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*A
History
of the
Photographic Lens*

Rudolf Kingslake

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A History of the Photographic Lens

Rudolf Kingslake

*The Institute of Optics
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Rochester, New York*



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leading to an inward-curving field. On the other hand, in a lens of the Rapid Rectilinear type, an error as large as 1.0% has only a negligible effect on the field curvature and almost no effect on the coma, an increase in the airspace leading to a backward-curving field. In general, it is usually found that the better the lens the greater is the effect of an error in the central airspace.

II. A BRIEF HISTORICAL SURVEY

Any attempt to develop a strictly chronological approach to the history of the photographic objective is invariably confused by a hopeless mass of crosscurrents. It would be easier if each type of lens had been invented, developed, perfected, and then abandoned in a limited period of time, after which another type had appeared and been similarly treated. Unfortunately for the historian, but fortunately for the working photographer, the lenses available at any one time cover a wide range of constructional types, some being suitable for use at high apertures, some covering a wide angular field, some being usable over a broad range of magnifications, some being simple and cheap, while some are complicated and expensive. It is, in fact, only recently that a high aperture and a wide angular field have become possible simultaneously in the same lens, and it is only in the last forty years that lenses with a variable focal length have become available. Consequently, in this book it has been decided to follow the rise and decline of each type separately, starting with its first introduction and continuing its development to the present day, or until it was abandoned.

A. 1840 to 1866

Photography was invented by L. J. M. Daguerre (1789–1851) in 1839, and the first lens to be used on a camera was the achromatic landscape lens of C. Chevalier (1804–1859). The aperture of this lens was only $f/15$, and the need for a much faster lens was immediately obvious. This requirement was soon met by J. M. Petzval in his famous Portrait lens of 1840. A few high-aperture objectives were developed by other workers but they were not good enough for practical portraiture.

Partly because of the slowness of the original daguerreotype process, many photographers were in the habit of photographing inanimate objects such as fine buildings; the appearance of barrel distortion in landscape lenses became evident by the curvature of straight lines in the outer parts of the field. So a demand arose for distortionless lenses, and a number of symmetrical systems were developed empirically by such workers as Cun-

dell, Ross, Davidson, Sutton, and others. The first symmetrical objectives to be properly designed were the 1859 Panoramic lens of T. Sutton (1819–1875), the 1865 Periskop of C. A. Steinheil (1801–1870), and the 1860 Globe lens of Harrison and Schnitzer in New York.

A few unsymmetrical distortionless lenses appeared on the market. In 1859, when the cry for distortionless lenses was at its height, the Petzval Orthoskop appeared. This lens was hailed as the solution for all the photographer's problems, but careful investigation showed that it was not perfectly distortionless and the field was somewhat curved, so the new lens was soon forgotten.

B. 1866 to 1890

In 1866 the Dallmeyer Rapid Rectilinear and the identical Steinheil Aplanat were produced. At that time there were four types of lens available to the working photographer, namely, the Landscape lens, the Portrait lens, the wide-angle Globe lens, and the intermediate Rapid Rectilinear, which together met most of their needs. However, all these lenses suffered from overcorrected astigmatism in the outer parts of the field, which was serious in lenses of high aperture but scarcely significant in lenses of very low aperture.

C. 1890 to 1914

The correction of astigmatism and the development of the Anastigmat lens of 1890 were made possible by the introduction of barium crown glasses by E. Abbe (1840–1905) and O. Schott (1851–1935) of the Zeiss Company, in 1885. Now for the first time it was possible to eliminate the astigmatism that had bedevilled all previous lenses, leading to the design of such well-known objectives as the Tessar, Dagor, and many others. Nevertheless, old favorites such as the Petzval Portrait and Rapid Rectilinear lenses took a long time to disappear. They were still being made and used extensively by 1930. The year 1890 also saw the introduction of telephoto lenses by Dallmeyer and others and, on the whole, it was a period of steady improvement in lenses of many new types.

D. The Interwar Period, 1918 to 1940

By 1920 lenses of $f/2$ aperture were becoming available, and the period around 1930 was particularly active in the development of new lenses. Reversed telephotos were appearing, at first for close-up projection and then for use in the Technicolor three-strip camera, where a long back

focus clearance was needed to house the beam-splitting prism. Some primitive zoom lenses were being developed for professional 35 mm movie cameras, and the use of anamorphic compression in motion pictures was being proposed by Chrétien. During this period, 16 mm and 8 mm movies were being developed for the amateur photographer, requiring the design of many new lenses. Toward the end of the period, some very large lenses were being developed for use in aerial cameras.

