New Lenses – New Principles of Lens Design (II)*

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Long, high-aperture DISTAGON lenses

Long overall lengths and relatively large diameters in the central lens part were allowed for the design of these lenses.

The design principle of long overall lengths is not yet fully exploited for photographic lenses. The situation is different with microscope objectives, for instance, where overall lengths may be more than 20 times the focal length. The lenses discussed in this chapter are particularly intended for movie cameras where a relatively long overall length is permissible.

A new design principle of relaxed lenses was searched for, which allowed high apertures (f/1.2 and more) in the wide-angle and semi-wide-angle range at long overall lenghts, yet without increasing the front lens diameter. Fortunately a solution without aspheric surface was found by providing a new central part in retrofocus lenses as illustrated in Fig. 17. Relaxed retrofocus lenses are known to be of long overall length. In the past decade this lens type was developed mostly for still SLR cameras and the trend was towards short overall lengths. The lens section (Fig. 17, above) is an example of such a short lens.
The new lenses were designed for movie cameras with a revolving mirror between lens and film inclined 45° from the axis. The higher the aperture in such an arrangement the greater the demand for an over-proportional increase of back focus. For this reason alone lenses with long back focus were required.

Three lens sections are compared in Fig. 17, which are drawn to the same scale. All three have approximately the same ratio of back focus to focal length (between 1.4 and 1.5). The lens section above applies to the DISTAGON 2.8/25 for the 35 mm SLR camera (1963), that in the middle to the DISTAGON 2/16 for 35 mm film (1966), and the section below to a new DISTAGON 1.2/12 [17] for 16 mm film (1974). The development in the framed central part is of particular importance: at first there was only a biconvex convergent element. A weak convergent meniscus was put behind. The lower lens section shows a new, three-lens configuration which consists of two strongly bent menisci enclosing a convergent element. The menisci are bent for minimum angles of incidence of aperture rays, i.e. the front meniscus is concave towards the object and the rear one towards the image. With this meniscus configuration the contribution of this central part to the PETZVAL sum can be kept arbitrarily small. The principal difference is the magnitude of the contributions to I, II and III of corresponding surfaces. Only the largest surface contributions in the central lens part are given, because the relationships are similar for the other ones. According to Fig. 17 the largest contributions to I and to II decrease by about one decimal power.

Adding the surface contributions to I through IV over the new, three-element configuration gives small values, especially of II, which means that the new configuration is insensitive to displacement of the bundle (or the pupils), which is especially valuable because it permits small front lens diameters. Fig. 18 shows how far the aperture stop can be moved to the front. Up to an angular field of 60° the front lens diameters are hardly larger than the diameters in the central part, and these hardly exceed the diameters in the rear part required by the aperture. The upper lens section of Fig. 18 is already known; it shows the DISTAGON 1.2/12 for 16 mm film. The two other lens sections are different versions of the new design principle, the one in the middle a DISTAGON 1.3/29 [18], the lower one a DISTAGON 1.0/24 [18], both for 35 mm film. These lens sections are scaled to equal image diameters. In the lower lens section the central part is now longer than the other two parts together. With an angular field of 60° in the object space, the bundles are telecentric in the image space, and distortion is less than 2%. The new design principle permits an entirely different design of the rear part. The two lower lens sections are in no way similar to Triplets or double Gauss lenses. Only three convergent elements are left in the rear part, which is again similar to microscope objectives or early retrofocus designs for wide-angle projection, published, for instance in the patent literature as early as 1930 [19]. The design of the central part reminds [20] of the "eyepiece by *Bertele*", the "new binocular eyepiece by ZEISS", and the "newer wide-angle eyepiece by *Bertele*". Unfortunately further interrelationships cannot be dealt with here.

A few words on the image quality of these lenses. There is not yet an application of the DISTAGON 1.0/24. In its present form it does not fit into any existing movie camera with revolving mirror. Hence this design is not a final one. Fig. 19 shows the modulation transfer of the DISTAGON 1.3/29 for 10, 20 and 40 lines/mm as a function of the image height. It is calculated by a spot diagram *Fourier* transform with integral light [21] represented by 6 spectral lines; optimum focus for 25 lines/mm on axis at full aperture. The curves to the right apply to full aperture, those to the left to the diaphragm stopped down to f/2.8. This high performance for 35 mm film is achieved with 11 lens elements. For an angular field of 53° the outlay is great, but production could be facilitated considerably by the realized relaxation and reserves in image quality.

