

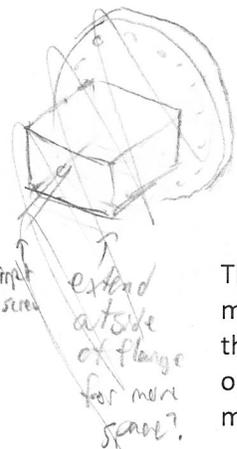
Disclosure: In this PUPS assignment, I am only documenting a single "concept" for my project. This is primarily because my application has a fair amount of non-standard constraints insofar as its operating envelope, and despite a good deal of thought and exploration I've really only been able to come up with one reasonable way to do it that meets all of these constraints. That being said, I do think that this idea is a pretty solid one. Of course, I would be quite excited to hear any clever alternative ideas or suggestions you have.

1. Create several concept sketches for your design that include the structure, bearings, and carriage for one simple "precision" linear motion axis of your design (make sure to leave room for the actuator!) (2 pts):

- a. Label the sensitive directions!
- b. Assign coordinate systems (label), which will be used for error budgeting.

In the past few weeks I've spent a good deal of time determining the exact constraints (functional requirements) for the telescoping sample transfer mechanism I am hoping to build for my class project. The most important of these requirements (which will be re-represented in the FRDPARRC later on) are below:

- Compatible with and operates well in a low-to-medium vacuum environment (pressures as low as 10^{-4} torr (0.0133 Pa))
- Able to interface with / attach to a silicon wafer or wafer carrier ≤ 2.5 inches (mm) in diameter
- Collapsible to a length of < 3 inches (76.2mm), *excluding any wafer attachments.*
- Able to provide a stroke length (extended length minus collapsed length) of > 10 inches (254mm)
- Fully actuatable from outside the vacuum chamber (thus allows both manual and motorized control)
- Mountable entirely on a CF4.5" vacuum flange (or a comparably sized flange, e.g. an ISO-F 63 flange). *This is so it can be modularly mounted onto any system, rather than having to modify an existing part.*
- Cost $< \$500$. *If I can't do it for less than \$500, it's not going to be viable for our full system, which itself has a functional requirement of being ultra-low cost.*

