

# Chapter 14

## Ocular Lenses

### 14.1 Eyepiece

An eyepiece is a magnifier with its entrance pupil defined by the lens stop of an objective lens. It is also known as an ocular lens. A typical ocular has a focal length of 25 mm, which is one-tenth of the near point of human vision at 250 mm. An image conjugate of the tube lens serves as the object of an ocular. The object is located at the front focal point of the eyepiece. The angular size of the image is 10 times greater than the angular size of the object at the standard near point. Consequently, the angular magnification of a typical eyepiece is 10X. The angular magnification of an arbitrary eyepiece is defined by Eqs. (2.7) and (3.27).

### 14.2 Pupils

The entrance pupil of an eyepiece is defined by the lens stop of the objective lens. In a system with finite tube length, the object NA is defined by the diameter of the objective lens stop and the length of the tube. In a system with infinite tube length, a tube lens creates a distant image of the objective lens stop, and the object NA is defined by the diameter of the lens stop and the focal length of the tube lens.

The exit pupil of an eyepiece is an image of the entrance pupil, which is the lens stop. During proper illumination, the exit pupil appears as a bright white disk floating above the eyepiece. The exit pupil should fit within the pupil of a human eye. The distance from the last surface of the ocular to the exit pupil is the eye relief.

The eye relief is an important functional parameter. At short distances of 10 to 15 mm, the eye relief prevents contact with eyelashes. At longer distances of 25 to 30 mm, the eye relief provides space for eyeglasses. A flexible eye cup on the ocular acts as a shield from room light for an operator without eyeglasses. The eye cup is folded backward along the ocular for operators with eyeglasses.

The diameter of the exit pupil defines an artificial pupil for the operator's eye. At small pupil values of 1.25 mm, the human eye is diffraction limited: this is true even for people with minor astigmatism. This artificial pupil provides a significant advantage over the natural pupil of 2.5 mm at which the eye is

aberration limited. Proper room light is required for dilation to a natural size of 2.5 mm.

The field stop of the ocular is placed at an image field of the tube. The field stop of the ocular defines the vision field at the specimen. An image of the field stop may be projected onto the vision field. The size of the field stop is dependent on the type of ocular lens. The diameter of the field stop can vary from 15 mm in a Kellner ocular to 25 mm in an Erfle ocular.

In a microscope of finite tube length in 1980, an image is located at 160 mm from the objective flange—this defines a tube length of 160 mm with an image located at its end. The field stop of the ocular is located at the end of the tube. A field stop of 22 mm defines a chief ray angle of 3.9 deg in an eyepiece of 25-mm EFL. Beyond this angle, the image quality becomes more difficult to maintain. Consequently, the lens stop of a microscope of finite tube length is typically 22 mm or less.

In a microscope with infinity correction, a 10-mm lens stop and a 200-mm tube lens create a tube NA of 0.025. The field stop of the ocular is located at the back focal point of the tube lens.

