 \Phi \\
\frac{1}{2} t_{p2} t_{p1} \sin 2\Phi - \frac{1}{2} t_{s2} t_{s1} t_{s2} t_{s1} \sin 2\Phi
\end{bmatrix}
\]  

(10)

Further more, we also can get the angle between its electric vector and x axis by the formula:

\[
\beta = \arctan \frac{E_y}{E_x}
\]  

(11)
The rule of the angle $\beta$ between electric vector of the emergent ray and x axis shown by Fig.3 at the angle $\Phi$ range from $0^\circ$ to $360^\circ$ on such conditions as $r_1=100.65\,\text{mm}$, $r_2=154.48\,\text{mm}$, $d_1=8.49\,\text{mm}$, $r_3=154.48\,\text{mm}$, $r_4=100.65\,\text{mm}$, $d_2=8.49\,\text{mm}$, $n_1=1.52$, $n_2=1.52$. The emergent ray is linearly polarized light known by the fact that the two components are real number, and the vibration direction at such points as $0^\circ$, $90^\circ$, $180^\circ$, $270^\circ$, $360^\circ$ are the same and at those points $45^\circ$, $135^\circ$, $225^\circ$, $315^\circ$ are maximum when the Jones vector of the incident light is \[ \begin{bmatrix} E_x \cr E_y \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}. \] But the change of the vibration is very little. Its range of variation is $0.085^\circ$, so the effect of the incident light is little too.

3. Analysis of the polarization aberration of the Pehan prism and the telescope system included Pehan prism

Research shows using the same method on the polarization aberration\textsuperscript{[4]} before that they are elliptically polarized light having different ellipticity and azimuth angle exiting from the two ridges of Pehan prism when the linearly polarized light got through the Pehan prism, thus having the polarization aberration obviously in Pehan prism. When in confocal system included Pehan prism, the polarization aberration caused by the lens and Pehan prism. In the following, we will analyse the main factors that affected the polarization aberration of telescope using the contrastive experiments.

3.1 Design of experiment

We got the fact that the change of the vibration direction is not large by analyzing the polarization state of the emergent ray when the collimated light got through the confocal system in the front page. We analyse the main factors which affect the system of telescope’s polarization aberration. Because the telescope made up of the confocal system and Pehan prism, we design two groups of experiment to analyse the change of polarization state of exiting from the up-ridge and down-ridge and compare with the theory that the one is the incident light got through the Pehan prism only and the other is the incident light got through the confocal included the Pehan prism.
In the Fig.4, Fig.5., P1 is beam expander, P2 is collimating lens, P3 is diaphragm, P4 is polarizer, P5 is object lens, P6 is Pehan prism, P7 is ocular, P8 is 1/4 lambda plate, P9 is Analyzer. In the Fig.4. P5, P6, P7 build up the telescope, the others are the same. Thus providing the same conditions, the experiment result can contrast easily.

3.2 The test of polarization state

We test the polarization state by Stokes vector method \(^5\). The experiment get such photos as Fig.6., Fig.7., Fig.8., Fig.9. showing the rules of the azimuth angle and ellipticity angle by that adopt the P8, P9 testing the polarization state Principle of Stokes vector as following.

\[
S_0 = I(0^\circ) + I(90^\circ)
\]
\[
S_1 = I(0^\circ) - I(90^\circ)
\]
\[
S_2 = I(45^\circ) - I(135^\circ)
\]
\[
S_3 = I(\frac{\lambda}{4}135^\circ) - I(\frac{\lambda}{4}45^\circ)
\]

\(I(\gamma)\) is the power that the angle between P9 and x is \(\gamma\) not through P8. \(I(\lambda/4, \gamma)\) is the power that the angle between P9 between P8 and x is \(\gamma\) through P8 and the fast axis of 1/4 lambda plate and y axis coincide. The azimuth angle \(\Phi\), ellipticity angle \(\beta\) and the polarization degree P of the exited elliptically polarized light can be expressed as.

\[
\tan 2\Phi = \frac{S_2}{S_1}, (-\frac{\pi}{2} \leq \Phi \leq \frac{\pi}{2})
\]
\[
\sin 2\beta = \frac{S_3}{(S_1^2 + S_2^2 + S_3^2)^{1/2}}, (-\frac{\pi}{4} \leq \beta \leq \frac{\pi}{4})
\]
\[
P = \frac{(S_1^2 + S_2^2 + S_3^2)^{1/2}}{S_0}
\]

According to the formulas above, we can get the result of experiment and known by the comparison the following, the down-ridge.
Known by the analyses above, the azimuth angles and the ellipticity angles of the elliptically polarized light exiting from up-ridge and down-ridge are little too when the light through the Pehan prism and the telescope. The deviation of the ellipticity angle is larger than the azimuth angle when the light got through the interface, but still at the scope of ±1°. The average polarization degree of the exit light from the up-ridge of Pehan prism is \( P_1 = 1.01 \), and from down-ridge is \( P_2 = 0.99 \) by the date of experiment and the formula of polarization degree. The average polarization degree of the exit light from the telescope’s up-ridge of Pehan prism is \( P_1' = 0.99 \), and from down-ridge is \( P_2' = 0.98 \).

4. Conclusion

This paper analyze the polarization state in theory and experiment when the linearly polarized light got through the confocal system, Pehan prism and the telescope included the Pehan prism, and get such conclusions as following: (i) The exit light is linearly polarized light too when the incident linearly polarized light and the axis are parallel, and there is a little change between the incident light and the emergent ray on the Jones vector, but the exit light become elliptically light when the linearly light got through the Pehan prism. (ii) The azimuth angle and the ellipticity angle of the elliptically polarized light exiting from the up-ridge and down-ridge are both coincide when the linearly polarized light got through the Pehan and the telescope and the incident linearly light’s vibration at the range from -90° to 90°, and they are both discrepancy not 1°. From the analysis, we can got that the polarization aberration of the telescope is caused by the Pehan prism mainly.

References

[1] Shen xueju, Liu bingqi, Wang Fu. Analysis on polarizing aberration when partially polarized light penetrate lens [J]. Optical Technology. 1998, (2):51-54.
[2] Wang lijuan, Huang zuohua, Cheng fengchao. The analysis of polarization state when the polaried light past through the lens[J]. Optics & Optoelectronic Technolog. 2007.
[3] Born, Wolf. Principles of Optics [M]. Bei Jing: Publishing House of Electronics Industry, 2009:32-36.
[4] Lv Hua, Lu Jinjun, Yuan Qiao. The tested reseach on the polarization aberration when the p-polarization got through the Pehan prism [J]. Science and Technology Innovation Herald. 2009.
[5] Liao Yanbiao. Polarization Optics [M]. Bei Jing: Publishing House of Science, 2003:204-244.