E. The Post World War II Period

As soon as World War II ended, there was a great rush of pent-up activity in the design of new photographic lenses. Practical zoom lenses for 35 mm motion pictures soon appeared, and these were followed by lenses for the new field of television. The CinemaScope system of 1952 gave the cinema a much-needed boost; this involved the use of anamorphic compression in both the camera and the projector. New lenses of high quality were required for the new film formats of the 126, 110, and Disc cameras.

Starting in the early 1950s, Japanese camera and lens manufacturers began to take over the amateur camera market and soon outstripped European countries in the low cost and high quality of their products. Eventually, even the German manufacturers could no longer compete, and today Japan has a virtual monopoly in the 35 mm still-camera market.

As an example of Japanese enterprise, we may consider the offering of a single company, Nikon, which currently makes over fifty lenses for 35 mm SLR cameras. They have three fish-eye lenses from 6 mm to 16 mm focal length; eleven reversed telephoto wide-angle lenses from 13 mm to 35 mm; three normal lenses of 50 mm focal length; twenty-three telephotos from 80 mm to 1200 mm; three mirror lenses from 500 mm to 2000 mm; and eleven zoom lenses ranging from 28–85 mm to 180–600 mm. Several other companies are manufacturing similar lines of first-quality lenses, all reasonably priced and readily available in this country.

These developments have been made possible by the introduction of the high-speed digital computer (see Section VC). Other contributing factors are efficient antireflection coatings and the introduction of new types of high-index optical glass.

III. LENS MARKINGS

At first very few lenses carried any indication of the maker or the structure of the lens. There were exceptions, of course, but often the lens would be housed in a polished brass barrel and that was it. The user had to fit the

best lens he could find to his camera, and most photographers were reasonably successful in doing so.

By the middle of last century, lens names began to appear. These were proprietary and indicated both the manufacturer and the type. Owners of a Tessar or a Heliar would be very proud of having such a fine lens. Eventually, however, the same name might be used for various types of construction. Today, lens names have almost entirely disappeared, with only the maker's name and the lens data being engraved on the mount.

In a few cases, importers have marked their names on the lenses that they sell; the actual maker is unknown to the purchaser. Sometimes a patent number or the date of issue of a patent has been engraved on the lens mount. Although this was presumably done to discourage copying, it actually serves as a useful indication of the lens structure.

Many lenses carry a serial number alongside the other data. This can provide an indication of the year of manufacture, although it is sometimes coded in such a way that the owner cannot interpret the number; more often, it serves merely as an identification label for insurance purposes.

A. Aperture Control Devices

In the days of the daguerreotype, obviously no means for reducing the lens aperture was required, as photographers needed all the light they could get. However, with the introduction of the wet collodion process by F. Scott Archer (1813–1857) in 1851, the emulsion speed was so great that some means had to be found for reducing either the lens aperture or the exposure time. The latter possibility had to wait for the invention of mechanical shutters in the 1870s, but a simple means for reducing the lens aperture was introduced by John Waterhouse in 1858.³

The Waterhouse stop consisted of a flat piece of metal having a circular or other hole to form the actual aperture, which was slipped into a slot at the correct place in the lens barrel. Many early lenses were accompanied by a neat leather case holding a set of Waterhouse stops to be used with that particular lens.

Some of the early Jamin-Darlot lenses were equipped with three swing-out stops on levers so that any stop could be swung into position as desired. Another common arrangement was a wheel of stops pivoted at one side of the lens barrel, which could be rotated to bring the desired aperture into position.

³ *Phot. J.* 4, 258 (1857–58).

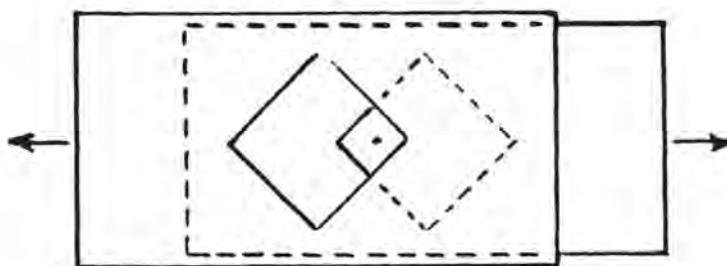


Figure 1.2. The Noton cat-eye diaphragm.