The DISTAGON 1.2/12 for 16 mm film features the same number of lens elements at an angular field of 67°, an outlay which is necessary. Fig. 20 shows the modulation transfer analogous to Fig. 19, yet for 15, 30 and 60 lines/mm, focused for 30 lines/mm. The image quality is adapted to the new KODAK film ECN II type 7247, which is now frequently used.

You have now become acquainted with some lenses included in the new CARL ZEISS sets of high-speed lenses for 35 mm and 16 mm film. In practice these lenses with T* coating yield T-stops of 1.3 to 1.4. For nearly a decade there has been a standstill in the development of good high-aperture lenses of fixed focal length for 16 mm and 35 mm film cameras. Movie cameras have been gradually repelled by electronic cameras. Only now is it possible to film even at dimmed light (130 lux) with photochemical receivers and compete again with photo-electric receivers. Normal street lighting suffices. Close-ups can be taken while lighting a cigarette, and expensive illumination equipment is not necessary. Natural colors are retained. Test films have shown that at full aperture the film offers more details and better color than the cameraman sees, but this and the high aperture may produce uncertainty in focusing.

Lenses for step and repeat cameras

There are certainly further applications allowing long overall lengths, which are worth an exploitation, for example lenses for step and repeat cameras, two of which are shown in Fig. 21. With these lenses patterns are reduced at scales from 1:20 to 1:5, preferably 1:10, mainly for the production of masks with microstructures. Image formation is limited by diffraction at apertures which are now .25 to .35. The electronics industry calls for ever increasing image fields to be able to include more complex functions on a chip.

For mounting in the camera the lens

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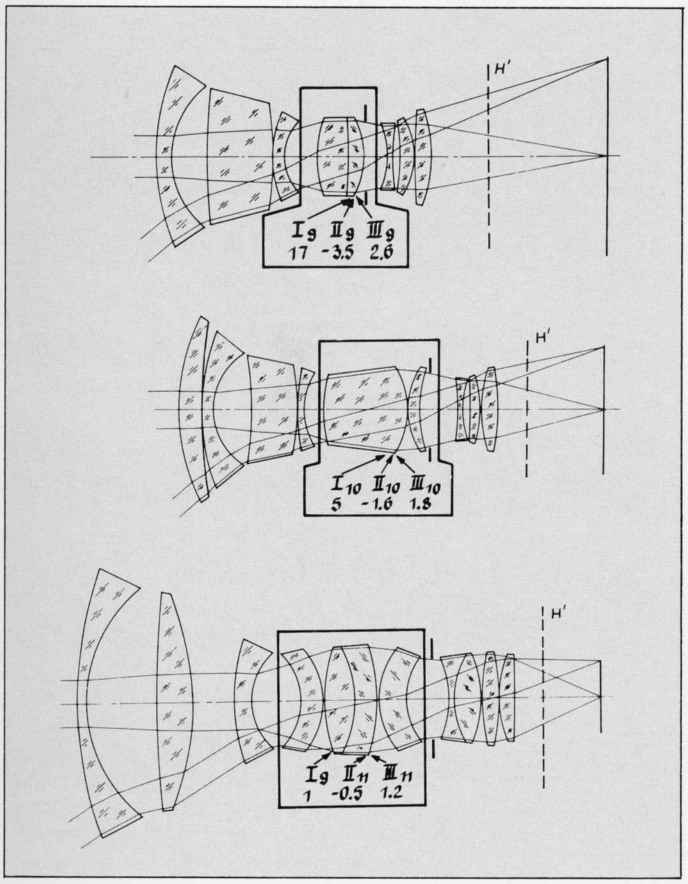

Fig. 17:
DISTAGON 2.8/25, 2/16 and 1.2/12: largest surface contributions.

