Telescoping Wafer Transfer Mechanism Dimensioning and Error Budgeting
PUPS 6

Desired Stage Length	3.05 in	77.47 mm
Per Stage Overlap (when retracted)	0.05 in	1.27 mm
Desired Stroke Length	10 in	254 mm
Thread Overlap when extended	0.25 in	6.35 mm
Stop Flange Length	0.25 in	6.35 mm
Effective Stage Length	2.55 in	64.77 mm
Minimum Required Stages	5 stages	
Actual Stroke Length	10.2 in	259.08 mm
Actual Retracted Length	3.3 in	83.82 mm
Smallest Possible Stage (Thread OD)	0.5 in	12.7 mm
Minimum Acceptable Wall Thickness	0.1 in	2.54 mm
Threads Per Inch	20 tpi	0.787402 tpmm
Thread Height	0.027063 in	0.687408 mm
Additional Stop Flange Width	0.025 in	0.635 mm
Stop Flange Clearance	0.05	1.27
Stage 1 Diameter (smallest)	0.55 in	13.97 mm
Stage 2 Diameter	0.8 in	20.32 mm
Stage 3 Diameter	1.05 in	26.67 mm
Stage 4 Diameter	1.3 in	33.02 mm
Stage 5 Diameter	1.55 in	39.37 mm
Stage 6 Diameter	in	0 mm
Stage 7 Diameter	in	0 mm
Stage 8 Diameter	in	0 mm
Stage 9 Diameter	in	0 mm
Stage 10 Diameter	in	0 mm

There are two main types of errors that I anticipate encountering in this mechanism: positioning errors (from the non-perfectness of the screw actuator), and twisting errors (from the torque induced by the rotation of the screw actuator).

The two big positioning errors I am conerned with are:

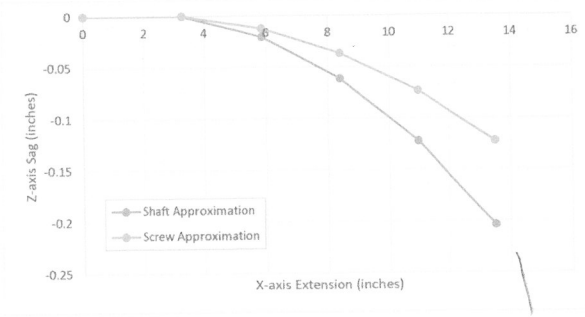
1. Gravity-Induced "sag" Abbe errors in the z-axis from small dimensional differences in the mating threads (at each stage)
2. Backlash or "slop" errors in the x-axis from small dimensional differences in the mating threads (at each stage)

The big twisting error I am worried about is:

1. Roll errors about the x-axis if the screw torque overcomes the rotational/torsional stiffness of the shell (Concept #1) or is mismatched to torque produced by the opposite screw actuator (Concept #2)

Sag Errors At Full Extension (negative z-axis)		
Number of Sag Joints	4 joints	
Male-Female Diameter Difference	0.002 in	0.0508 mm
Effective Diameter Difference (screw approx.)	0.0012 in	0.03048 mm
Sag Per Stage (worst case - shaft approx.)	0.0204 in	0.51816 mm
Sag Angle (worst case - shaft approx.)	0.458371 degrees	0.008 rad
~~Total Sag (worst case - shaft approx.)~~	~~0.0816 in~~	~~2.07264 mm~~
Sag Per Stage (screw approx.)	0.01224 in	0.3109 mm
Sag Angle (screw approx.)	0.275021 degrees	0.0048 rad
~~Total Sag (screw approx.)~~	~~0.04896 in~~	~~1.24358 mm~~

		Shaft Approximation					Screw Approximation				
	Joint	Angle (radians)	Δx	Δz	x	z	Angle (radians)	Δx	Δz	x	z
Fixture		0	0	0	0	0	0	0	0	0	0
Biggest Stage		0	3.3	0	3.3	0	0	3.3	0	3.3	0
Next Smallest	1	0.008000085	2.549918	-0.0204	5.849918	-0.0204	0.004800018	2.549971	-0.01224	5.849971	-0.01224
..	2	0.016000171	2.549674	-0.040798694	8.399592	-0.0612	0.009600037	2.549882	-0.02448	8.399853	-0.03672
..	3	0.024000256	2.549266	-0.061194778	10.94886	-0.12239	0.014400055	2.549736	-0.03672	10.94959	-0.07344
..	4	0.032000341	2.548694	-0.081586944	13.49755	-0.20398	0.019200074	2.54953	-0.04896	13.49912	-0.1224
..	5										
..	6										
..	7										
Next Biggest	8										
Smallest Stage	9										