The commonest means for aperture control is the familiar iris diaphragm. It is not known who invented this extremely ingenious mechanism, but it was apparently known early in the last century. The mechanism consists of a set of identical arcuate leaves mounted around the lens aperture, each leaf having short studs at the two ends, one stud being at the front and the other at the back of the leaf. All the studs above the leaves fit into holes spaced around a metal ring, while the studs below the leaves fit into radial slots in a second ring. When one ring is rotated relative to the other, all the leaves move inward, creating an aperture of reduced diameter. If only three leaves are used, the resulting aperture is a curvilinear triangle, but if a large number of leaves are used, the result is a good approximation to a circle. Sometimes bright lights in a night photo exhibit radial streaks on the negative. These are due to diffraction at the edges of the diaphragm leaves, there being the same number of streaks as there are diaphragm leaves.

In 1858 C. C. Harrison of New York patented a novel type of iris diaphragm in which both studs were at the same end of the leaf, the length of the leaf being slightly greater than the semidiameter of the aperture.⁴ This form of iris was little used at the time, but when iris shutters were introduced in the 1880s, the shutter blades were invariably constructed on Harrison's principle, there being anywhere from three to twelve or more blades around the aperture. Today, when most cameras are equipped with some kind of automatic aperture control, Harrison's iris is the only kind that is capable of responding sufficiently rapidly to be useful. If Harrison were living today, he would have profited greatly from his invention.

Another type of aperture control that is occasionally used is the cat-eye diaphragm, originally proposed by M. Noton in 1856 (Fig. 1.2). Here two overlapping metal plates carry square openings, which together form a

⁴ U.S. Pat. 21,470 (1858).

square aperture, its size being continuously variable by moving the two plates at equal rates in opposite directions.

B. Aperture Designation

Several systems of aperture designation have been introduced over the years. Some early lenses carried diaphragm markings that merely indicated the diameter of the iris opening in millimeters, leaving it to the user to interpret this in relation to the focal length of the lens and the required aperture.

About 1880 it began to be understood that the speed of a lens and also the depth of field are dependent upon the slope angle U' of the steepest ray emerging from the lens and proceeding to form the axial image. Lens speed is thus proportional to $\sin^2 U'$, the quantity $\sin U'$ being known as the numerical aperture of the lens. For photographic purposes, it soon became the custom to designate the lens aperture by the ratio of the focal length to the diameter of the entrance pupil, the so-called F -number of the lens. In Europe and Japan this ratio is indicated as a fraction, (e.g., $1 : 4.5$ if the focal length is 4.5 times the aperture diameter). In English-speaking countries the diameter of the aperture is usually expressed as a fraction of the focal length (e.g., $f/4.5$). The denominator, in this case 4.5, is called the F -number of the lens, often represented by the symbol N . Unfortunately, a high value of N indicates a small lens aperture and vice versa, which can be confusing.

The relation between the F -number and the numerical aperture is given by:

$$N = \frac{1}{2 \text{ N.A.}} = \frac{1}{2 \sin U'}$$

or

$$\sin U' = \frac{1}{2N}.$$

The first standard series of F -numbers was that proposed by Franz Stolze (1830–1910)⁵:

$f/1.1, 1.6, 2.2, 3.3, 4.5, 6.3, 9, 12.5, 18, 25, 36, 50, 71, 100.$

⁵ C. Diserens, *Traité de Photographie: Vol. 1, Optique*, p. 326. Gauthier Villars, Paris, 1943.

The ratio of each number to the next is the square root of 2. For many years, most European lenses were marked according to this system. However, in recent years it has become customary to use a different series, which is now universal:

$$f/1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32, 45, 64, 90.$$

The maximum aperture of a lens can be anything, but the smaller apertures are invariably marked with one of these series.

In the past, a few attempts have been made to mark the lens aperture by the relative image illumination. Paul Rudolph of Zeiss proposed two such systems. In his first system the stop was marked by the approximate value of $10,000/N^2$. Thus, $f/9$ became 128 in his system, and so on. Later he divided these numbers by 4 so that $f/9$ became 32.

Around 1890 the opposite scheme was proposed, in which the aperture markings were intended to be proportional to the exposure. This was called the Uniform Scale system, abbreviated to U.S. Here $U.S. = N^2/16$, so that $f/16$ became U.S. 16, and $f/4$ was marked U.S. 1. For many years all of the lower-priced Kodak and other cameras were marked on this system.

