

• = Nick's comments

1. State the problem to be solved, what else exists, and why you think you should design a new machine (even if just for fun). (1 pt)

Load locks are used in semiconductor processing equipment to facilitate the transfer of wafers to and from the equipment while maintaining a vacuum-pressure environment (this minimizes the risk of contamination and reduces process time by avoiding excess chamber pump-downs). The actual transfer of wafers from the load lock to the equipment (and vice versa) is typically accomplished using linear motion feedthroughs, rotating and/or telescoping arms, or simple leadscrew mechanisms. These are fine choices for the standard equipment of today, which is very large. However, when space is at a premium (as it is in the small equipment built for the 1" Fab) these mechanisms become problematic. Linear motion feedthroughs require at least 2x the length of actuation along the actuation axis and have limited load-handling capability. Arms require significant space in the lateral (transverse) direction. Single leadscrew mechanisms can only provide limited translation length.

Good description of problem

could add a sketch?

In a small-scale deep reactive ion etching system we are currently developing in our lab, we currently employ a linear motion vacuum feedthrough with a travel of ~15in (380mm) to transfer our wafers (*which reside on cylindrical wafer carriers with a diameter of 2.5in (64mm) and height of 0.5in (13mm)*) from our load lock to the processing chamber. Since it is a simple single shaft-based feedthrough, when the feedthrough is in the retracted position (which is most of the time), it adds ~15in (380mm) to the length of our system, which is only ~24in (610mm) long to start. This addition to the system footprint is non-ideal, and we would like to eliminate it by developing a transfer mechanism that can reside totally in the load lock (thus adding no length to the system).

2. State the Functional Requirements and specifications for your machine, with the understanding that other than three stepper motors and the Arduino control board and stepper motor drivers, each student has to scrounge up their own materials. (1 pt)

a. Remember to also consider important details

- i. Safety is a critical part of design to be considered from the beginning!
- ii. Seals, bellows, wires, cutting chips, fixturing...

1. The entire (retracted) mechanism must fit inside of the current load lock. The available space is basically the bottom half (in Z) of a cylinder with a diameter (spanning the Y-Z plane) of 3in (76mm) and a length (X-axis) of ~4.5in (115mm).
2. When retracted, the middle of the wafer carrier must sit at or behind the carrier load/unload door (which is at least 3in (76mm) from the gate valve door).
3. When extended, the middle of the wafer carrier must be able to reach the middle of the chuck assembly (which is 10in (254mm) away from the middle of the carrier load/unload door).
4. The entire transfer mechanism will reside in a vacuum environment, and so it must be made entirely from vacuum-friendly (i.e. low out-gassing and for this type of etcher, fluorine-compatible) materials. This means mostly stainless steel and/or aluminum.
5. ...

Accuracy?
cost?

2/20

3. Embody the FRs in a FRDPARRC table for your machine (where a lot of the entries of course will be blank, but as your design progresses you can fill them in). (1 pt).

See FRDPARRC table at end of document.

4. What are the forces the machine has to withstand? (1 pt)
 a. If a cutting machine, think of the power of a similar machine, the speed of the spindle, and diameter of the tool to estimate forces...

Form: Force cause (force direction)

Weight of the carrier and extended arm (-z-axis): Assuming a solid block of stainless steel (density 8000kg/m^3) with dimensions 2.5in wide x 0.5in tall x 6in long (extended length), this is a weight of $\sim 1\text{kg}$, so a worst case (all the weight at the very end) scenario of $\sim 10\text{N}$ in the -z direction.

Chucking/clamping force (+/- y-axis): This is the force exerted on the extended arm when the wafer carrier is attached or detached from the chuck assembly. The attaching process requires rotating the chuck assembly clockwise $\sim 30^\circ$, which I would guess takes about $< 3\text{N}$ of force (the rotation seals the bottom of the wafer carrier against an O-ring on the top of the chuck assembly, so there is definitely a frictional force to overcome). The attaching force is in the -y direction, and the detaching force is the +y direction.

Load/unload into/from load lock (+/- y-axis): This is the force exerted on the retracted transfer mechanism when the wafer carrier is loaded or unloaded from the load lock. Currently this is a pretty low force (probably $< 2\text{N}$) operation, and since it will occur on the retracted mechanism, which will presumably be much stiffer than the extended mechanism, it is not really that important (compared to the chucking/clamping force).

Sudden vacuum loss (+z-axis or -x-axis): If there is a sudden loss of vacuum coming from the chamber (resulting in a force in the -x direction) or the load lock pump (+z-axis force), the transfer mechanism needs to be able to handle this. Fortunately, the two possible forces should be in some of the stiffer axes of the mechanism. A full vacuum loss produces $\sim 100,000\text{N/m}^2$ of force, so taking rough dimensions of 2.5in x 0.5in looking into the -x direction and an area of 2.5in x 2.5in in the +z direction, we get a possible force of $\sim 80\text{N}$ in the -x direction and $\sim 400\text{N}$ in the +z direction. The mechanism will be solidly fixtured to the load lock, so the +z force can likely be ignored, leaving the -x force as the potential point of concern.

