Name:____

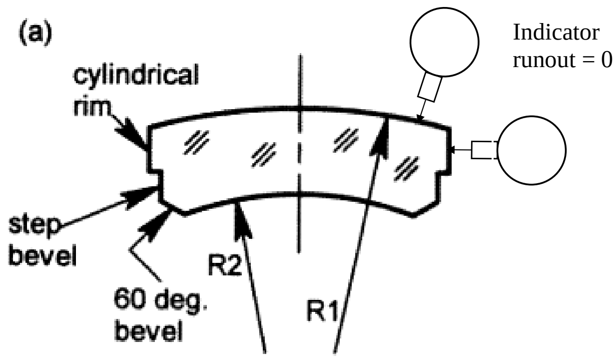
Introductory Optomechanical Engineering 421/521 – Fall 2015: Final Exam

One page of notes is allowed (single-side 8.5" x 11"). Some equations are provided. See page 12.
110 minutes.

1) Lens alignment (10)

Consider a 50 mm diameter meniscus BK7 lens with the following properties:

The lens is aligned in a centering station such that the cylindrical rim and the convex optical surface are aligned to the axis of rotation, showing no runout, as shown below:



R1 = 200 mm convex

R2 = 160 mm concave

Ct = 15 mm

But the light projected through the center of the lens wobbles by ± 1 mrad as the lens is rotated.

Calculate the wedge in the lens.

Make a sketch that shows the position of the center of curvature of each surface with respect to the rotation axis.

It is possible to compensate the lens wedge by decentering the element in its barrel. Use the geometry in your sketch to determine the amount of decenter required to fully compensate for the wedge in the lens.

2) Flexure stage design and analysis (10)

Sketch a design that uses two blade flexures to allow a small linear translation in the z direction, yet constrains all other degrees of freedom. On your sketch, define the x, y, and z axes and provide all important dimensions of the flexures. Use auxiliary views as necessary.

Provide the equations that would be used to determine k_x and k_y, the stiffness of the flexures against forces in **each of the two directions** perpendicular to the motion allowed by the flexure.

k_x : Description:

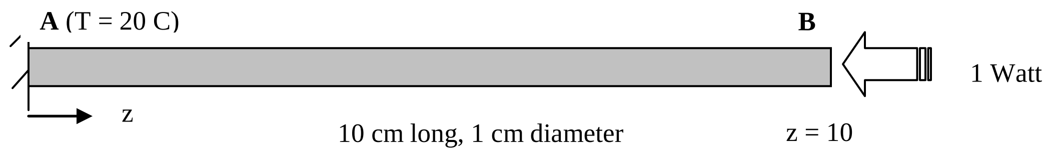
Equation:

k_y : Description:

Equation:

3) <u>Heat flux and thermal expansion (15)</u>

Consider a 1 cm diameter rod made of invar 36, heated from the end with 1 Watt of thermal power. (λ = 14 W/m-K for invar36)



Define z=0 at the cantilever interface, which is always maintained at 20 C. Provide a plot that shows the temperature profile from z = 0 to z = 10 cm as the rod conducts 1 Watt of power steady state.

