Front stop photo lenses

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ABSTRACT

Lens systems having external pupil positions are mainly used in connection with optical scanners. In consequence, these so-called f-Θ lenses show barrel distortion. This paper, however, is considering the front stop lenses (FS-lenses) poor in distortion and therefore, suitable for photographic purposes.

1. INTRODUCTION

FS-lenses may be used for different photographic applications, e.g. for observations especially connected with illuminators; in space in order to keep the baffel systems as small as possible; for automatic cameras and also as parts of the so-called tandem optical systems. The greatest difficulties arises w.r.t. the correction of distortion. These questions are theoretically described in [1]. In order to keep the distortion in given limits, an introduction of aspherics seems to be necessary in some cases. This paper will give some examples and design steps of FS-lenses, mainly from a practical point of view. These developments have begun already in the 70ies and led to practicable lens systems without aspheric surfaces.

2. THEORETICAL ASPECTS

It is well known that the Seidel imaging errors are depending on the pupil position. The connection is given in [2] e.g. The most interesting error is the distortion, expressed by the Seidel sum (or Seidel aberration coefficient) S_5. When shifting the entrance pupil position by z, the Seidel coefficient S_5 will be changed into:

$$S_5' = (-z)^3 * S_1 + 3 * z^2 * S_2 - z * (3 * S_3 + S_4) + S_5 \qquad (1)$$

where an infinite object position is assumed, and where S_1 ... S_5 denote the Seidel coefficients of the basic system:

S_1 = spherical aberration, S_2 = coma, S_3 = astigmatism, S_4 = Petzval curvature, S_5 = distortion. S_5' is the arising Seidel distortion coefficent due to pupil shift. You can see: If you had an optical system without any aberrations affecting the sharpness of imaging, no additional pupil position depending aberrations would arise.

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But, disregarding possible mechanical constraints, also a well corrected optical system has remaining Seidel aberrations in practice. Taking into consideration that a pupil shift towards the object space means a negative sign of z and that a corrected optical system has in general positive remainder of the S_1 and S_4 aberrations, you can see that a pupil shift demanded will lead to an increased Seidel aberration S_5, i.e. the barrel distortion is growing.

3. REALIZED FS-LENSES

In the following, different types of FS-lenses are listed with respect to the available back focus distances and the fields of view (FOV).

3.1. High speed lenses having short back focus distances

Of course, there are high speed lenses of apertures up to f/0.7 covering a small FOV less than 20° and having a short back focus of less than 10% of the focal length. In case the aberration is corrected over the whole pupil area, a withdraw of the pupil position towards the object space is possible. These lens systems having a distribution of refractive power similar to that of a tele-lens system, tend to a pincushion distortion and, therefore, they have resources for optimization to realize a front stop position without distortion. Such systems are published in [3,4,5]. Having a lens system according to Fig. 1 (see [4]), you can realize a front stop position in the order of the focal length and over a FOV of approximately 20° without any distortion. To avoid vignetting, the aperture has to be reduced to f/2. Such a system has an excellent imaging quality. The only unavoidable error is the secondary lateral color.

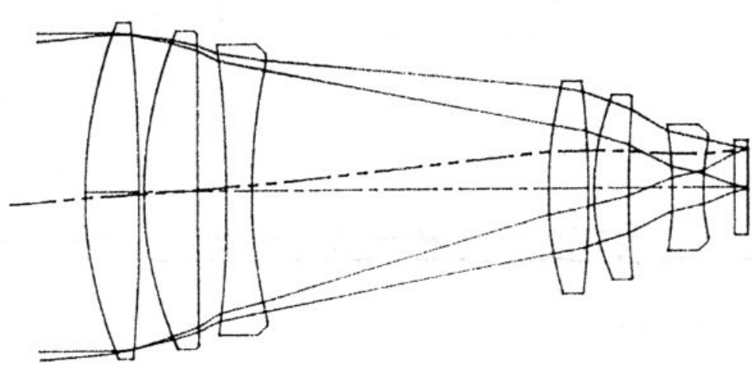

Fig. 1: High speed front stop objective

3.2. Development of FS-lenses having a relatively long back focus

The development of FS-lenses having a relatively long back focus distance in the range of 80% to 110% of the focal length had been carried out already in the 70ies. It was very difficult to find a suitable start system that could realize a sufficient correction of the imaging errors and a small distortion of, if possible, less than 5% over a FOV of 55^{o} to 63^{o}. A Tessar type lens could not meet these requirements, but also not a turned around Tessar. Our expectation was confirmed after some years: We found a Tessar front stop design [6] that did not meet the requirements in imaging quality because of the extensive field curvature (Fig. 2). But taking this opportunity, it should be pointed out that, in contrary, excellent behind stop Tessar type lens systems had been developed in Japan [7].

