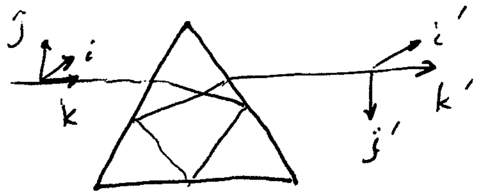
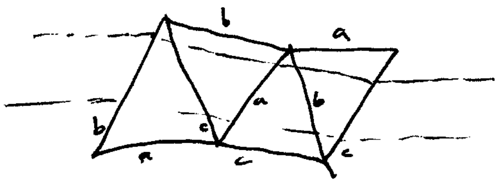
Introductory Optomechanical Engineering 421/521 – Fall 2007
Final Exam Open Book, open notes, 110 minutes.

Please provide a reference for anything that you look up.

1.) (5) For a Schmidt rotation prism made
  a) Sketch the prism
  b) Draw a tunnel diagram
  c) Write the mirror matrix





$$M = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

2.) (5) Consider using a grade 2 cap screw, ¼ inch.
  Compare UNC (standard coarse) and UNF (standard fine) .
  a) Give the number of threads per inch

UNC 1/4 - 20 20 threads/inch
UNF 1/4 - 28 28 threads/inch

  b) Give the suggested torque (lubricated of course and the ~~clamp~~ clamp load.

(p.14 18 Fasteners)

	clamp	torque
1/4 - 20	1320 lb	49 in·lb
1/4 - 28	1500 lb	56 in·lb

  c) Give the cross sectional area which is used for the stress calculations.

1/4 - 20 .0318 in²
1/4 - 28 .0364 in²

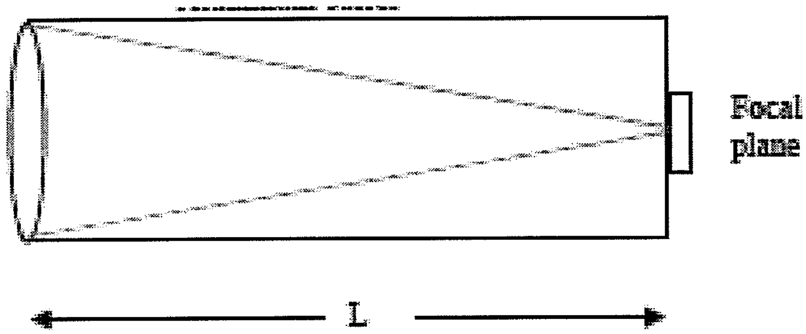
  d) Give the tensile strength **of the screw** (proof load) in pounds.

strength = 55 ksi · A

1/4 - 20 1749 lbs
1/4 - 28 2002 lbs

a. (10) Consider a 50 mm focal length lens and housing, both made from PMMA plastic. The aperture is 12.5 mm.

P. 45 Vuk.



PMMA

n_d 1.492

dn/dT −105 ppm/°C

α 60 ppm/°C

For 20°C temperature change, calculate:

a) change in focal length of the lens
b) change in length of the tube (lens to focal plane distance)
c) show the resulting optical effect of the focus from the combined effect of parts a) and b) assuming 0.5 μm wavelength light.

$$\phi = \frac{n-1}{R} \qquad \frac{d\phi}{\phi} = \frac{dn}{n-1} - \frac{dR}{R} \qquad \frac{d\phi}{\phi} = -\frac{df}{f}$$

$$\frac{1}{f}\frac{df}{dT} = \alpha - \frac{1}{n-1}\frac{dn}{dT}$$

$$= 60 - \frac{1}{.49}(-105) = 274 \text{ ppm/°C}$$

$\Delta T = 20°C$

$f = 50$ mm

a) $\Delta f = 50 \cdot 20 \cdot 274 \times 10^{-6}$

$= 0.27$ mm

b) $\Delta L = L \alpha \Delta T = 50 \cdot 60 \times 10^{-6} \cdot 20 = 0.06$ mm

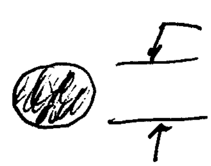
c) Defocus : $\Delta f - \Delta L = .27 - 0.06 = 0.21$ mm

f/4 : diffraction limit is $2\lambda f_{\#}^2 = 0.016$ mm

Geometric Limit

$210 \mu m / 4 = 53 \mu m$

PSF

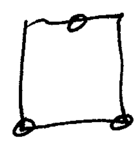


b. (10) Consider a square flat plano-plano fused silica mirror, 150 x 150 mm, 6 mm thick

a) For the case where the mirror is on its back (optical axis vertical), determine the self weight deflection when supported optimally by three points at the edge.
b) Find the optimal location for three support points on the back and calculate the self-weight induced figure errors for this case.
c) Describe the scaling law for deflection vs thickness for this case.
   (If the glass is 10% thicker, how much less is the deflection