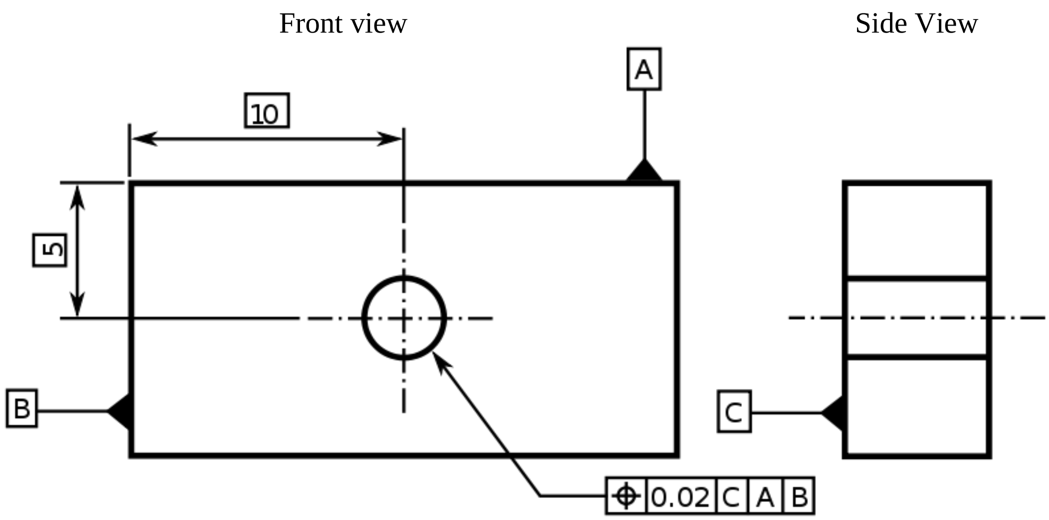
Compared to a 20 ° C isothermal state --
Determine the stress in the rod due to the thermal gradient.

Determine the shift of point B at the end of the rod due to this thermal gradient.

If a constraint is added so that point B cannot move as the thermal gradient is applied, determine the reaction force at A.

Determine the maximum stress in the rod for the case above with the overconstrained rod and the applied thermal gradient.

4) <u>Drawings (8)</u>



a) What does it mean for the dimensions 5 and 10 to be in a box as shown?

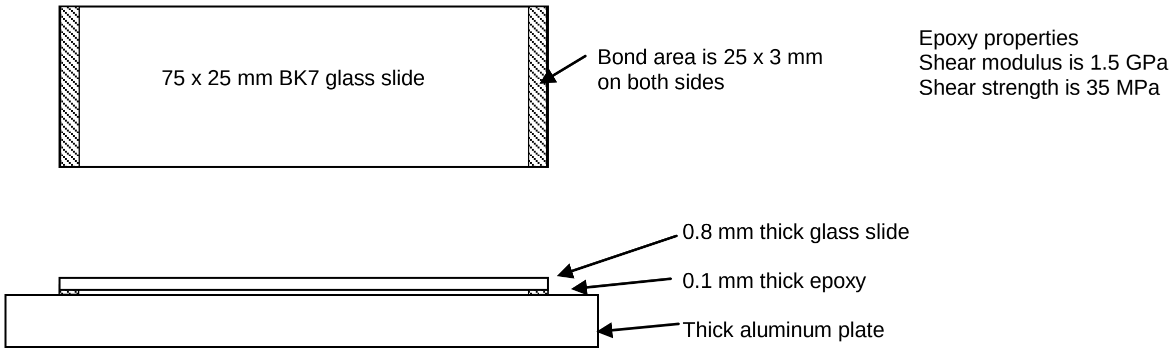
b) Explain the meaning of all parts of the control frame defining the hole in the drawing below (units are inches).

c) On the drawing, show correctly how to specify the front surface to be perpendicular to A and B to within 0.1 mrad and flat to 0.0001"

d) Find one mistake in this drawing

5) Optical mount (12)

A 75 x 25 x 0.8 mm BK7 microscope slide is bonded to an aluminum plate using an epoxy as shown. When observing specimens on this slide, we observe that focus changes with temperature due to bending of the slide. If the system is cooled 1° C, determine the **amount** and **direction** of the focus change.