5. Given the desired accuracy of the machine, what is the required stiffness? (1 pt)

Desired accuracy: 0.5-1mm (x-axis), 0.5mm (y-axis), 1mm (z-axis, droop)

Needed stiffness (x-axis): $(80\text{N}/0.5\text{mm}) * (2x \text{ safety factor}) = 320,000\text{N/m}$

Needed stiffness (y-axis): $(3\text{N}/0.5\text{mm}) * (2x \text{ safety factor}) = 12,000\text{N/m}$

Needed stiffness (z-axis): $(80\text{N}/1\text{mm}) * (2x \text{ safety factor}) = 20,000\text{N/m}$

6. Assume the structural loop length of your machine is three times the sum of the distances each axis must travel, to get a feel for the structural loop: (2 pts)

maybe do distributed source calculations?

you are really building a 2-axis machine - one linear axis + one rotation

later, might want to check buckling

there is no force in this direction so will only depend on fabrication?

This is actuated by hand

what is an appropriate safety factor? (I don't know)

a. What is the size of a cantilever beam (tube cross section) whose length is the length of the structural loop?

- i. State your assumptions on proportions.
- ii. Assume tube outer dimension is 1/5 the length, and wall thickness 1/20 the diameter.

For my proposed linear actuator, a total travel of 10 inches (~250mm) is needed. A cantilever beam analog would then have a length of 750mm, an OD of 150mm, and an ID of 135mm. This beam has a stiffness of **0.000972(E)**N/m (so **6.70x10⁷**N/m for 6061 aluminum and **1.94x10⁸**N/m for 304 stainless steel), so it would deflect **~1.2μm** (for 6061 aluminum) if subjected to a force of **80N** (the maximum expected force for the application).

b. What is the size of a C-shaped (curved beam 180 degree segment) (tube cross section) whose length is the length of the structural loop?

- i. State your assumptions on proportions.
- ii. Assume tube outer dimension is 1/5 the length, and wall thickness 1/20 the diameter.

For my ~250mm actuator, a C-shaped cantilever of length of 750mm, an OD of 150mm, and an ID of 135mm. This C-beam has a stiffness of **0.00153 (E)**N/m (so **1.05x10⁸**N/m for 6061 aluminum and **3.05x10⁸**N/m for 304 stainless steel), so it would deflect **~0.8μm** (for 6061 aluminum) if subjected to a force of **80N** (the maximum expected force for the application).

If the mass of the machine is **N** x the mass of the tube, what is a first order estimate of the natural frequency of your machine as a function of **N** (plot it).

Using the formula ($f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$) for natural frequency, I get a natural frequency of $\sim \frac{500}{\sqrt{N}}$ Hz for the straight beam and $\sim \frac{620}{\sqrt{N}}$ Hz. The plot is below.

PLOT

I assumed this was a separate question? Since (ii) then gives you the proportions to assume.

For your project, does it make sense to consider a C-shaped machine at all? ditto

Problem 6

Part A (cantilever beam, simply supported, force on end)

$$k=3EI/L^3$$

Thing

		6061 Alumin	304 Stainless Steel
Elastic Modulus	E	6.89E+10	2E+11 N/m ²
Tube OD	r2	0.15	0.15 m
Tube ID	r1	0.135	0.135 m
Wall Thickness	t	0.0075	0.0075 m
Moment of Inertia	I	0.00013674	0.00013674 m ⁴
Length	L	0.75	0.75 m

Modulus-independent

Stiffness

k	66995214.2	194470868 N/m
k	66.9952142	194.470868 N/um

0.000972

Force Applied

P	80	80 N
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Deflection

δ	1.1941E-06	4.1137E-07 m
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Mass density

ρ	2700	8000 kg/m ³
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Resonant Frequency

f	499.593187	494.491446 Hz
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spring estimation

Resonant Frequency

f	58.7581801	58.1581538 Hz
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alternate definition (ca

Part B (C-shaped beam)

$$k=2EI/\pi \cdot R^2$$

<http://www>

Thing

		6061 Alumin	304 Stainless Steel
Elastic Modulus	E	6.89E+10	2E+11 N/m ²
Tube OD	r2	0.15	0.15 m
Tube ID	r1	0.135	0.135 m
Wall Thickness	t	0.0075	0.0075 m
C Radius	R	0.23873241	0.23873241 m
Moment of Inertia	I	0.00013674	0.00013674 m ⁴
Length	L	0.75	0.75 m

Modulus-independent

Stiffness

k	105235836	305474126 N/m
k	105.235836	305.474126 N/um

0.001527

Force Applied

P	80	80 N
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Deflection

δ	7.602E-07	2.6189E-07 m
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Mass density

ρ	2700	8000 kg/m ³
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Resonant Frequency

f	626.147205	619.75312 Hz
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spring estimation

Resonant Frequency

f	58.7581801	58.1581538 Hz
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alternate definition (ca

7. Sketch stick figures for different strategies you now envision for solving the problem. (1 pt)
- Use the basic starting FRDPARRC and enter more detail for each strategy

To be added

- Apply Error Apportionment for different strategies

See spreadsheet 1

8. Create geometric error budgets for "top" strategies. (2 pts)

See spreadsheet 2 (very simple though....)

Ly shall be made this 2-20-17

