# Lens imaging distortions (barrel and cushion) and coma

## Objects of the experiment

- Investigation of the cushion distortion.
- Investigation of the barrel distortion.
- Investigation of the “coma”.

## Introduction

Lenses are optical elements which are used in many applications like (digital) cameras, microscopes, telescopes, glasses, spectroscopes and optoelectronic applications. In constructing such optical systems lens errors are unavoidable.

Basically, there are four basic types of imaging errors:

- “spherical aberration” (P5.1.3.1)
- “chromatic aberration” (P5.1.3.4)
- “curvature of the image field in lens imaging” (P5.1.3.2)
- “Lens imaging distortions” (this experiment).

If the light beam passes the lens by an oblique angle further lens errors might occur:

- “astigmatismus”
- “coma”

In this experiment the “imaging distortions” and the coma are investigated. This experiment is closely related to experiments P5.1.3.1, P5.1.3.2 and P5.1.3.4.

## Principles

If a lens is used to form an image of an extended 2-dimensional object (e.g. picture) the image obtained might be different to the object (Fig. 1 to Fig. 3). This is due to the fact that the ratio image size to object size (magnification) changes with the distance to the optical axis. As a result the image of an illuminated square (object) appears distorted either into a pincushion (Fig. 2) or a barrel shape (Fig. 3).

This distortion is quite undesirable when measuring the objects by viewing their images. These distortion errors can be avoided by suitable shape of the lenses.

Another aberration occurs when forming images with rays whose direction makes an angle with the axis of the lens. This effect is called “coma” and is related to the one-sided distortion i.e. “plumb-like” or blob-like”, of images.

## 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 = +50 mm | 460 02 |
| 1 Lens f = +150 mm | 460 08 |
| 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. 4.
- 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. 5 and place the lens f = +150 mm with its convex side towards the screen (plane side towards the lamp) between lamp and translucent screen.
- Insert the transparency with the grid (spacing 5 mm x 5 mm) into the holder attached to the aspherical condensor.
- Place the lens f = +50 mm in front of the lamp. Remove the lens from the setup; the Leybold multiclamp is left for experiment b) on the optical bench.

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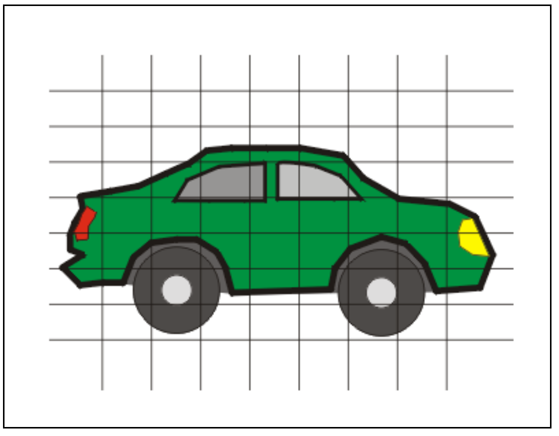

Fig. 1: Object with square grid.

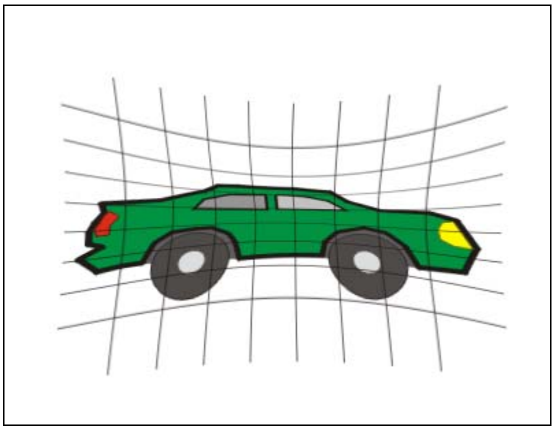

Fig. 2: Image of object from Fig. 1 with cushion-type distortion obtained by imaging with a lens according the setup shown in Fig. 5.

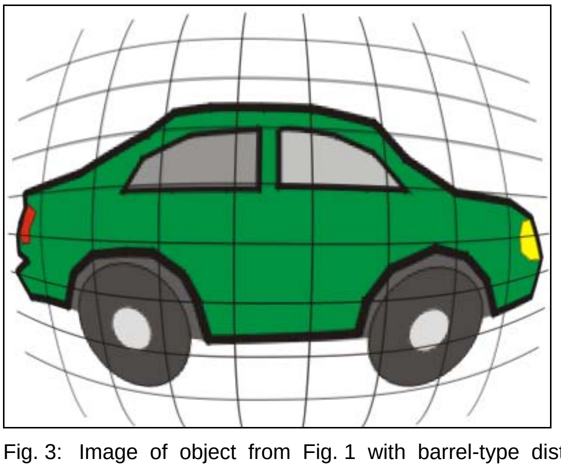

Fig. 3: Image of object from Fig. 1 with barrel-type distortion obtained by imaging with a lens according the setup shown in Fig. 6.

