

Assignment 9

OPTI 502 Optical Design and Instrumentation I

University of Arizona

Nicolás Hernández Alegría

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Exercise 1

We use raytracing with the chief and marginal ray and the information given. Recall that the stop is placed at the primary mirror, so the chief ray must have 0 height at that location. Also, we put a **dummy surface** at the primary mirror to use it for vignetting, and working

	Object space	EP		M_1 (stop)		M_2		Dummy		XP		Image space
R				-500		-125		∞				
t			$z_{EP} = 1$		-200 -1		200 1		= 1			
n	1										1	
$-\phi$				-0.004		0.016		0		0		
t/n			$\tau_{EP} =$		200		200		-247.619		297.625	
y				0				104		0		
CR			0.1		0.1		0.42		0.42			
nu												
u												
MR			$R_{EP} =$	1	-0.004	0.2	-0.0008	0.04	-0.0008	$R_{XP} = 0.2381$	-0.0008	0
y			0									
MR												
nu												
u												

Table 1: Raytrace, with CR=Chief ray, MR=Marginal ray.

From the marginal ray, we know that the effective focal length is:

$$f = -\frac{y_1}{\omega_k} = -\frac{1}{-0.0008} = 1250 \text{ mm.}$$

The working distance is the sum of the distance from the dummy surface to the exit pupil and the distance from the exit pupil to the image location:

$$\text{WD} = -247.619 + 297.625 \approx 50 \text{ mm.}$$

By looking the distance of the dummy to the exit pupil, we say that the exit pupil is located 247.619 mm to the left of the primary mirror. The diameter of the pupils are obtained through the f-number requirement.

$$f/\# = 4 = \frac{f}{D_{EP}} \longrightarrow D_{EP} = \frac{1250}{4} = 312.5 \text{ mm.}$$

Exercise 2

A relaxed eye means that the intermediate image must be at the front focal plane f_{EP} of the eyepiece so that the rays output parallel. The magnifying power is:

$$MP = \frac{250 \text{ mm}}{f_{EP}} = 10 \longrightarrow f_{EP} = 25 \text{ mm.}$$

- a) For a simple eyepiece, the f_{EP} corresponds to the front focal length of the eyepiece: $f_{eye} = f_{EP}$. Because the stop is 200 mm to the left of the intermediate image, which is 25 mm to the left of the eyepiece, the total distance from this lens is:

$$z = -200 - f_{eye} = -200 - 25 = -225 \text{ mm.}$$

Using the thin-lens equation, we find the distance of the object and therefore the eye relief:

$$\frac{1}{ER} = \frac{1}{z} + \frac{1}{f_{eye}} \longrightarrow ER = \frac{1}{\frac{1}{-225} + \frac{1}{25}} = 28.125 \text{ mm.}$$

- b) In the case of a compound eyepiece, the field lens is placed at one front focal length from the eye lens. This implies that only the rear principal plane and the ER change from the simple eyepiece discussed previously. It is shifted by the following amount:

$$d' = -\frac{\phi_F}{\phi_{EP}}t = -\frac{f_{eye}^2}{f_F} = -\frac{25^2}{40} = -15.625 \text{ mm.}$$

The eyerelief is then shifted by the same amount to the left:

$$ER = 28.125 - 15.625 = 12.5 \text{ mm.}$$

- c) In the Ramsden eyepiece, we need to have the same eye relief of part b) knowing that the field lens is located 12 mm to the right of the intermediate image plane. Recall also that we have to achieve the magnifying power and the image location, so we have three conditions to meet.

$$f_{EP} = 25 \text{ mm}, \quad d' = -\frac{\phi_F}{\phi_{eye}}t, \quad f_{EP} = 12 + d = 25 \text{ mm}, \quad \frac{1}{z'} = \frac{1}{z} + \frac{1}{f_{EP}}.$$

First, the focal length f_{EP} allows us to obtain the shift of the front principal plane:

$$f_{EP} = 12 + d = 25 \longrightarrow d = 13 \text{ mm.}$$

This shifting is equal to the ratio of powers, which enables us to solve for the power of the eye:

$$d = 13 = \frac{\phi_{eye}}{\phi_{EP}}t \longrightarrow \phi_{eye}t = \frac{d}{f_{EP}} = \frac{13}{25} = 0.52.$$

The distance of the stop to the front principal plane is:

$$z = -200 - 23 - d = -225 \text{ mm.}$$

Using the thin-lens equation:

$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f_{EP}} \longrightarrow z' = 28.215 \text{ mm.}$$

This distance is from the rear principal plane to the exit pupil so we can extract the shift d' :

$$ER - d' = 28.215 \rightarrow d' = -15.625 \text{ mm.}$$

We can relate it to the formula and get the term $\phi_F t$:

$$d' = -\frac{\phi_F}{\phi_{EP}} t \rightarrow \phi_F t = -\frac{d'}{f_{EP}} = 0.625.$$

Using the overall power multiplied by t allows us to get this distance,

$$\phi_{EP}t = \phi_F t + \phi_{eye}t - \phi_F \phi_{eye}t^2 = 0.625 + 0.52 - 0.625 \cdot 0.52 = 0.82.$$

Therefore,

$$t = \frac{0.82}{\phi_{EP}} = 0.82 f_{EP} \rightarrow t = 20.5 \text{ mm.}$$

With this distance, we now have the focal length of the eye and the field lens:

$$\begin{aligned}\phi_{eye} &= \frac{0.52}{20.5} = \frac{1}{f_{eye}} \rightarrow f_{eye} = 39.42 \text{ mm} \\ \phi_F &= \frac{0.625}{20.5} = \frac{1}{f_F} \rightarrow f_F = 32.8 \text{ mm.}\end{aligned}$$