Paraxial Approaches for Optical Zoom Systems in Consideration of Relevant Constraints for Pupil and Field

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An approach for a two lens zoom system consisting of ideal thin lenses is presented. It considers the mechanical design requirements of the zoom lens and the external requirements of such a system. The approach is separated into four different methods to calculate a zoom system with variable specifications depending on the application of the zoom system.

1 Introduction

This paper presents a new paraxial approach which considers the mechanical design requirements of a zoom lens with two moving elements (Fig 1). The zoom elements could be surrounded by fixed elements so that they must have a constant imaging length at different magnifications. Mechanical design requirements are the overall length and the maximum diameter of an optical system. These conditions are important for the producibility and convenience of a lens.

The paraxial approach shall help to optimize the design of zoom systems by providing equations with practical specifications. Equations must be found for the parameters of the system such as focal lengths and focus distances which meet the mechanical design requirements in an optimal way.

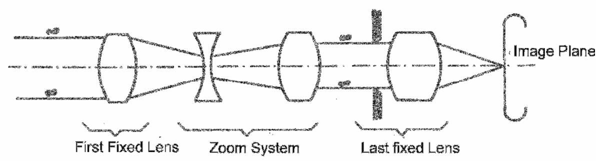

Fig. 1 *Typical design of a zoom lens*

2 Requirements of Photo Zoom Systems

External Requirements

When a new zoom lens e.g. a photo lens has to be designed, the optical designer has to deal with certain external requirements which define the zoom lens.

The parameters are:

- Primary and terminal focal length
- Image size
- F-numbers at the initial and terminal zoom position
- Diameter of the first lens group
- Overall length
- Exit focus distance of the last lens
- Diameter of the last lens
- Maximum diameter of the objective
- Stroke of the zoom elements during zooming

The external requirements constrict the optical design of the zoom system, the fixed elements as well as the moving elements. They can limit each other as well as exclude themselves.

Specifications of the Internal Zoom System

The specifications for a zoom system which result from the external requirements and the design of the fixed elements are:

- Magnification at the terminal zoom position (index E) $\beta'_E \in R, \beta'_E \neq 0$
- Magnification at the primary zoom position (index A) $\beta'_A \in R, \beta'_A \neq 0$
- Imaging length $L \in R_0, L = const.$
- Height of the first zoom element $HV_1 \in R, HV_1 \neq 0$
- Height of the second zoom element $HV_2 \in R, HV_2 \neq 0$
- Distance between the entrance pupil and the object $k \in R, k \neq 0$
- Height of the entrance pupil $HEP \in R, HEP \neq 0$
- Object height $y \in R, y \neq 0$
- Distance between the exit pupil and the image $k' \in R, k' \neq 0$

In a two element zoom system different limiting focus distances can be defined by the height of the zoom elements. Certain limiting entrance and exit focus distances of the zoom system shall be laid out so that the heights of the zoom elements are used at most (Fig. 2). There are four rays which characterize the zoom system, the chief ray and the marginal ray, respectively for the primary position and the terminal position.

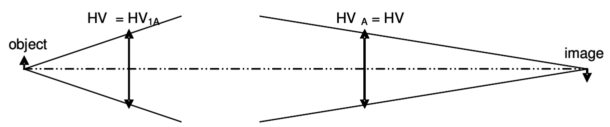

***Fig. 2** Focus distances defined by lens heights*

The chief ray which passes the object or image at maximum height intersects the optical axis at the pupil. In contrast, the marginal ray crosses the rim of the pupil and intersects with the optical axis at the object/image plane. Altogether, there are eight different focus distances which are listed in Tab 1. The index EP refers to the marginal ray, the index y marks the chief ray.

	Primary Position	Terminal Position
Marginal Ray	$s_{A,EP}$	$s_{E,EP}$
	$s'_{A,EP}$	$s'_{E,EP}$
Chief Ray	$s_{A,y}$	$s_{E,y}$
	$s'_{A,y}$	$s'_{E,y}$

***Tab. 1** Limiting Focus distances*

To determine a zoom system one entrance focus distance and one exit focus distance have to be choosen so that there are 16 different combinations. With these 16 combinations a zoom system can be calculated in four different ways. The different approaches depend on wether

1. the focus distances are determined for the same or for different zoom positions and
2. the exit focus distance is determined with the chief ray or the marginal ray. If it is determined by the chief ray the object imagery as well as the pupil imagery is fixed.

An overview is shown in the following figure:

same zoom position different zoom position

$s_{1,EP} / s_{1,y}$ → $s'_{1,EP}$, $s'_{1,y}$ $s_{1,EP} / s_{1,y}$ → $s'_{2,EP}$, $s'_{2,y}$

***Fig. 3** Four Ways for determining a zoom system*

3 Approaches with Specification of the Mechanical Design Requirements

The four approaches are listed below and explained briefly.

1. Approach with a Marginal Ray in One Zoom Position

   The focus distances are determined for one zoom position e.g. $s_{E,EP} / s'_{E,EP}$. The distance betweeen the two lenses can now be calculated over the constant imaging length: $e = L - s_{E,EP} + s'_{E,EP}$. Afterwards the focal legths of the two lenses can be determined. There is only one solution. The lens distance and the focus distances in the other zoom position can be calculated with the Wuellner Equations [1],[2].

2. Approach with Marginal Rays in Different Zoom Positions

   The two zoom positions are linked by the stroke of the zoom elements during zooming (change of the lens distance) and the constant imaging length L so that the euqations can be found to calculate the remaining focus distances and the focal length.

3. Approach with a Chief Ray in One Zoom Position

   The distance between the lenses has to be calculated with the pupil control equations: $e(\beta', L, k, k', s_y)$. There is only one solution for the calculation of the focal lengths. Now the exit focus distance s' has to be recalculated and checked if it meets the mechanical design requirements (Fig. 2).

4. Approach with Chief Rays in Different Zoom Positions

   Approaches 2 and 3 are mixed because the focus distances determine the entrance and exit zoom position as well as object and pupil imagery are fixed.

4 Conclusion

While adhering to mechanical design requirements the entrance and exit focus distances of certain chief rays and marginal rays in the primary and terminal zoom position are determinable so that these rays pass the zoom elements at their maximum height. Two focus distances, one entrance focus distance and one exit focus distance, are sufficient to determine a zoom system. Altogether, there are 16 different combinations of focus distances but only four different methods to calculate the zoom system.

References

[1] Klein, W: „Einige optische Grundlagen zu Vario-Systemen“, *Jahrbuch für Optik und Feinmechanik*, Fachverlag Schiele & Schön: 33-64 (1972)

[2] Landolt, H: „Über die Anwendung des Projektionsapparates in chemischen Vorlesungen“, *Berichte der Deutschen chemischen Gesellschaft 9*, 1849-1858 (1876)

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