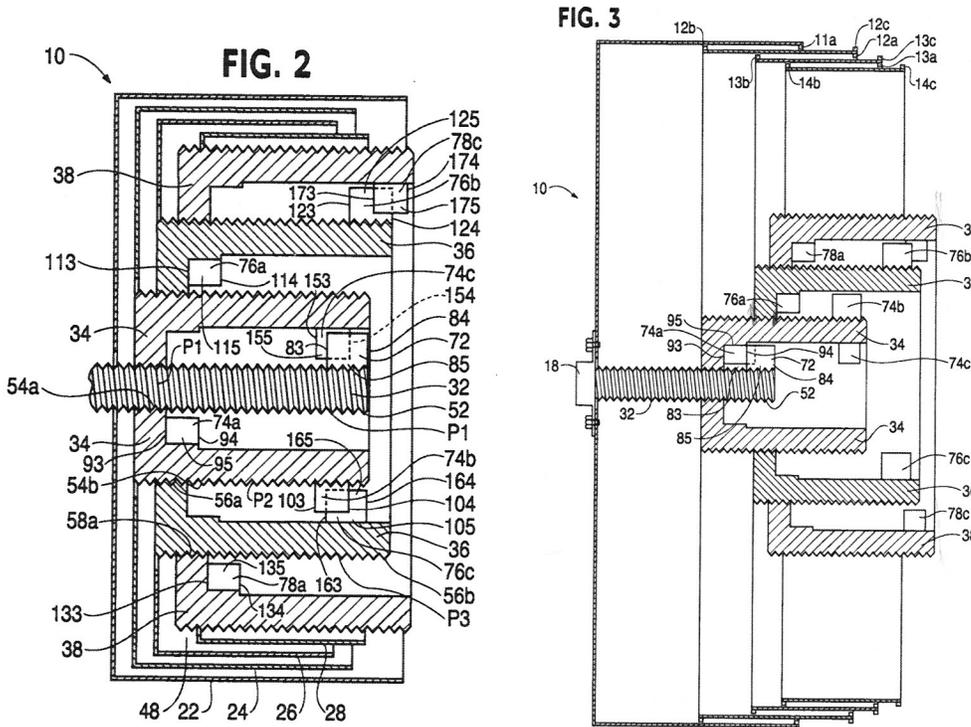


These are all constraints / FRs that have nothing to do with the physical "performance" of the mechanism (e.g. stiffness, accuracy, precision, etc.). Fortunately, the performance requirements for the mechanism are not that stringent, as it will only encounter very small loads during normal operation. The real challenge has lain in coming up with a telescoping actuation mechanism that meets all of the non-performance requirements listed.

Two of the ideas that have been shelved are belt or pulley-based extension lifts, and telescoping pneumatic actuation. Belt or pulley-based extension lifts have material vacuum compatibility issues, and with the number of stages required to achieve the collapsed length and stroke length requirements, the overall width of the mechanism will likely exceed the space available inside the load lock. A telescopic pneumatic system is inherently risky due to the vacuum environment, and it would rely on dynamic o-ring/gasket seals, which are something I try to avoid wherever possible (and especially in a vacuum). Such a system also eliminates the possibility for manual control, which is still very much desired for our not-yet-100%-reliable semiconductor fabrication tools.

*list for those unfamiliar
→ fluorous sensitive
-particle generating*

The basis for the idea shown in the sketches below came from the [US Patent 7225694B2](#), which has since lapsed. The screw-based telescopic actuator shown in this patent is fixed at one end (the larger diameter segments in the patent drawings) and driven from the opposite end (to prevent the whole thing from just spinning). Two of the patent figures are included below, which show the general idea behind the actuator.



For my actuator, I have modified this design to be driven and fixed on the same side (because of the functional requirement for the actuator to be mountable on a single vacuum flange). I have also decided to drive the largest diameter threaded segment (as opposed to the smallest one, as shown in Figs. 1, 3, and 4 of the patent drawings) to maximize the stiffness of the actuator.

Driving and fixing the actuator at the same end does (re)introduce the problem of the whole actuator just spinning (rather than extending or collapsing by threading or unthreading) when the driving thread segment is rotated, so my design also includes 2 telescoping support beams that will prevent the final (smallest) segment from spinning. This certainly adds some complexity to the design (and some questions of rotational and torsional stiffness), but due to the mountable on a single flange functional requirement, it seems to be the only real way to do it (as far as I can tell from my thinking so far).

while only 1 axis, this is becoming a very challenging packaging/rigidity/machining problem

c. Assess Risks and Countermeasures

See answer to question 5

2. Allocate allowable errors (feel free to use *Axis_error_apportionment_estimator.xls*) for each axis and components of your envisioned machines (2 pts).

See "Gould_PUPS_5_Error_Apportionment.xlsx"

3. Pick at least two concepts for further exploration (2 pts):

a. FRDPARRC table for each concept

See FRDPARRC table at the end of this document (and in "Gould_PUPS_5_FRDPARRC.xlsx").

b. Label the sensitive directions and coordinate systems used for error budgeting!

See the drawings above.

c. Create sketch models (wood, cardboard, Legos™) for at least two of your concepts

Pics / SolidWorks models of initial actuators.

4. Create first order error budgets for your favorite design(s) (just like you did in PUPs 3) (2 pts):

a. From the error apportionment, assign errors to structure, bearings...

- i. From the stiffness estimates obtained in PUPs 2, assume a distribution of stiffness between axes and bearings... (play, explore... use spreadsheet to test ideas and assumptions).**

See "Gould_PUPS_5_Error_Budgets.xlsx" (which includes some drawings)

b. As a result of building the error budget for each concept and wiggling values to see the effects on performance, try to pick the "best" concept you want to move forward with, or if needed its OK to take more time).

Until a better alternative comes around (*not to imply that I'm dissatisfied with my design, but rather that I believe a better idea may be out there*), I am going with the idea described in this PUPS.