C. Focusing Devices

Lenses intended to be used on a bellows camera needed no focusing arrangement, but they were often equipped with a rack and pinion to provide more sensitive focusing than was possible by using the heavy front board and rear supports of a large wooden camera. For smaller cameras, a helical focusing arrangement was often used.

The required movement of a lens from its infinity position when focusing on an object at a distance L from the lens is given by the formula

$$X = f^2/(L - f),$$

where f is the focal length. Thus, a lens of 4 inches focal length, when focused on an object 3 feet away, must be moved forward from its infinity position by a distance of $4^2/(36 - 4) = 0.5$ inch. This movement can be handled without difficulty, but a larger focusing movement becomes mechanically troublesome.

The quantity L in this formula is, strictly speaking, the distance of the object from the front nodal point of the lens. As the location of this point is generally unknown, particularly in the case of a long telephoto or zoom lens, a better procedure is to measure the distance S of the object from the

film plane, which is often marked by the symbol ϕ on the top of the camera. The required lens movement X when the distance S is known is found from the quadratic equation

$$X^2 - X(S - 2f) + f^2 = 0.$$

About 1900 someone suggested focusing a lens by moving only the front element instead of the whole objective. The advantage of this procedure is that in a Triplet or a Tessar the power of the front element is about three times the power of the whole objective, so that the required focusing movement is only about one-ninth as great as for the lens as a whole. Furthermore, if only the front element is to be moved, the rest of the lens and the shutter can be rigidly fixed in position. The penalty of using this arrangement is that the aberration correction carefully built into the design is completely upset if the front airspace is altered. However, by over-correcting the spherical aberration at the infinity setting, where the lens will generally be used stopped down, the undercorrection at close distances will be reduced. Also, when the object is close to the camera, the image will be large, and some degree of spherical aberration can be tolerated. With the coming of miniature cameras, the need for front-element focusing has largely disappeared, although it is still used in some zoom lenses.

Recently a few lenses have been constructed that are focused by a movement of an internal rear element, the remainder of the system remaining fixed. This arrangement is particularly convenient for cameras equipped with some type of automatic focusing.

Even when the entire lens is moved for focusing, some changes in the aberration correction can be expected. One proposal to maintain good image correction with a very close object is to move one of the lens elements (a floating lens) at a different rate from the rest of the system. Such an objective is known as a macro lens.

IV. IDENTIFYING A GIVEN LENS

The various photographic museums around the world possess numerous examples of early lenses, but because many of these carry no engraving of any kind, the curator often has difficulty in identifying some particular lens or even determining who made it. Some lenses carry the maker's name but no indication of the type of construction. If the lens has a long barrel with rack-and-pinion focusing, the chances are that it is a Petzval portrait lens, but, of course, this conclusion is not always valid. In a few cases the

maker's name and other data have been written by hand on the ground rim of a negative element in the lens.

If the lens can be readily disassembled into its separate elements, the type of construction can be quickly determined, but if cemented components are involved, identification becomes more difficult. One possible procedure is to remove the cemented unit from its mounting and hold it horizontally beneath a single light bulb near the ceiling. On slightly tilting the lens, the various reflected images of the light will move across it, and a little thought will often indicate whether the surface causing the reflection is convex or concave toward the observer. Uncoated glass-air surfaces yield bright images, while cemented surfaces form faint reflections. For example, one-half of a Rapid Rectilinear lens contains two external surfaces and one internal surface all facing the same way, so that when this lens is tilted the three reflections move in the same direction but at different rates. On the other hand, in the front component of a Petzval Portrait lens, the interface reflection and the reflections from the two outer surfaces move in opposite directions. In a cemented triplet such as one-half of a Dagor, the two cemented interfaces have opposite curvatures and sometimes with a little care it is possible to identify the lens structure. This process becomes much more difficult if the outer lens surfaces are coated.

In some cemented lenses there is a visible groove or step around the edge of the lens where the cemented interface emerges, but in some cases the edge of the intersection is barely visible even under a magnifier. If the positive element in a cemented combination runs out to a knife edge, it is virtually undetectable.

V. SOME RECENT DEVELOPMENTS

A. Aspheric Surfaces

The only kind of surface that can be conveniently and accurately generated on a piece of glass is a sphere or a plane. When several elements are assembled in a lens barrel, the centers of curvature of all the lens surfaces must be made to lie on a straight line called the lens axis. Failure to achieve this will result in a decentered lens, and good definition becomes impossible.