Vuk. p 247 - 249

a.



$$\delta_{pp} = \frac{12}{\psi^2} \frac{\rho}{E} \left[\frac{a^4 (1-\nu^2)}{h^2} \right]$$

$$\psi = \frac{7 (a/b)}{\left[1 + (0.461\, a/b)^{13} \right]^{1/13}}$$

$E = 73$ GPa

$\rho = 2.2\ \mathrm{g/cm^3} \cdot 980\ \mathrm{cm/s^2}$

$\nu = 0.17$

$\rho = 22E3\ \frac{\mathrm{kg\,m}}{\mathrm{s^2}} \frac{1}{\mathrm{m^3}}$

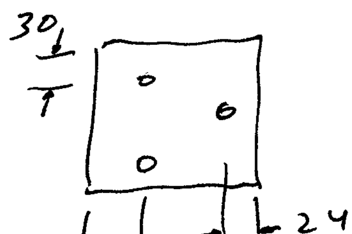
$a = .150$ m

$b = .150$ m

$\psi = 7$

$\delta_{pv} = 1\,\mu m$

b



from table on p. 249

this doesn't seem right

$$\delta_{pp} = \frac{1}{310} \left[\frac{13.25}{(b/a)^{11/3}} + 1 \right] \frac{\rho a^4}{E h^4} (1-\nu^2)$$

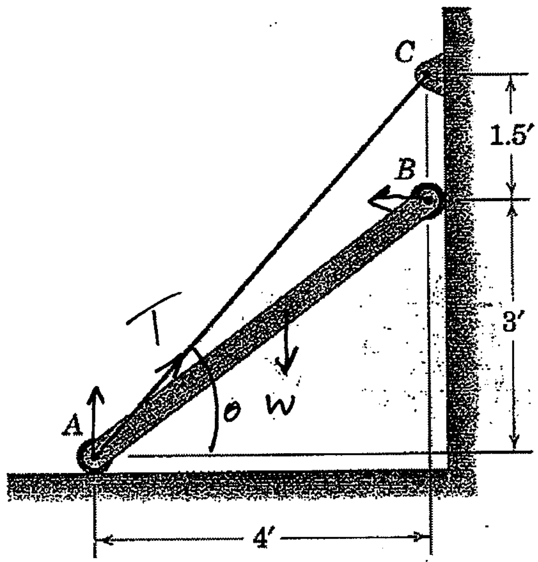
$= 0.19\,\mu m$

c) scales as h^{-2}

10% thicker, 20% less deflection.

5) (5) Static equilibrium.

The uniform bar with end rollers weighs 60 lb and is supported by the horizontal and vertical surfaces and by the wire AC. Calculate the tension T in the wire and the reactions against the rollers at A and at B.



$\theta = 48.4°$

$\sin\theta = \frac{4.5}{6.02} = 0.747$

$\cos\theta = 4/6.02 = 0.664$

$T_y = T \cdot 0.747$

$T_x = T \cdot 0.664$

$\Sigma M_A = 0 = W \cdot 2' - B \cdot 3'$

$W = 60$
$B = 40$ lbs

$\Sigma M_c = 0 = A \cdot 4' + B \cdot 1.5' - W \cdot 2'$

$A \cdot 4' = 60 \cdot 2 - 40 \cdot 1.5$

$A = 15$

$\Sigma F_x = 0 = B - T\cos\theta \quad \therefore \quad T = 60.2$

$A = 15$
$B = 40$
$T = 60$ lbs

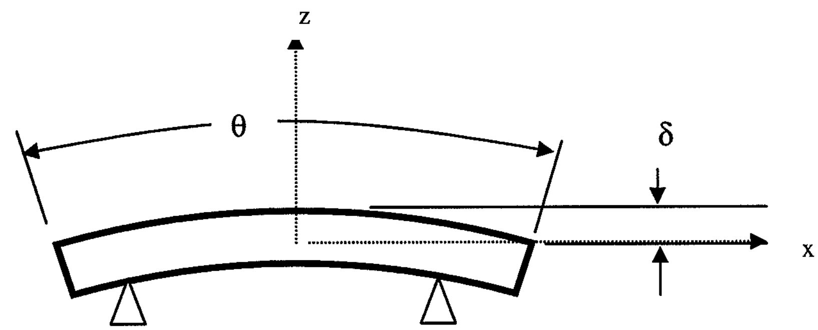
check $\Sigma F_y = 0 \quad A + T\sin\theta - W = 15 + 45 - 60$ ✓

7) (10) Describe a method for mounting three 25 mm diameter lens elements in a barrel, controlling tilt, decenter, and axial position to 50 μm accuracy.