5. Assess Risks and Countermeasures and use to evolve designs and trim options to help converge on a design: (2 pt)

a. Risks include:

- i. Safety review: pinch points, cutters, impacts, tipping, electrical shock...**
- ii. Wiring (cable tracks, isolation power and signal...)**
- iii. Seals, bellows... (survival of the machine in use)**
- iv. Coolant delivery and containment (if needed)**
- v. Chip handling**
- vi. Ergonomics (does it look good? Will people want to use it?)**

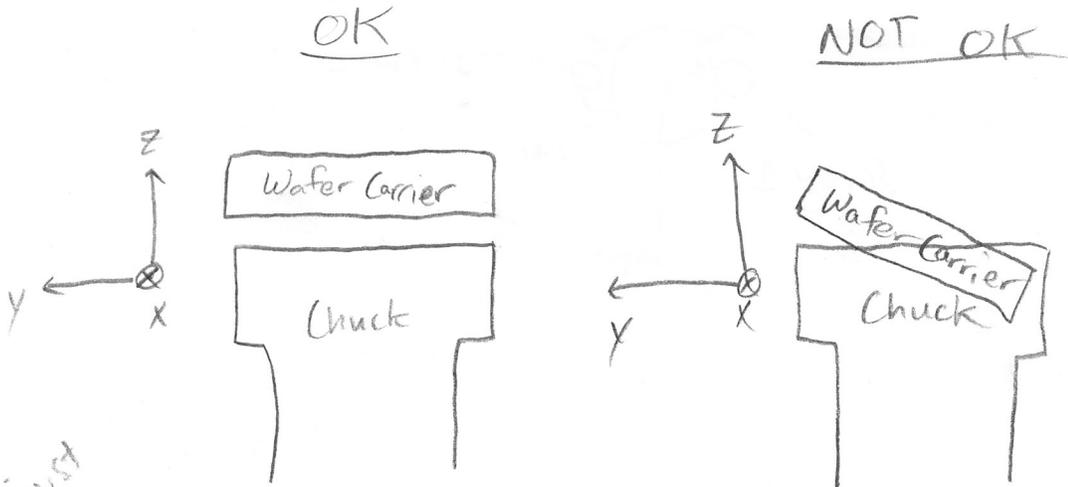
haha
Fortunately, the vacuum requirement of my system (and it's lack of a cutting element) eliminates many of the risk categories above. However, there are a variety of other risks to consider because of that very same vacuum requirement. The first of these is the risk of galling in the screw-based actuator. There are a few anti-galling compounds that are "vacuum-compatible" (i.e. low-outgassing)¹, but most of these are not explicitly compatible with the chemistry used in our current tools (particularly fluorine). While the transfer system will never be in the main vacuum chamber while a process is running, it is still reasonable to believe that trace amounts of fluorine or other halogens or halides will still remain in the chamber during sample loading and unloading. One way to avoid galling without lubricants is by silver-plating the threads. This however is quite costly, especially if you have to send the parts out to a third-party plating vendor. Another potential way to

¹ <http://www.swagelok.com/downloads/WebCatalogs/en/MSDS-VACGOOP.PDF>

avoid galling is by using different materials (or in some cases just different alloys) for the male and female threads. Typically, two materials with an appreciable difference in hardness will be reasonably resistant to galling.

The second significant risk due to the vacuum requirement is particle generation from the screw threads. Any particulate matter in the main vacuum chamber or load lock could make its way into the vacuum pump, or become a contaminant for the processing environment. One simple way to avoid a good fraction of these particle would be to cover the screw thread with some sort of wrapper / seal, but care must be taken when doing this so as to not generate a trapped volume of gas (which could then act as a virtual leak to the vacuum system). *Bellows with a few holes*

Another of the more significant risks to the system is whether the telescoping support rods can actually prevent the roll rotation from the screw action of the telescoping actuator. The placement of these rods, their relative stiffness, their connection between each other, and their connection to the last stage of the actuator (which will be connected to the wafer holding fixture) will all be important in making sure that the wafer can stay horizontal during the load and unload procedures. Fortunately, (and this isn't so much of a countermeasure as just a feature of the design) the roll rotation is only induced while the screws are being rotated (i.e. while extending or collapsing). During the loading and unloading procedures (both in the load lock and the processing chamber), the actuator is static, and so there should be no roll rotation. However, there are still geometric restraints (particularly in the processing chamber) that require that the wafer or wafer carrier remain substantially horizontal during the loading process. The drawing below helps illustrate this.