repeatable? might be fine

or use shim

Bending Errors (negative z-axis)				
Tube OD	0.55 in	13.97 mm	This is the smallest segment, so the worst case for bending	
Tube ID	0.35 in	8.89 mm		
Wall Thickness	0.1 in	2.54 mm		
Moment of Inertia	0.060083 in^4	25008.4 mm^4		
Length	3.3 in	83.82 mm		
Force Applied		10 N		
Elastic Modulus (6061 Aluminum)		68900 N/mm^2		
Mass density (6061 Aluminum)		2.7E-06 kg/mm^3		
Stiffness (k) (6061 Aluminum)		8777.76 N/mm	8.77776 N/um	
Deflection (δ) (6061 Aluminum)	4.49E-05 in	0.00114 mm	1.139243 um	So, compared to the sag errors, the bending errors are insignificant
Mass (6061 Aluminum)	0.045411 lbs	0.02064 kg		
Resonant Frequency (6061 Aluminum)		3282.02 Hz		
Elastic Modulus (304 Stainless Steel)		200000 N/mm^2		
Mass density (304 Stainless Steel)		8E-06 kg/mm^3		
Stiffness (k) (304 Stainless Steel)		25479.7 N/mm	25.47971 N/um	So, compared to the sag errors, the bending errors are insignificant
Deflection (δ) (304 Stainless Steel)	1.55E-05 in	0.00039 mm	0.392469 um	
Mass (304 Stainless Steel)	0.134552 lbs	0.06116 kg		
Resonant Frequency (304 Stainless Steel)		3248.51 Hz		

but this is a huge overestimate

seems like quite a lot of deflection

↳ more overlap - packaging issue

Slop Errors (± x-axis)				
Number of Sag Joints	4	joints		
Male-Female Diameter Difference	0.002	in	0.0508	mm
Max Possible Slop Per Joint	0.001155	in	0.029329	mm
Maximum Total Slop	0.004619	in	0.117318	mm

can I see formulas behind this
↳ (St. Venant's) + Abbe errors result from diametrical clearance

Shell Twist Errors (roll about x-axis)				
Motor Pull-In/Out Torque			0.3	Nm
Max Possible Shell Diameter	2.5	in	0.0635	m
Force Felt by Shell At Edge			4.724409	N
Shell Stage Length	3.05	in	0.07747	m
Shell Stage Wall Thickness	0.025	in	0.000635	m
Shell Inner Diameter	2.45	in	0.06223	m
Polar Moment of Inertia (J)	0.297714	in^4	1.24E-07	m^4
Modulus of Rigidity (G) (6061 Aluminum)			2.4E+10	N/m^2
Rotation Angle Per Stage (6061 Aluminum)	0.000448	degrees	7.81E-06	rad
Total Rotation (6061 Aluminum)	0.002239	degrees	3.91E-05	rad
Modulus of Rigidity (G) (304 Stainless Steel)			7.8E+10	N/m^2
Rotation Angle Per Stage (304 Stainless Steel)	0.000138	degrees	2.4E-06	rad
Total Rotation (304 Stainless Steel)	0.000689	degrees	1.2E-05	rad

these are guesses from <http://reprap.org/wiki/Stepper_torque> and <http://www.pbclinear.com/Download/DataSheet/Stepper-i