1. Make lenses with tolerance ~ 25 μm
2. Make cell with tolerances ~ 25 μm
   define interface carefully
3. Assemble the parts.
4. System test

8) (10) Consider a 5 cm x 5 cm x 50 cm bar made from 304 stainless steel, simply supported. There is a heat source on the top which causes a uniform thermal gradient of 1° C from top to bottom. This gradient bends the bar in to a shape with constant curvature, expressed as $z = C x^2/2$ where C is the curvature.

a) Calculate the thermal power required to maintain this gradient
b) Calculate the angular change θ from one end of the bar to the other due to the thermal gradient.
c) Calculate δ, the total deflection as shown, due to the bending from the gradient.
d) The bar straightness could be maintained by applying a moment at each end. Calculate the value of this moment.



304 SS: $E = 193\ GPa$

$\alpha : 17\ ppm/°C$

$\lambda = 16\ W/m\cdot K$

$I = \frac{1}{12} b h^3 = 6.52E6\ mm^4$

a) $P = \lambda \frac{A\,\Delta T}{h} = \frac{16 \cdot (0.5 \times 0.05) \cdot 1°}{0.05} = 8$ Watts

b) $\Delta\theta = \frac{\alpha\, \Delta T\, l}{h} = \frac{17 \cdot 1 \cdot 50}{5} = 170\,\mu rad$

c) $z = C\frac{x^2}{2}$ $\theta = \frac{dz}{dx} = Cx$

$\Delta x = \cancel{25 cm}\ 50\ cm$

$\theta = 170\,\mu rad$

$C = 3.4\ \mu rad/cm$

$= 0.34 \times 10^{-6}\ mm^{-1}$

$z(x=25cm) = \frac{(3.4E\text{-}6\ cm^{-1})(25cm)^2}{2}$

$= 1063 \times 10^{-6}\ cm = 0.01\ mm$

d $\theta = \frac{ML}{EI} = 170\,\mu m = \frac{M\ 500\ mm}{193E3\ N/mm^2 \cdot 0.52E6\ mm^4}$ $M = 34\ N\cdot m$

6) (15) A 25 mm BK7 cube beamsplitter is bonded to aluminum with 100 μm thick 3M 2216 epoxy, The bond area is roughly rectangular 5x 10 mm

a) Calculate the shear strength of the bond. (The shear force in N required to fail the adhesive.)
b) Calculate the lateral (shear) stiffness of the bond. (The force in N per mm lateral displacement.)
c) Calculate the axial (compressive) stiffness of the bond. (The force in N per mm axial displacement.) Hint, consider use of the bulk modulus.
d) Calculate the stress in the bond for a 10°C change in temperature

$A \doteq 50 \text{ mm}^2$ 2216 $E = 690$ MPa

$G = 241$ MPa

$\Delta\alpha = 23 - 7 = 16$ ppm $\nu = 0.43$

a) for 2 ksi (14 MPa) strength

$14 \text{ MPa} \times 50 \text{ mm}^2 = 700 \text{ N}$ strength

b) $\Delta F / \Delta y = \frac{G \cdot A}{t} = \frac{241 \cdot 50}{0.1} = 120{,}000 \text{ N/mm}$

c) Bulk modulus $k = E / 3(1-2\nu) = 1640$ MPa

$\Delta F / \Delta z = \frac{E \cdot A}{t} = \frac{1640 \cdot 50}{0.1} = 820{,}000 \text{ N/mm}$

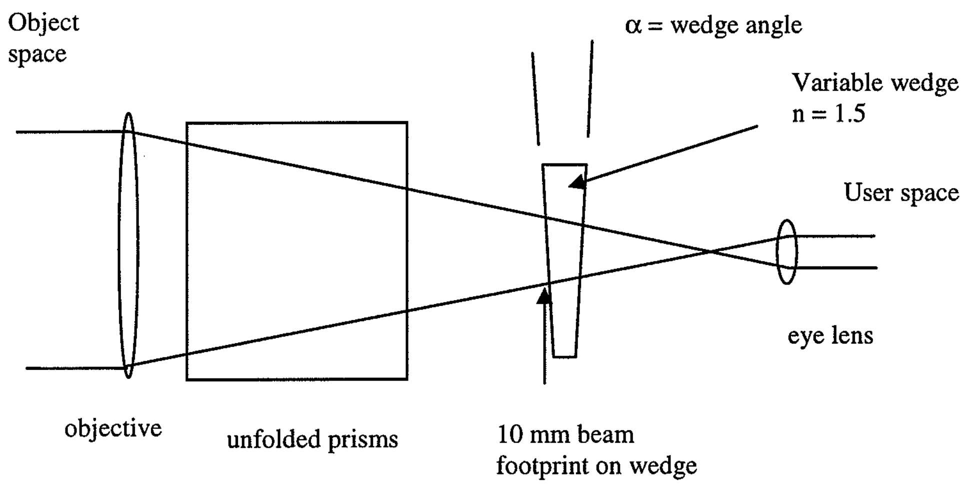
d) $\gamma = \frac{\ell}{2} \frac{\Delta\alpha \cdot \Delta T}{t} = 5 \text{ mm} \cdot 16 \cdot 10° = \frac{0.8 \mu m}{100 \mu m}$