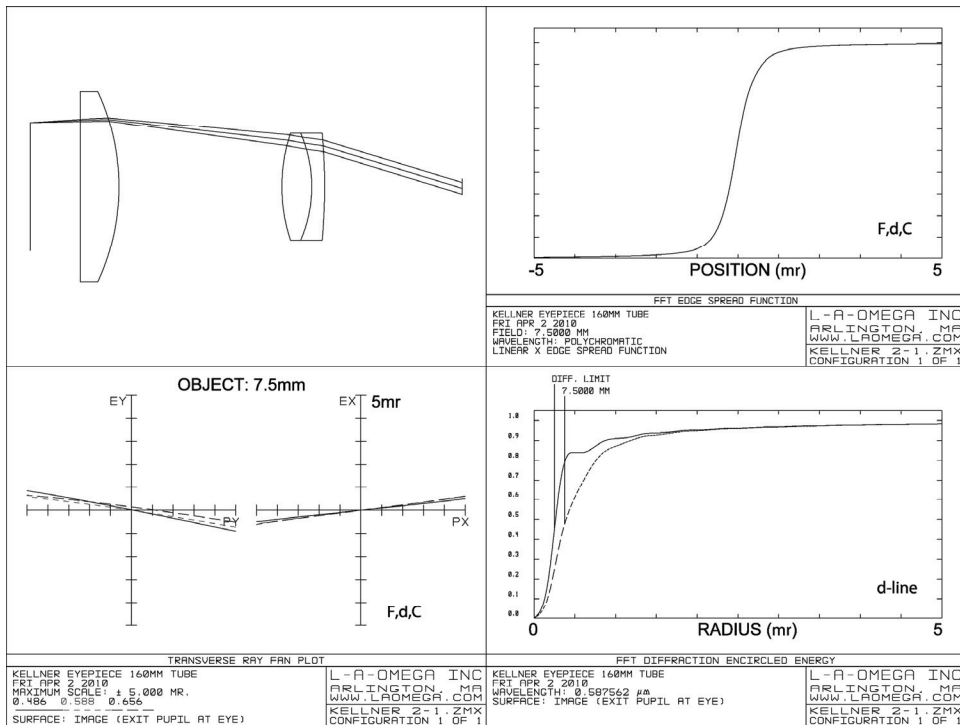
### 14.3 Kellner Ocular

In Fig. 14.1, a Kellner eyepiece employs a doublet and a plano-convex singlet. The doublet acts as a magnifier on the image, while the singlet acts as a relay lens for the entrance pupil (which is the lens stop). The singlet is called a field lens because it is located near the image field, where it has little effect on the magnification of the field. Defects of the singlet can represent a significant portion of a ray bundle. Consequently, the singlet is placed near the image field but not at the image field.

In Fig. 14.2, a Kellner ocular lens is formed by two stock items, a plano-convex lens of 25-mm EFL and doublet of 30-mm EFL. The maximum field is limited to 7.5 mm in the field stop and 17 deg in the image. The collinear ray-intercept plots of the  $x$  plane indicate a nearly perfect spot on axis with a small Petzval curvature. The ray-intercept plots of the  $y$  plane indicate axial color, lateral color, and astigmatism. The field-stop diameter is limited to 15 mm by the outer diameter of the doublet.



**Figure 14.1** Kellner ocular at a finite distance to the lens stop. The lens stop (LS) is 8 mm in diameter. The tube length is 160 mm. The object NA is 0.025. The field stop (FS) is 15 mm in diameter. The exit pupil (EP) is 1.6 mm in diameter at an eye relief of 15.5 mm. the field of the image is 17 deg. The field lens (FL) is a standard plano-convex lens at 50 mm in focal length. The magnifier (M) is a stock doublet at 30 mm in focal length. The EFL is 25.0 mm at the d line. The angular magnification is 10X the near-point view.