It has long been known that the use of a nonspherical surface of revolution on a lens would give the designer several additional degrees of freedom with which to work, but the practical problems involved in the generation of such surfaces on a piece of glass are horrendous. Such a surface has its own axis, of course, and this axis must be made to coincide with the axes

of the other surfaces in the system. Nevertheless, in spite of these problems, some success is being achieved in the production of lenses having aspheric surfaces. Kodak, Corning, and other companies have recently had some success in molding glass to an accurately known aspheric surface⁶. Of course, it is just as easy to mold a plastic asphere as a spherical surface; the only problem is how to make the aspheric mold. One good mold can be used to make thousands of plastic aspheres, and this may well be the way in which low-cost aspheres will be made. Several recent patents have appeared for high-aperture television projection lenses in which two or more plastic elements have aspheric surfaces on one or both surfaces. Plastic biaspheres are being proposed for the high-aperture lenses used in video disc recorders. It has even been proposed to make a base lens of glass and cover it with a thin layer of epoxy in which an aspheric surface has been pressed.

B. Antireflection Coatings

An important limiting factor in all early lenses was the presence of interreflection of light between the various glass-air surfaces in the lens. This led to a general loss of light in the image, but the worst consequence was the formation of ghost images and flare spots in the picture. Lenses having two or four glass-air surfaces did not suffer unduly in this respect, and six glass-air surfaces were generally considered acceptable. Lenses such as the original Anastigmat and the Dagor were admired, in spite of their excessive zonal aberration, largely because they had only four reflecting surfaces. However, when eight-surface lenses began to appear, such as the Celor of Goerz and the Unar and Planar of Zeiss, some users became unhappy and maintained vigorously that the old landscape lenses used in simple box cameras yielded negatives with more contrast. Certainly no designer dared to go beyond that limit.

Around 1896 H. Dennis Taylor observed that some old lenses that had become tarnished by exposure to the atmosphere actually transmitted more light than a newly polished lens. He reasoned that the thin layer of tarnish on the lens surfaces had a lower refractive index than the body of the glass, leading to a reduction of loss by reflection and a consequent increase in the light transmission. In 1904 Taylor patented the use of acids or other chemicals to cause tarnish deliberately on the surfaces of a lens, to

⁶ P. L. Ruben, "Design and Use of Mass-produced Aspheres at Kodak." *Appl. Opt.* **24**, 1682 (1985).

reduce reflectivity.⁷ However, this process proved to be uncertain in operation, some of the lenses in a batch becoming tarnished quickly while others did not tarnish at all or only very slowly.

The whole subject was opened up in 1936 when A. Smakula of Zeiss invented the process of coating lens surfaces in a vacuum with a thin evaporated layer of low-index material.⁸ A single layer of such material, originally calcium fluoride or magnesium fluoride, has the effect of reducing the reflectivity greatly at one wavelength in the middle of the spectrum, but less at the longer or shorter wavelengths at the ends of the spectrum. Later on, various plans were presented for the evaporation of several layers of differing materials on top of one another, by which means the reflectance could be reduced almost to the vanishing point throughout the entire spectrum.

The discovery of antireflection coating of lenses opened up the whole field of multielement optical systems, so that now almost any desired number of airspaced elements can be used without danger of ghosts and flare. Without such coating all the modern zoom and other complex lenses would be impossible. Of course, a layer of cement used to join two lens elements together cannot be coated, and such a surface may reflect a considerable amount of light. Today one occasionally sees a row of ghost images in television images when the sun is in or close to the picture, in spite of the efforts of the designer to avoid this possibility.

C. Computers

By far the most important recent advance in lens-design technology has been the advent of the digital computer. No matter how it is performed, lens design necessarily involves an enormous amount of numerical computation ("number crunching"). These computations consist mainly, but not entirely, in the tracing of numerous selected rays through a possible lens using eight-place trigonometry. In the old days this was performed by hand with the help of a table of logarithms, and the time required to trace a ray through a spherical refracting surface might run anywhere from two to five minutes, or even longer toward the end of the afternoon! Motor-driven mechanical desk calculators, starting from about 1930, were a help, and by using today's programmable electronic pocket calculators this time has been reduced to about five or six seconds per ray-surface and a great

⁷ Brit. Pat. 29,561/04.

⁸ Ger. Pat. 685,767 (1936).