The final risk that exists for this design is the sag (negative z-axis) that will undoubtedly exist to some degree from the gaps between the screw threads on each threaded stage. These gaps will cause Abbe errors at each junction, and could lead to a wafer or wafer carrier angle at the fully extended length that is incompatible with the loading or unloading process from the chuck assembly in the main processing chamber. The ideal countermeasure for this risk is keeping very tight tolerances on the screw threads and/or the "stop rings", but if this becomes unreasonable, the overlap length for each segment will need to be increased as a countermeasure.

Arrange this in tabular form?

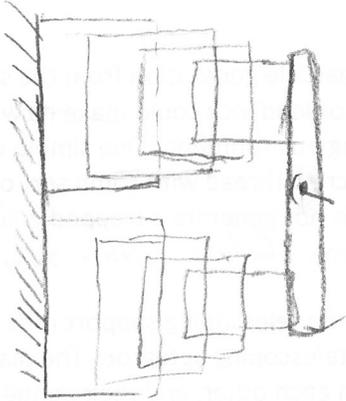
SEE BACK FOR
NEW CONCEPT
SKETCH

Design risks

- Friction + efficiency → first order power calc?
- classes of fit in the threads
↳ preload them somehow?
- telescoping beams are supposed to be used solely in an axial mode (you need to have them in bending in your design)

if you just characterize the abbe errors super well & it's repeatable, this might not be such a con.

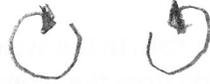
same screw mechanism as depicted earlier



