Optics

Geometrical optics
Image distortion

LD Physics Leaflets

P5.1.3.2

Astigmatism and curvature of image field in lens imaging

Objects of the experiment

- Investigation of the astigmatism and curvature of the image field.

Introduction

Lenses are optical elements which are used in many applications like (digital) cameras, microscopes, telescopes, glasses, spectroscopes and optoelectronic applications. By applying lenses in such optical systems imaging errors are unavoidable.

Basically, there are four basic types of imaging errors:

- "spherical aberration" (P5.1.3.1)
- "chromatic aberration" (P5.1.3.4)
- "lens imaging distortions and coma" (P5.1.3.3).
- "astigmatism" and "curvature of image field in lens imaging" (this experiment)

In this experiment the "astigmatism" and "curvature of image field in lens imaging" is investigated. Note, in this experiment the "spherical aberration" is excluded by using a iris diaphragm in front of the lens. Thus only bundles of parallel light rays which are incident on the optical axis at a large angle are considered.

This experiment is closely related to experiments P5.1.3.1, P5.1.3.3 and P5.1.3.4.

Principles

When forming an image with a lens of a small aperture (obtained by the iris diaphragm), one expects a faithful representation of the object in the image. However, where extended objects are to be imaged it is not sufficient to avoid spherical aberration by screening off the outer portions of the lens with an iris diaphragm:

If, for example, a landscape is imaged on a screen one can then focus the centre of the image very exactly, but this is not possible for the outer portions of the image, which are formed by beams of light that penetrate the lens obliquely. For these beams the screen must be placed somewhat more closer to the lens, but a sharp image is not obtained. This can be demonstrated by a simple experiment of imaging a square grid like depicted in Fig. 1.

Now, the lens will be turned a few degrees about its vertical axis (Fig. 1 a). The image of the square grid on the translucent screen becomes diffuse. The translucent screen has to be shifted towards the lens in order to image the horizontal grid lines sharply (The vertical lines are still diffuse.). This image is called the sagital (or secondary) image (Fig. 1 b).

Shifting the translucent screen further towards the lens the vertical grid lines become sharply imaged. This is called the tangential (or primary) image (Fig. 1 c).

The astigmatic difference is given by the distance between the primary and secondary image of the lens.

The position of the secondary and primary images depends very much upon the position of the lens, i.e. the angle formed between the narrow light beam and the optical axis.

The greater this angle the more the image is shifted towards the lens. The primary image is always closer to the lens than the secondary image. Therefore, these images lie on two "curved surfaces" which have different radii of curvature. The concave sides of the "curved surfaces" are facing the incident light. That is why this effect is called "curvature of the field".

Sagital and tangential rays do not produce sharp image points. They produce image lines. This is because in the sagital image the tangential beam is already fanning out in its own plane.

In compound lens systems curvature of the field and astigmatism are often eliminated by using meniscus lenses as their astigmatic difference is smaller.

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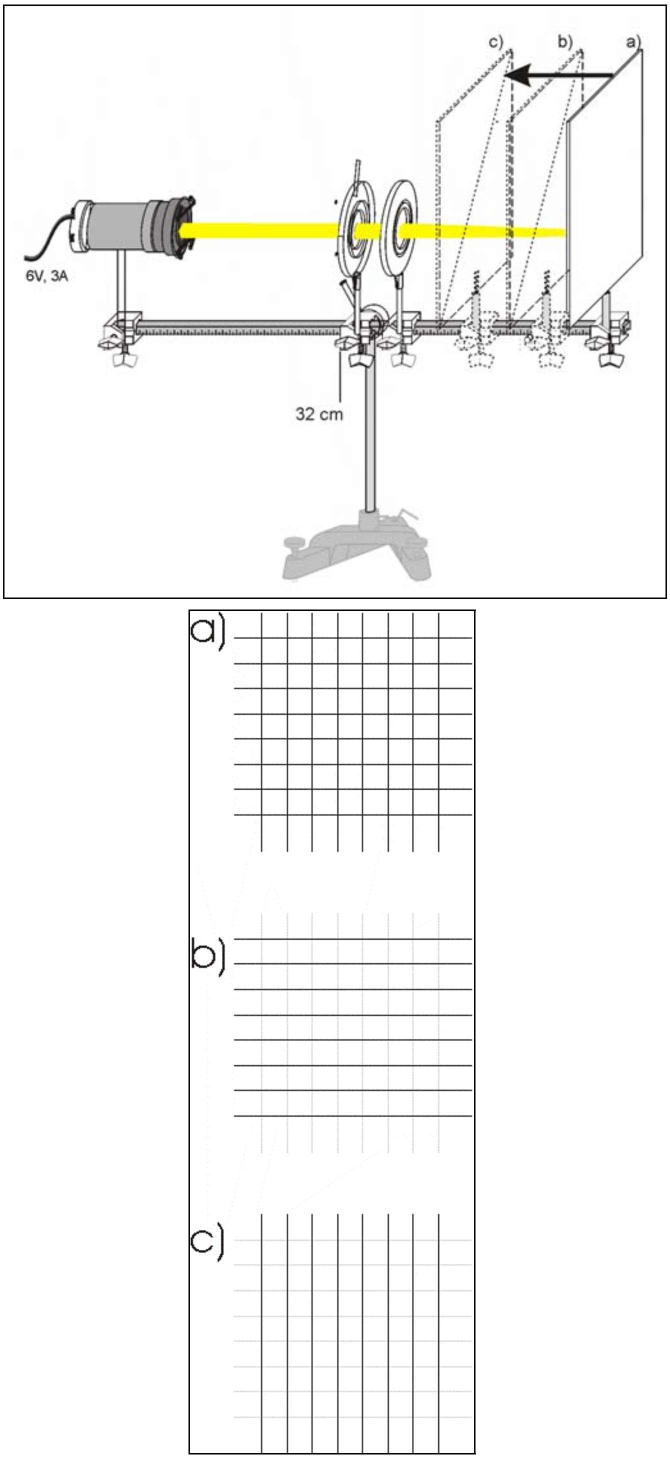

Fig. 1: top: Experimental setup for investigating the “astigmatism” and the “curvature of the field”.
bottom: image observed on the screen for the different positions a), b) c). Note for the screen position b) and c) the lens is turn by an angle of about 40 to 45 degree.