## Carrying out the experiment

### a) Cushion-type distortion

- Shift the lens f = +150 mm until a sharp image of the grid (center region only – see P5.1.3.2) can be observed on the translucent screen.

***Note:*** *A sharp image can only be obtained either for the center region or the marginal region. This effect of a diffuse border is described in experiment P5.1.3.2.*

### b) Barrel-type distortion

- Place the lens f = +50 mm in front of the lamp. It might be necessary to adjust slightly the lens f = +150 mm to obtain a sharp image of the center region.

### c) Coma

- Remove the lens f = +50 mm from the setup in order to see that the effect can be obtained just from one imaging lens.
- Turn the lens f = +150 mm so that the light beam passes the lens at an oblique angle (Fig. 7). The image will change as depicted in Fig. 8.

***Hint:*** *It might be useful to shift the transparency, i.e. grid object or vehicle object, in the holder for visualizing the image defects a) to c).*

***Note:*** *The so-called coma can also be observed with the lens system.*

## Measuring example

***Hint:*** *The distortion of the image might be determined for an object with non size.*

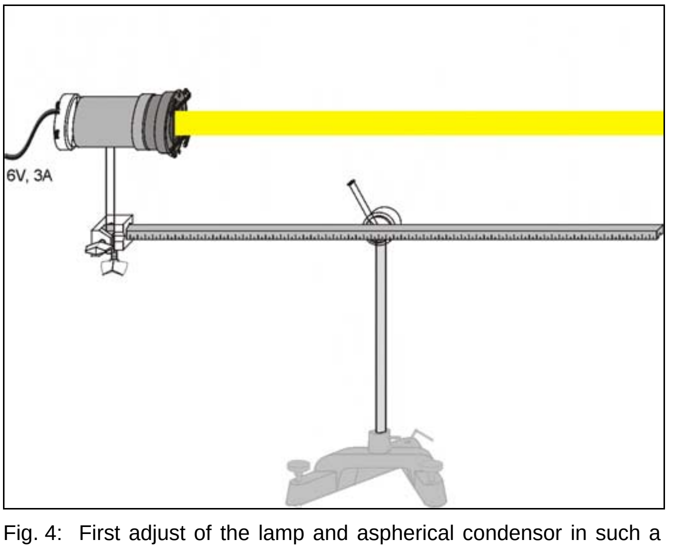


Fig. 4: First adjust of the lamp and aspherical condensor in such a manner that the light beam is parallel along the optical axis.

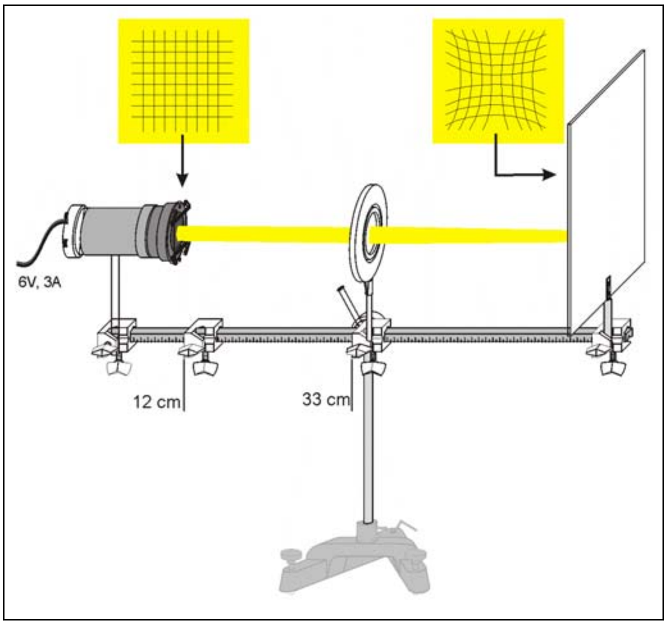


Fig. 5: Experimental setup to observe the cushion-type distortion.