γ ~~?~~ $\gamma = 0.008$

$\tau = G \cdot \gamma = 1.9$ MPa

9) (25) Canon sells binoculars that actively stabilize the image using a variable wedge. The angular accelerations are measured with sensors and a correction is applied by changing the wedge of a fluid filled cavity. For the case of 20 x 50 binoculars, calculate the wedge required to fully the effect of tilting the binoculars by 1 mrad.

a) Give the diameters of the entrance pupil, the exit pupil, and the magnifying power
b) If the binoculars are tilted by 1 mrad, how much motion does the user observe (hint: draw a sketch of this or you will probably get it wrong)
c) Give the general relationship for change in line of sight observed by the viewer as a function of
   - angular deviation due to change in an element
   - the beam diameter at the element
   - the exit pupil diameter
d) Show the relationship between a change in the wedge angle α and the deviation it causes in user space.
e) Calculate the required wedge to correct for the 1 mrad tilt of the binoculars

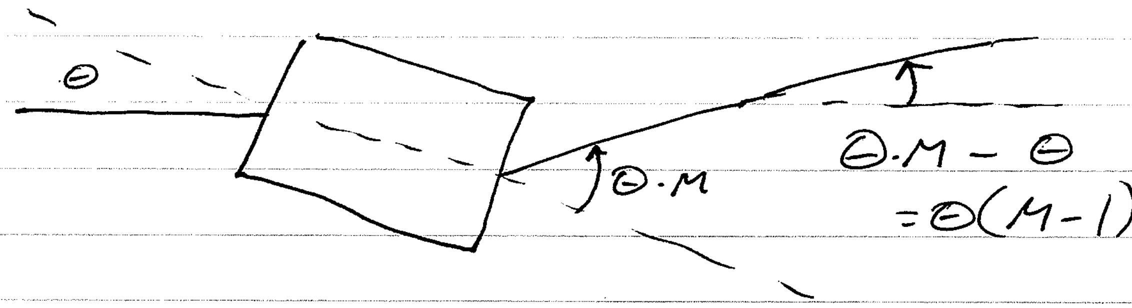


a) 20×50 $\quad MP = 20$

$EP = 50$ mm

$XP = 50/20 = 2.5$ mm

b)

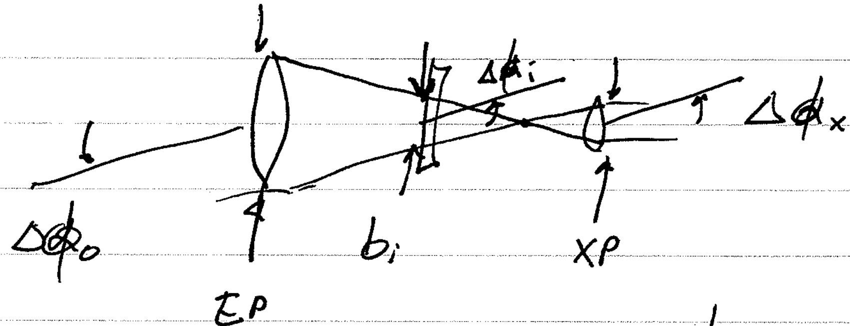


for $\Theta = 1$ mrad

$M = 20$

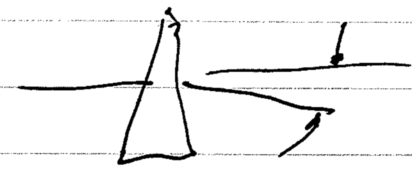
$\delta = 19$ mrad

c)



$$\Delta\phi_x = \frac{b_i}{XP} \cdot \Delta\alpha_i$$

$$\Delta\phi_o = \frac{b}{EP} \cdot \Delta\alpha_o$$

d) 

$$\Delta\phi = \alpha \cdot (n-1)$$

e) 1 mrad tilt moves LOS for user 19 mrad, correct with −19 mrad.

$$\Delta\phi_x = 19 \text{ mrad} = \frac{b_i}{XP} \cdot \alpha(n-1)$$

$$b_i = 10$$
$$XP = 2.5$$

$$\alpha = 19 \cdot \frac{2.5}{10} \frac{1}{0.5} = 9.5 \text{ mrad}$$