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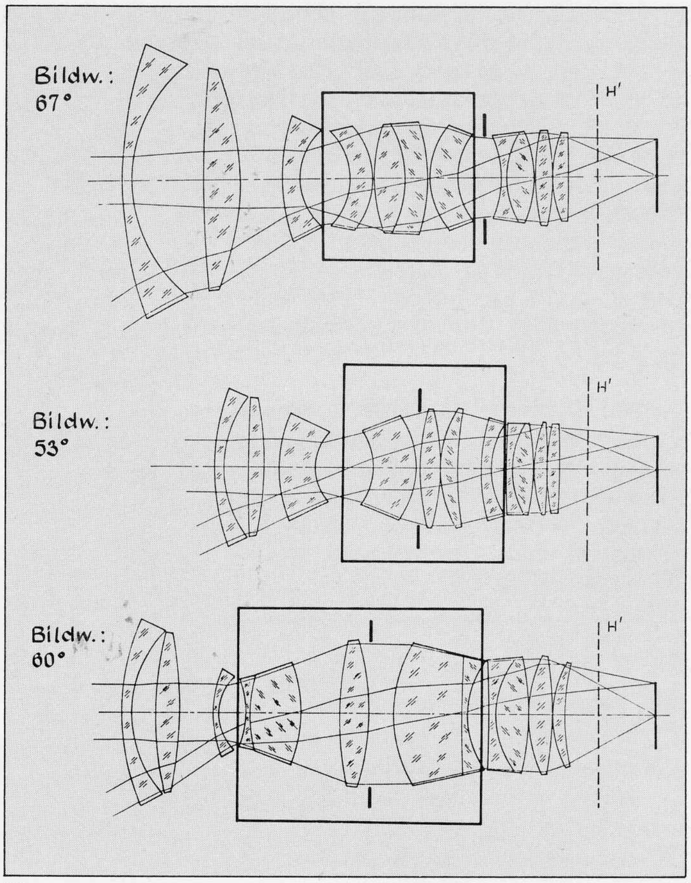

Fig. 18:
DISTAGON 1.2/12, 1.3/29 and 1.0/24.

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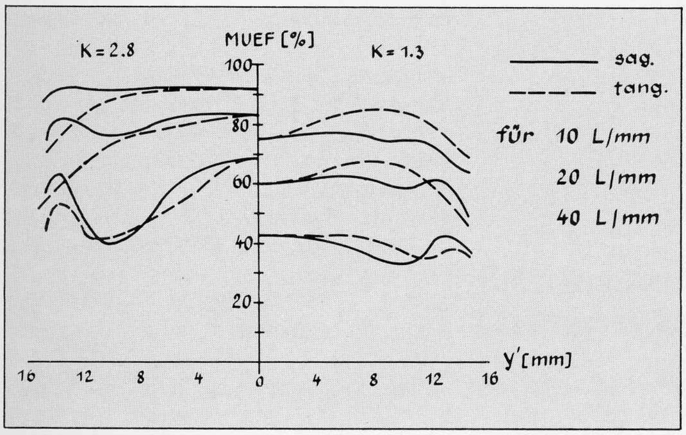

Fig. 19:
Modulation transfer of DISTAGON 1.3/29.

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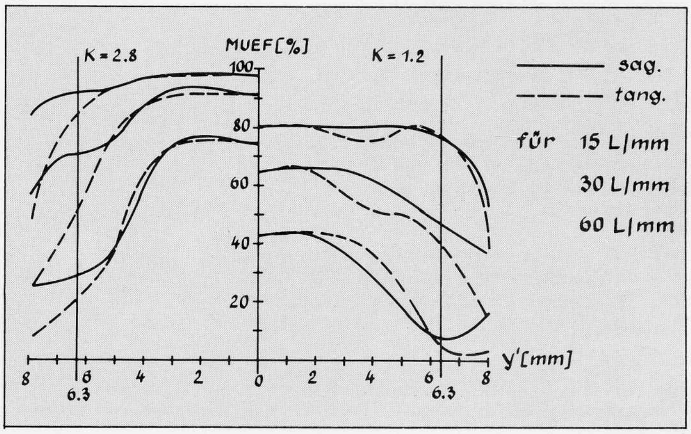

Fig. 20:
Modulation transfer of DISTAGON 1.2/12.

must be inserted around corners, which results in maximum outline; it is, however, at least three times as long as the modified double *Gauss* types used so far. To fully utilize this overall length, lenses are used which begin with divergent lens elements.

It seems absurd for large apertures to start with divergent lens elements which expand the bundle diameters. According to our experience, though, correction in the field is much more difficult and is eased by divergent lens elements on the object side. The gain in back focal length can be utilized by inserting correction means. The requirements with regard to the back focal length are not extraordinary, yet they preclude the use of field flattening lenses. Moreover, a long working distance is always of advantage.