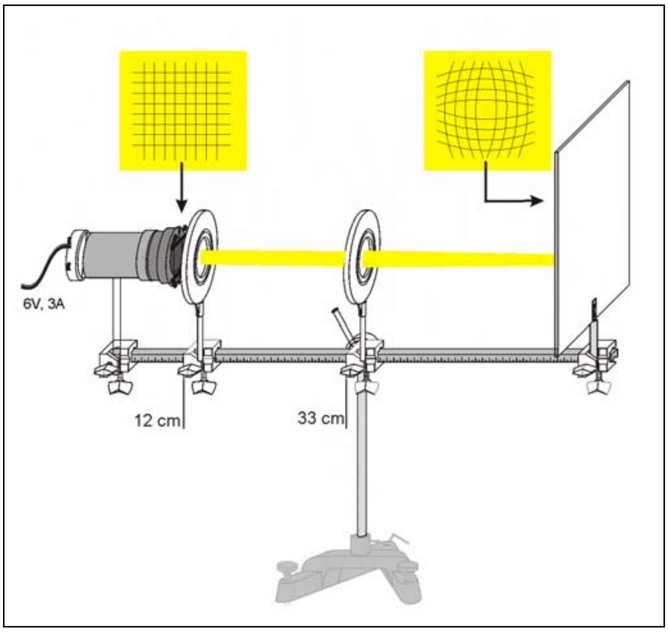


Fig. 6: Experimental setup to observe the barrel-type distortion.

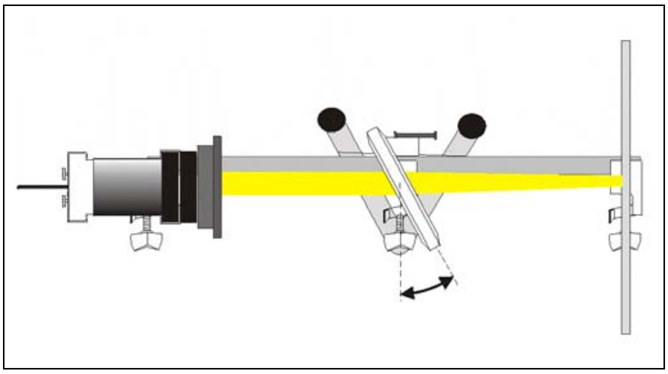

Fig. 7: Experimental setup for observing the "coma" image defect (see Fig. 8 and Fig. 9 (b)).

## Evaluation and results

Due to the fact that the magnification ratio (image size to object size) changes with the distance to the optical axis the image might be distorted either cushion-like or barrel like.

The so-called "coma"-effect occurs if the light beam passes the lenses at an oblique angle. The image is the picture one-sided distorted like depicted in Fig. 8 and Fig. 9 (a) and (b).

## Supplementary information

In this experiment the cushion-type and barrel-type distortion is combined with the image defect of the curvature of the image field in lens imaging, i.e. experiment P5.1.3.2.

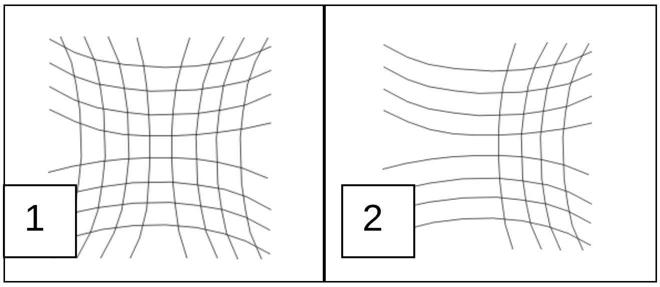


Fig. 8: The coma image defect: When rotating the lens in Fig. 7 the image (1) changes into image (2). See also Fig. 9 (b).

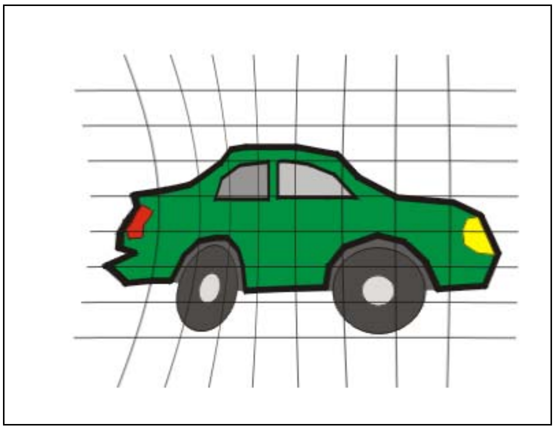

Fig. 9: (a): The coma image defect visualized for a the object of Fig. 1

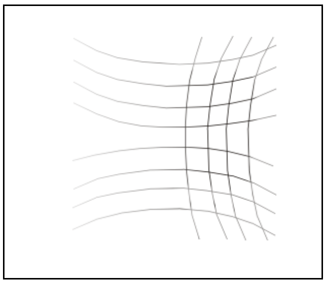

Fig. 9: (b): The image (2) of Fig. 8 is sharp only in the central region. The is due to the image defect "curvature of the image field" the marginal regions appear diffuse (see also experiment P5.1.3.2).