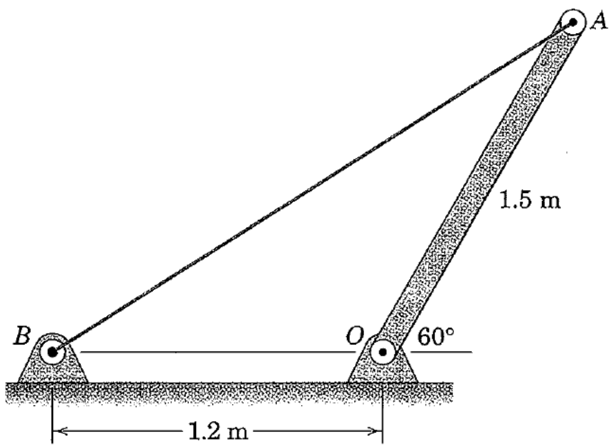


You can follow these easy steps

a) Using the CTE of aluminum and BK7, determine the change in dimension for a 1° C change
b) Calculate the bond stiffness in shear and the axial stiffness of the glass slide
c) If either compliance dominates, you can ignore compliance of the other. Otherwise use superposition. Determine the net force in the bond, normal strain in the glass slide, and shear strain in the bond.
d) Determine the moment applied about the neutral axis of the glass slide, caused by the shear force.
e) Treat the slide as a beam and calculate the resulting curvature due to the moment. Use this to determine the motion at the center.

6) <u>Statics (5)</u>

The uniform 18-kg bar OA is held in the position shown by the smooth pin at O and the cable AB. Determine the tension T in the cable and the magnitude and direction of the external pin reaction at O.



7) <u>Stages (5)</u>

In the design of linear stages, we strive to minimize the Abbe offset error. Make a sketch that defines the Abbe offset and show how it can affect performance of a linear stage.

8) Engineering mechanics (10)

Starting from first principles, derive the twist angle θ for a thin walled tube as a torque T is applied about the tube axis at one end while the other end is constrained.

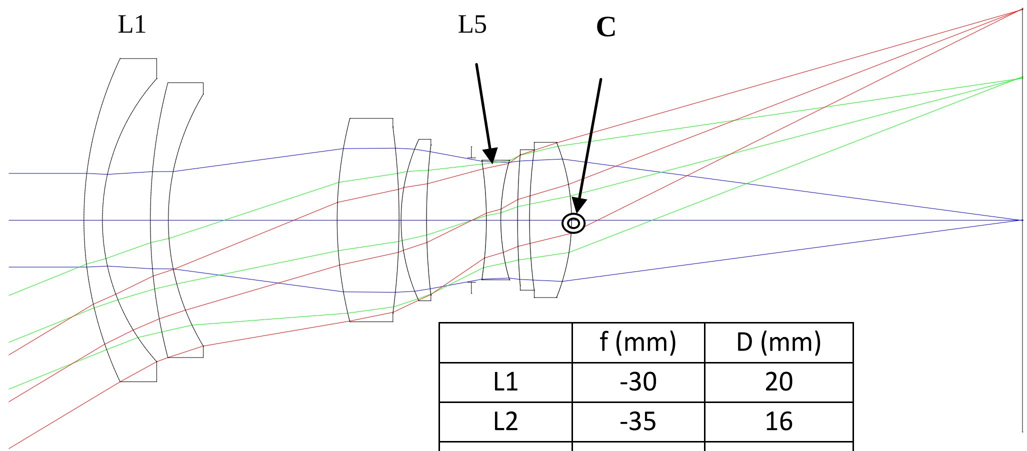
Use the following definitions:

Tube diameter = 2 r,
wall thickness = t,
length = L

Make a clear sketch, state all assumptions and show all steps.

9) <u>Line of sight (7)</u>

Consider the following objective lens. The system has 5 mm entrance pupil diameter and 25 mm EFL, 35 mm BFD (Back Focal Distance), and ± 31° FOV. The diameter and focal length of each lens element are provided.

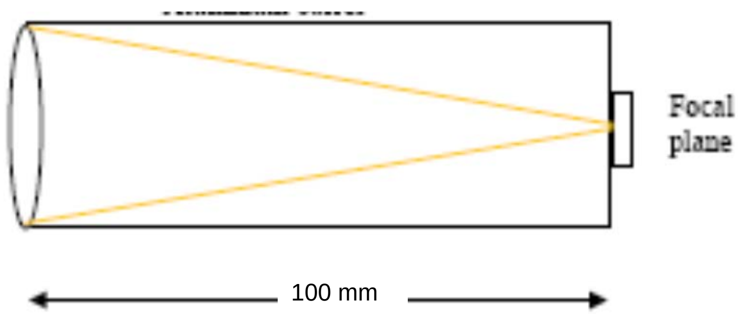


	f (mm)	D (mm)
L1	-30	20
L2	-35	16
L3	28	11
L4	28	9
L5	-12	6
L6	20	8

Calculate the image motion for 1 µm decenter of L1.