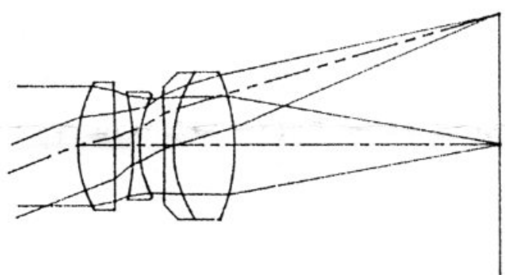

Fig. 2: Front stop Tessar lens design

In the development of a FS-lens design we started with a quite abnormal system for this reason, with a Distagon type lens created by Glatzel [8] (Fig. 3a). First, the 2 lenses in front forming in principle a weak afocal telescope, were removed (Fig. 3b). The automatic correction with the main conditions of a front pupil position and a long back focus leads to an unaesthetic system as shown in Fig. 3c. In the next design step, the biconcave lens element and the following convex meniscus had been joined by the help of cemented surface, and at least, the last convergent lens element had been splitted into 2 lenses.

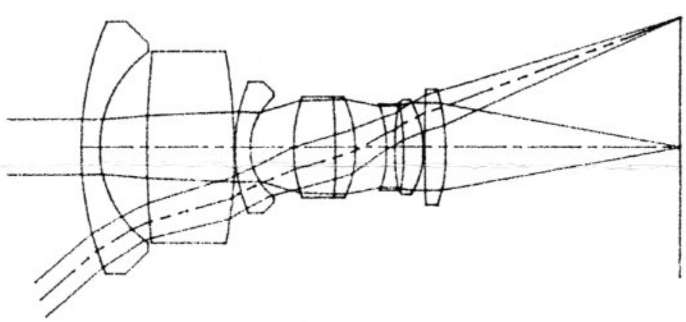

Fig. 3a: Distagon retrofocus lens

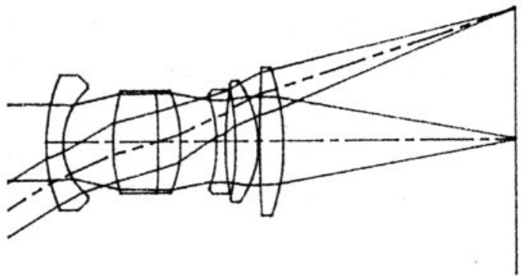

Fig. 3b: Design step

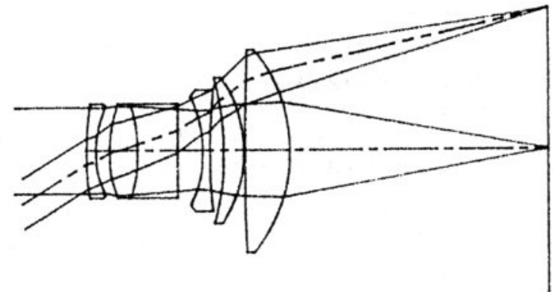

Fig. 3c: Design step

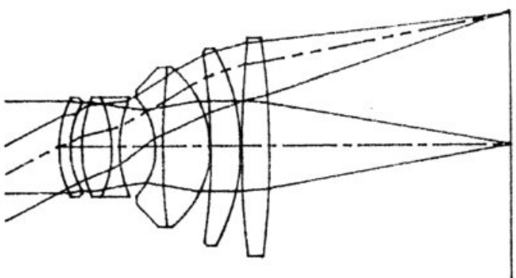

Fig. 4: FS-lens f/2.8

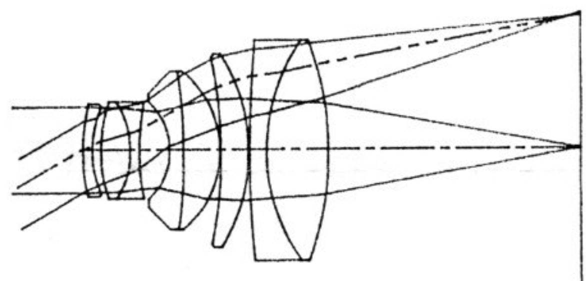

Fig. 5: FS-lens f/2.8

The result is shown in Fig. 4. This design has a back focus of approximately 90% of the focal length, the aperture is f/2.8. It covers a FOV of 55° with a distortion of 3.5%. The FOV might be extended up to 60°. The FS-lens in Fig. 5 is a modification of the system according to those of Fig. 4. It is characterized by an additional divergent cemented surface in the last lens element. The back focus is longer than the focal length, and the FOV may be extended up to 63°.