→ one right hand threaded

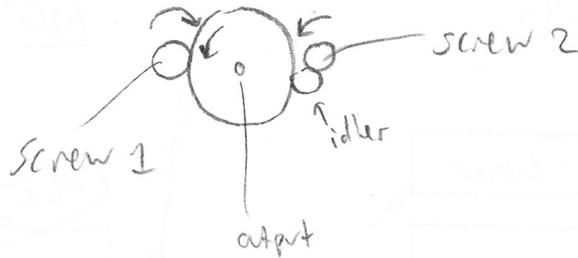
→ one left hand threaded

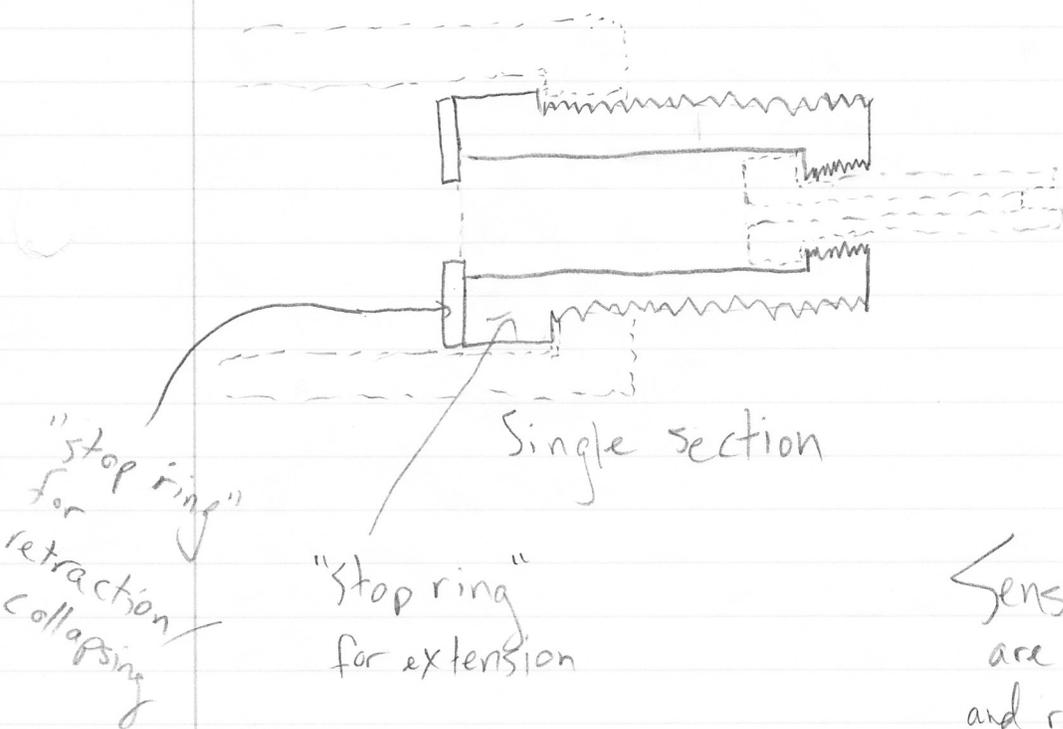
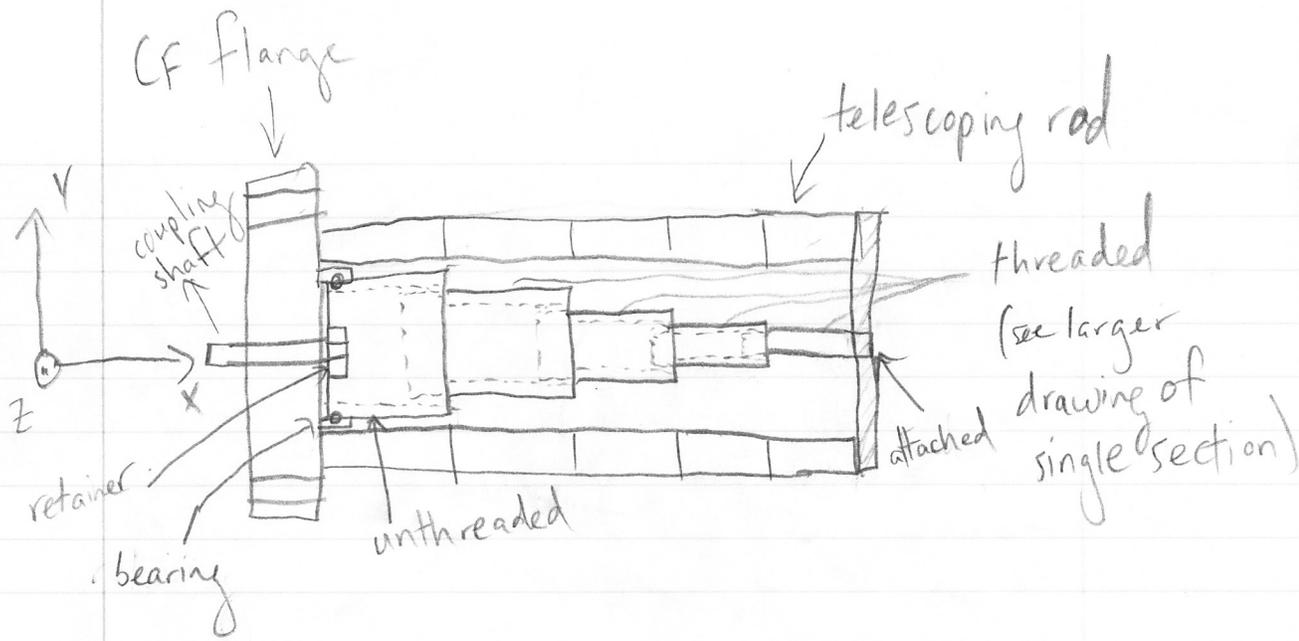
actuator plate



moments will cancel each other, actuator plate will move without pitching

can join two actuators with gears arrangement so powered by one actuator





Sensitive directions are the z-axis and roll about the x-axis

4 sections, 30% efficiency/section
 $= 0.3^4 ?$