10) Change in focus with temperature (10)

Consider a 100 mm focal length lens made from BK7 and support tube made from aluminum. The aperture is 25 mm.



For 20°C temperature change, determine the change in focus in mm.

11) Resonant frequency (8)

A 100 lb weight hangs at the end of a 100 inch long, 0.2 in diameter steel cable

a) Determine the natural resonant frequency of the mass in the vertical, “bounce” mode

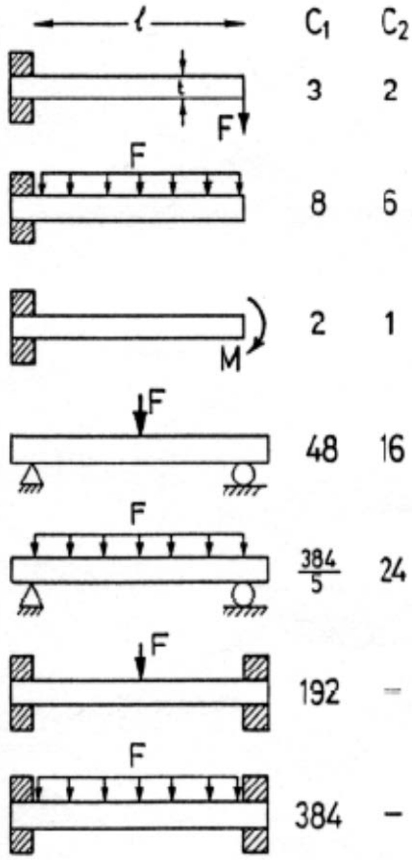
b) Determine the resonant frequency of the mass in the lateral, “swing” mode

Extra page

Useful expressions and data

$$\delta_{\max} = C_D \left(\frac{\rho}{E}\right)\left(\frac{r}{h}\right)^2 r^2 \left(1-\upsilon^2\right)$$

SUPPORT CONDITION	C_D
Ring at 68% of diameter	0.028
6 points equal-spaced at 68.1% of diameter	0.041
Edge clamped	0.187
3 points equal-spaced at 64.5% of diameter	0.316
3 points equal-spaced at 66.7% of diameter	0.323
3 points equal-spaced at 70.7% of diameter	0.359
Edge simply supported	0.828
Continuous support along diameter	0.943
"Central support" (mushroom or stalk mount)	1.206
3 points equal-spaced at edge	1.356



$$\delta = \frac{F\ell^3}{C_1 E I} = \frac{M\ell^2}{C_1 E I}$$

$$\theta = \frac{F\ell^2}{C_2 E I} = \frac{M\ell}{C_2 E I}$$

E : YOUNGS MODULUS (N/m^2)

δ : DEFLECTION (m)

F : FORCE (N)

M : MOMENT (N m)

ℓ : LENGTH (m)

b : WIDTH (m)

t : DEPTH (m)

θ : END SLOPE (-)

I : SEE TABLE 2 (m^4)

$$I = \frac{1}{12} b h^3$$

$$D = \frac{Et^3}{12(1-\nu^2)}$$

$$G = \frac{E}{2(1+\nu)}$$

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

$$T = \frac{\text{isolated motion}}{\text{base motion}} = \frac{x}{u} = \sqrt{\frac{1+\left(2\frac{\omega}{\omega_n}C_R\right)^2}{\left(1-\frac{\omega^2}{\omega_n^2}\right)^2+\left(2\frac{\omega}{\omega_n}C_R\right)^2}}$$

$$a_{rms} = \sqrt{\frac{\pi}{2} f_n \cdot Q \cdot PSD_{ISO}}$$