NEW ANGLES ON AN OLD EYEPIECE

C.J.R. LORD D.Phil., B.Ed., F.R.A.S.

The Tolles eyepiece, a simple solid lens with convex surfaces nicknamed, "the poor man's Orthoscopic" is no longer made. It has no internal air space or embedded high index surfaces, there are no internal light losses other than absorption. A MgFl2 anti-refection coated BK7 Tolles would have a transmission factor over 98%. The field is also very dark because, having only a pair of air-glass surfaces there is only a single potential ghost. It is not a very comfortable eyepiece to use however, due to its ill defined field boundary. The field stop is an internal groove ground into its cylindrical body. The eye clearance is also zero.

As Tolles designed it $2r_1 = -3r_2$ & $t = \dfrac{(r_1 - r_2)\mu^2}{\mu^2 - 1}$

This gives $Fe = \dfrac{2r_1}{5}\dfrac{(\mu+1)}{\mu(\mu-1)}$

The field of full illumination is given by $\tan\dfrac{\theta}{2} = \dfrac{\left(0.4r_1 - \dfrac{Ep}{2}\right)}{Fe}$ which at f/10, and using BK7 is only 17º.6.

I wondered if there was a way round these limitations without adding any cemented elements; whether or not it was feasible to reduce the separation in order to give some workable eye clearance and a sharply defined field stop, together with a wider apparent field, without introducing unacceptable longitudinal or lateral chromatic aberrations.

The generalised propterties of a solid eyepiece may be described by considering the power of a thick lens.

LENS POWER: $F = \dfrac{1}{Fe}$ where Fe = ocular EFL

$$\therefore \quad F = \frac{\mu(\mu-1)(r_2 - r_1) + t(\mu-1)^2}{\mu r_1 r_2}$$

where t = axial separation of r_1 & r_2

$$\therefore \quad t = \frac{F\mu r_1 r_2 - \mu(\mu-1)(r_2 - r_1)}{\mu r_1 r_2}$$

& Putting $r_1 = -\sigma r_2$ we have $r_2 = -\dfrac{1}{\sigma} r_1$

$$\therefore \quad t = \frac{\mu(\mu-1)\left(1 + \dfrac{1}{\sigma}\right)r_1 - \dfrac{1}{\sigma}F\mu r_1}{(\mu-1)^2}$$

$$\& \ \tan\frac{\theta}{2} = \frac{1}{2}\left\{(\mu-1) - \frac{1}{F\, f/no}\right\}$$

$$\therefore \quad r_1 = \frac{\left(1+\frac{1}{\sigma}\right)\mu(\mu-1) \pm \sqrt{\left(\left(1+\frac{1}{\sigma}\right)\mu(\mu-1)\right)^2 - \frac{4}{\sigma}F\,\mu(\mu-1)^2 t}}{\frac{2}{\sigma}F\,\mu}$$

FROM FERMAT'S RULE FOR SPHERICAL ABERRATION:

$$\left(\left(1+\frac{1}{\sigma}\right)\mu(\mu-1)\right)^2 - \frac{4}{\sigma}F\,\mu(\mu-1)^2 t = 0$$

$$\therefore \quad t_s = \frac{\sigma\left(1+\frac{1}{\sigma}\right)^2 \mu}{4F}$$

STOP LOCATION FORWARD OF r_2:

$$d = \frac{\left(1+\frac{1}{\sigma}\right)^2}{2F}\frac{\left(\mu^3-\mu^2\right)}{\left(\mu^2-1\right)}$$

$$r_1 = \frac{(\sigma+1)(\mu-1)}{2F}$$

$$-r_2 = \frac{\left(1+\frac{1}{\sigma}\right)(\mu-1)}{2F}$$

& PUTTING $D_1 = r_1$:

$$\theta = \frac{6}{\pi}\sin^{-1}\frac{(\sigma+1)(\mu-1)}{4}$$

FOR LONGITUDINAL ACHROMATISM:

$$\frac{t_c}{t_s} = \frac{2\left(\mu^2-\mu\right)}{\left(\mu^2-1\right)} = 1.2 \text{ for BK7}$$

GENERALISED LOCATION OF STOP:

The maximum value of $\frac{d}{t_s}$ occurs when $r_1 = -r_2$, hence $\sigma = 1$ (given that $r_1 > -r_2$)

at which: $$\frac{d}{t_s} = \frac{2}{\mu\sigma}\frac{\left(\mu^3-\mu^2\right)}{\left(\mu^2-1\right)} = 1.3 \text{ for BK7}$$

hence when $\sigma = 1$ the focal plane lies $0.2Fe$ beyond r_1 and the eye point $0.2Fe$ behind r_2. When $d \geq t_s$ the eyepiece is positive and acts as a solid Ramsden, the turning point occuring where $\sigma = 1.2$ for BK7. The field stop will be clearly defined and free from colour fringing.

When $d \triangleright t_s$ the eyepiece is negative and acts as a solid Huyghenian.

In the special case where $\sigma = \mu$

$$t_s = \frac{(\mu+1)^2}{4F}$$

$$d = \frac{\left(1+\frac{1}{\mu}\right)^2}{2F}\frac{(\mu^3-\mu^2)}{(\mu^2-1)}$$

$$r_1 = \frac{(\mu^2-1)}{2F}$$

$$r_2 = \frac{\left(\frac{1}{\mu}-\mu\right)}{2F}$$

$$\theta = \frac{6}{\pi}\sin^{-1}\frac{(\mu^2-1)}{4}$$

$$\frac{d}{t_s} = 2\frac{(\mu-1)}{(\mu^2-1)} = 0.8 \ for\ BK7$$

hence when $\sigma = \mu$ the focal plane lies $0.2Fe$ behind r_1

David Greenwood made eyepieces in several focal lengths to the modified design from 7mm to 28mm. I calibrated their focal lengths using a Troughton & Simms divided lens dynameter, and tested them on my Quantum 6 f/15 Maksutov-Cassegrain.

The on-axis image of αCyg was exquisitely sharp. The field was ***very*** black, and there were no ghosts. A little light leaked into the fov when the star was immediately outside the field. There was a little blue fringing to the edge of the field, but on the telescope the field stop was in focus and there was no lateral colour. The only off-axis Seidel error present was coma, and at f/15 was barely noticeable across the 30º apparent field. There was a small but comfortable eye clearance of $\frac{1}{4}Fe$, enabling all the field to be seen without eye movement.

On Venus in a dark sky there was some flaring indicating the pair of internal reflections had been scattered off the external glass surfaces.

Detail on Saturn (ringless) was also exquisite, every delicate nuance being resolved. The satelltite images also appeared tack sharp.

Although the design lacks sufficient degrees of freedom necessary to correct astigmatism and lateral spherical aberration (coma), at f/15 these aberrations 15º off-axis were barely detectable. The critical focal ratio is f/10.