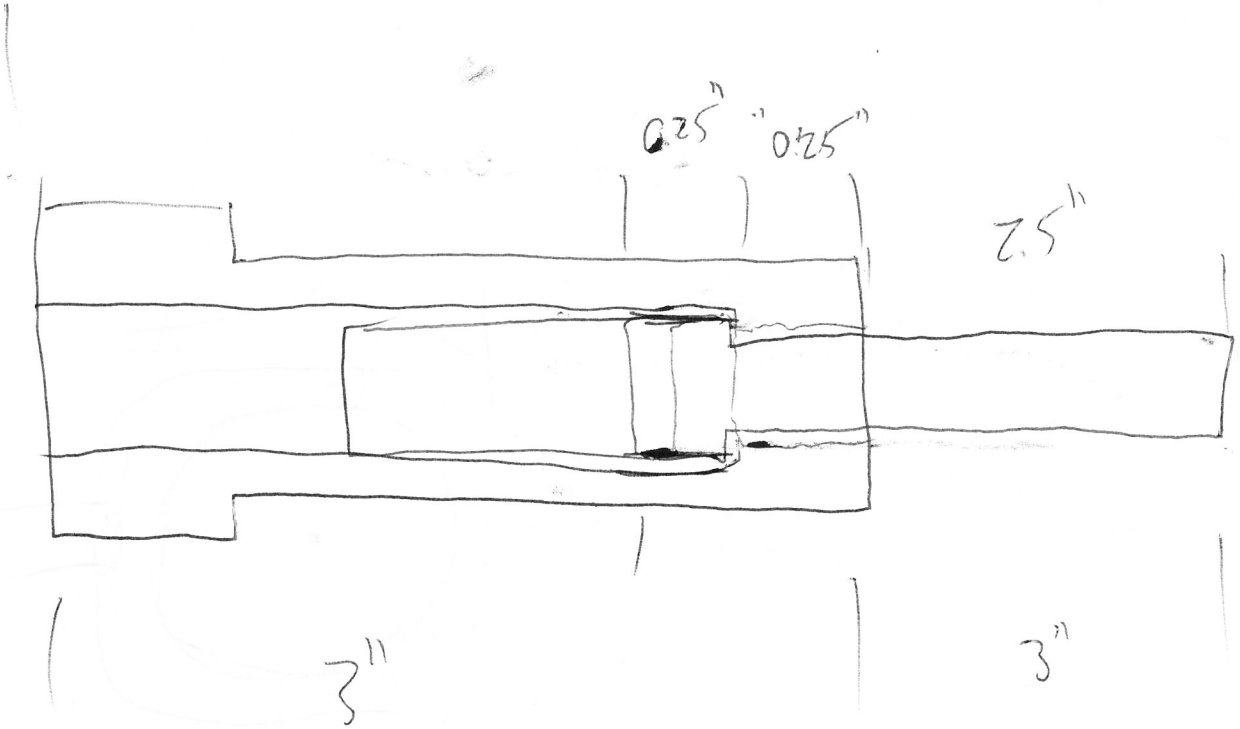
this is set by the standard dimensions of a CF4.5" flange

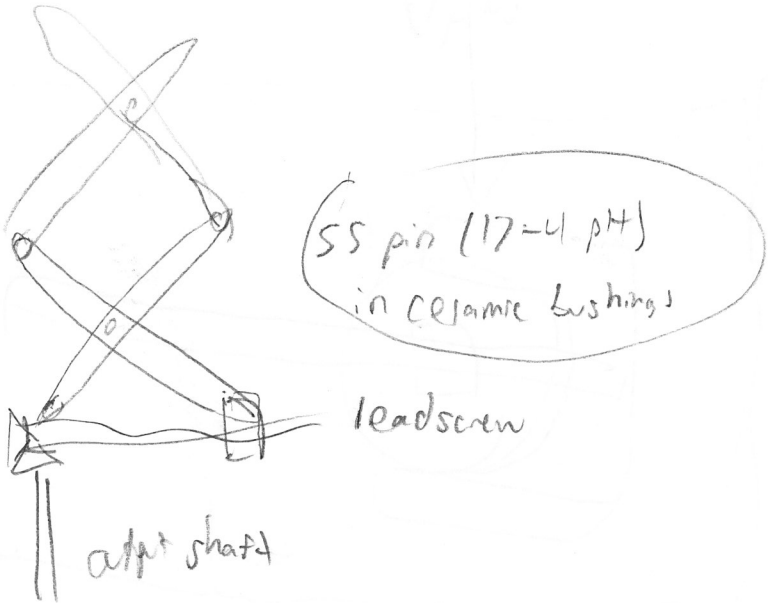
this is probably thinner than would be used, but it gives conservative numbers

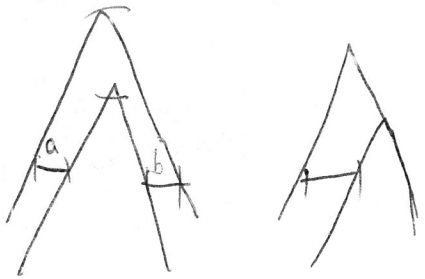
Stage Connection Key Slop	0.005	in	0.000127	m
Rotation From Each Key Slop	0.229183	degrees	0.004	rad
Total Key Slop Rotation	0.916732	degrees	0.016	rad

If we imagine the keying between each stage of the shell to be a simple protusion and recess system, there will be some rotational slop from that keying, primarily from dimensional differences in the fabrication

Total Rotation Of Shell (6061 Aluminum)	0.918971	degrees	0.016039	rad
Total Rotation Of Shell (304 Stainless Steel)	0.917421	degrees	0.016012	rad


0.25"
0.25"
2.5"
3"
3"


55 pin (17-4 pH)
in ceramic bushings
leadscrew
bevel gear
output shaft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