3.3. Wide angle FS-lens of the inverted Triplet type

A very different wide angle lens design is shown in Fig. 6 [9]. At the beginning of this design the backside part of the Russar type lens [10] had been. In the course of the development, it was extended to this unique form of an inverted Triplet which has a high aperture and an extended FOV. All the convergent refractive power is concentrated in the centre of the system and is formed by the two convex surfaces of the centrally located biconvex lens and the convex surface of the lens adjacent at the object side. The dispersive power is arranged at both the object and the image sides of the centre. The image side dispersive power is formed by a thin biconcave lens, whereas the object side dispersive power is formed only by a single cemented surface. The first air space of a conventional Triplet design is replaced by glass.

In this way it is possible to realize this inverted Triplet with 4 lens elements only. The back focus distance is 30% of the focal length, the aperture may be extended to f/3. This design covers a FOV of 75°. The distortion is 3.5% in maximum and shows a typical zonal behaviour. The general aberration values are seen in Fig. 7. When using a reduced FOV, the distortion may be essentially reduced. It should be remarked that this lens design is relatively insensitive w.r.t. decentrings.

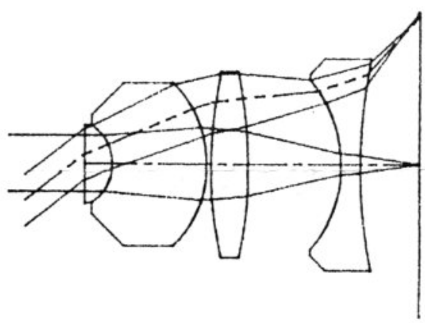

Fig. 6: Wide angle FS-lens

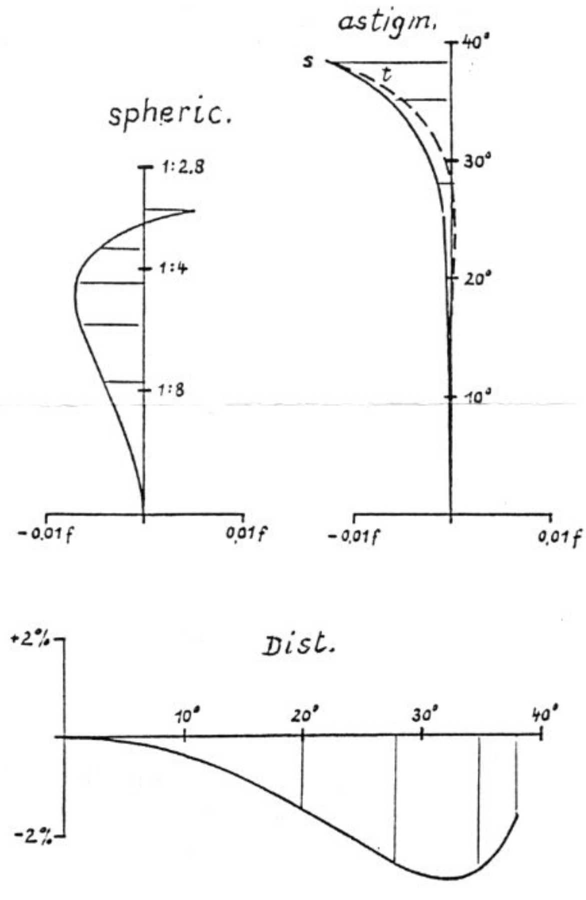

Fig. 7: Correction

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