Apparatus

1 Set of 2 transparencies	461 66
1 Lamp housing	450 60
1 Lamp 6 V / 30 W	450 51
1 Aspherical condensor	460 20
1 Transformer 6 V / 12 V	521 210
1 Lens f = +150 mm	460 08
1 Iris diaphragm	460 26
1 Translucent screen	441 53
1 Small optical bench	460 43
1 Stand base, V-shaped, 20 cm	300 02
4 Leybold multiclamp	301 01

Setup

- Set up the lamp with the aspherical condensor on the optical bench as depicted in Fig. 2.
- When illuminating with the 6 V lamp turn the insert of the lamp in the lamp housing so that an sharp image of the lamp filament can be observed on the opposite wall (The distance between lamp and wall should be in the order of 3 m to obtain parallel light.).
- Align the insert of the lamp so that the image of the lamp filament is horizontally. The parallelism of the light beam might be checked by, e.g. allowing the light to pass across a piece of paper just touching the surface. If necessary, readjust the lamp by the three adjusting screws at the rear of the lamp housing.
- Set up the translucent screen like shown in Fig. 1 and place the lens f = +150 mm between lamp and translucent screen.
- Place the iris diaphragm in front of the lens to reduce the effective aperture of the lens. (Thus image defects due to “spherical aberration” is excluded.)
- Insert the transparency with the grid (spacing 5 mm x 5 mm) into the slide holder attached to the aspherical condensor.

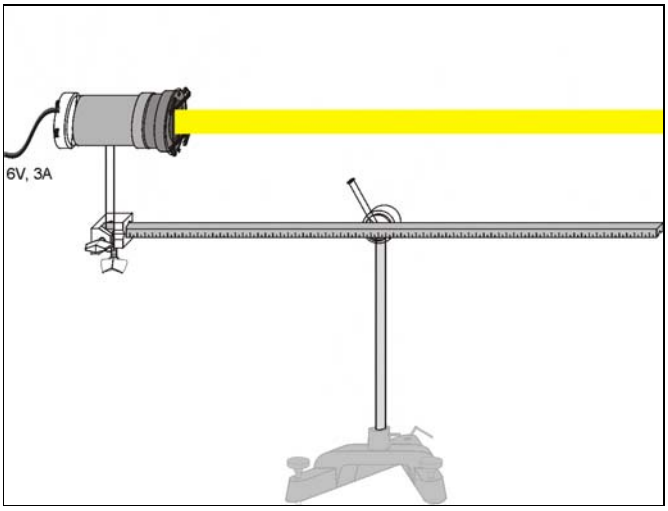

Fig. 2: First adjust of the lamp and aspherical condensor in such a manner that the light beam is parallel along the optical axis.

Carrying out the experiment

- Adjust the iris diaphragm that that the pinhole diameter is about 8 mm.
- Shift the lens f = +150 mm and the iris diaphragm until the image becomes sharp on the translucent screen (screen position a) in Fig. 1).
- Turn the lens around its vertical axis through about 45° as depicted in Fig. 3.
- Shift the translucent screen towards the spherical lens until the horizontal lines of the square grid are imaged sharply (screen position b) in Fig. 1).
- Shift the translucent screen further toward the spherical lens until the vertical lines of the square grid are imaged sharply (screen position c) in Fig. 1).

Note: *The image of screen position c) is smaller than in position b).*

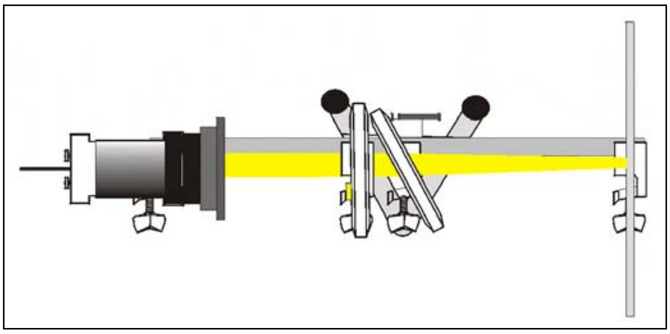

Fig. 3: Experimental setup for observing the “vertical” lines (screen position c) in Fig. 1) and “horizontal” lines (screen position b) in Fig. 1) only.

Results

An extended object cannot be imaged on a screen sharply both in the central region and the marginal region.

Aberration is noticeable for parallel bundles of rays which are incident on the optical axis at a large angle. For example:

- a point (pinhole) is imaged as a single line at two different distances from the lens. The two lines are perpendicular to each other.
- the vertical and horizontal lines of a cross are sharply imaged in two different planes.

Supplementary information

The aberration due to astigmatism can also be investigated with a pinhole diaphragm or by just imaging the filament of the lamp. Especially, the pinhole shows nicely the two perpendicular images of the bundle of parallel rays, i.e. the vertical and the horizontal line images.