Both lenses of Fig. 21 have a numerical aperture of .28 and are designed for the image scale 1:10. The upper lens section shows the S-PLANAR 1.6/25 (1970) with an object-to-image distance of 315 mm and an image field diameter of 8 mm. The lower lens section shows the S-PLANAR 1.6/50 (1974) which has been designed for a new step and repeat camera by DAVID MANN with an object-to-image distance increased to 600 mm, and an image field diameter of 14.5 mm. Both lenses have telecentric principal rays on the image side. These lenses are not easy to manufacture [22]. Relaxed systems are therefore of particular importance in the field of lenses with large fields, which are limited by diffraction. Such systems are presented here: compared with double *Gauss* lenses the corresponding menisci are flattened and the contraction of bundles relieved.

Fortunately another application was found of retrofocus lenses, although of considerably modified type. This type is preferable because it is likely to have a wide field of application.

Conclusion

A comprehensive analysis is given only in the first part of this paper. Anything analogous was impossible for the complex multi-lens retrofocus types. There are actually no systematic analyses dealing with the entire field of retrofocus lenses [23]. After more than 20 years of rapid development time has come for systematic analysis which still requires a lot of scientific work. This is indispensable for future systematic syntheses of lens systems. Industry alone cannot cope with this problem, because industry is above all interested in results earmarked for production. There has to be cooperation between science and industry.

Part of this work (DISTAGON lenses 1.2/25, 1.2/35, 1.2/12, 1.3/29 and 1.0/24) was sponsored by funds of the Bundesministerium für Forschung und Technologie (German Federal Ministry for Research and Development, signs NT 405 and NT 1017).

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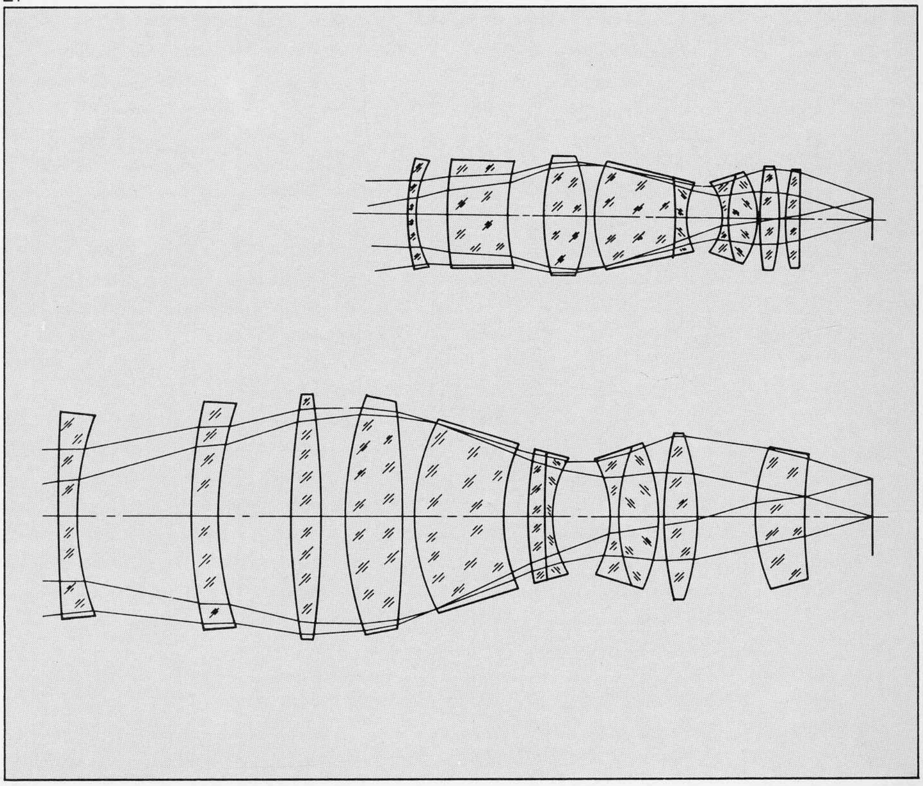

Fig. 21:
S-PLANAR 1.6/25 and 1.6/50.

References

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[23] Concerning some lenses for 35 mm SLR cameras see: *W.E. Woeltche,* Appl.Opt. **7,** 343 (1968).