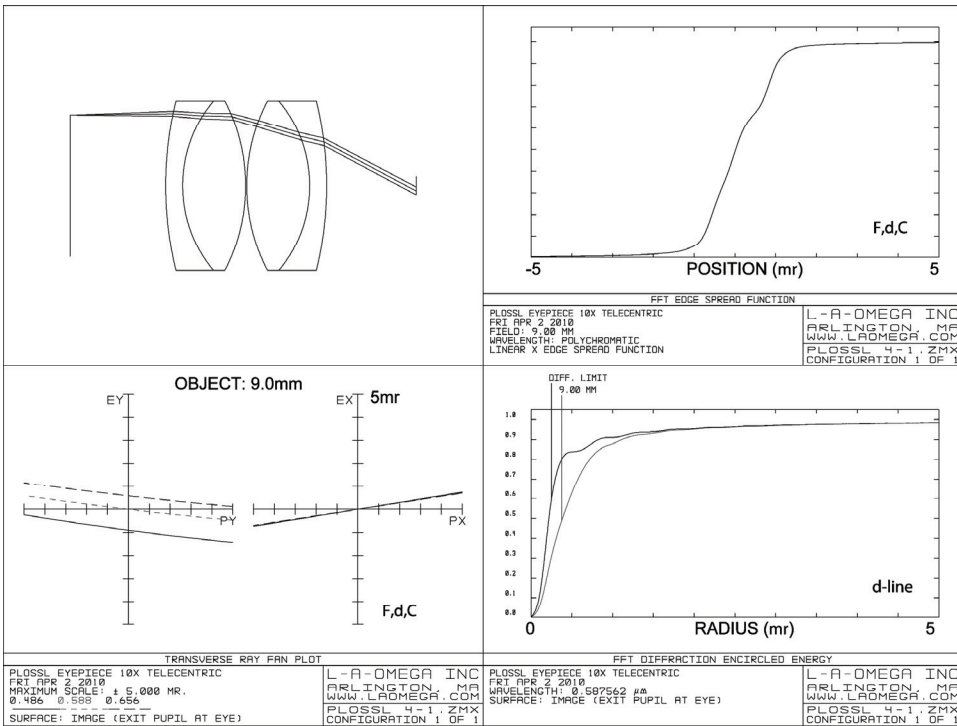
**Figure 14.2** Kellner lens report. Wavelengths are at the F, d, and C lines. Object height is 7.5 mm in the lens report. Maximum field diameter is 15.0 mm.

A Kellner lens is an excellent low-cost option with perfect image quality on axis. The angular field at 17 deg and the field stop at 15 mm are both small by today’s standards. Replacement of the doublet with a plano-convex singlet creates a Ramsden eyepiece, which is a predecessor to the Kellner.

### 14.4 Plössl Ocular

A Plössl eyepiece is formed by two modifications to the Kellner. The first modification involves splitting the doublets of a Kellner eyepiece into two doublets, and the second modification involves removing the field lens. Splitting the magnifier of the Kellner into two doublets greatly increases the diameter of the magnifier while maintaining its focal length. The increased diameter of the magnifier permits elimination of the field lens. A Plössl benefits from a telecentric object space because less bending of rays is required. A Plössl eyepiece is common in telescopes.

In Fig. 14.3, a Plössl ocular is formed by a pair of standard-stock doublets at 50 mm in focal length. The collinear ray-intercept plots of the *x* plane indicate near perfection on axis. The sloped ray-intercept plots of the *x* plane indicate field curvature. The ray-intercept plots of the *y* plane indicate astigmatism and lateral color. The field-stop diameter is limited to 25 mm by the outer diameter of the doublet.



**Figure 14.3** Plössl lens report. The lens stop is 50 mm in diameter at 1000 mm from the field stop. The object NA is 0.025. The exit pupil diameter is 2.0 mm at an eye relief of 19.0 mm. Doublets are identical stock products at 50 mm in focal length. The EFL of the doublet pair is 26.6 mm at the d line. The angular magnification is 9.4 times the near-point view. Object height is 9.0 mm in the lens report. Maximum field diameter is 25.0 mm.

A Plössl lens is an excellent low-cost option for a wide-field eyepiece. The angular field at 28 deg and the field stop at 25 mm are both large by today’s standards. Glass optimization can reduce the lateral color.

### 14.5 Erfle Ocular

A historical development of the Erfle eyepiece is described by two prescriptions. The original patent by Erfle in 1923 is displayed in Fig. 14.4. It was based on the limited selection of available glass at the time. An Erfle eyepiece of 1997 is displayed in Fig. 14.5 with higher-index glass and low-dispersion lanthanum glass. The glass types of these Erfle lenses are displayed in the glass map of Fig. 14.6.

The Erfle design of 1923 employs glass from the lower region of the glass map: borosilicate krone (BK) and flint (F). The refractive index does not exceed 1.62. Consequently, the element curvatures are steeply curved, which enhances lateral color and astigmatism. The dispersion of these glass types does not exceed 36. Consequently, there is limited color correction at large field angles. The field-stop diameter is limited to 25 mm by the outer diameter of the elements.