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A Miniature Cryogenic Scanning Fabry-Perot Interferometer for Mid-IR to Submm Astronomical Observations

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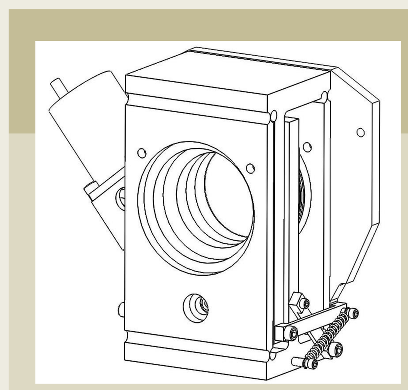


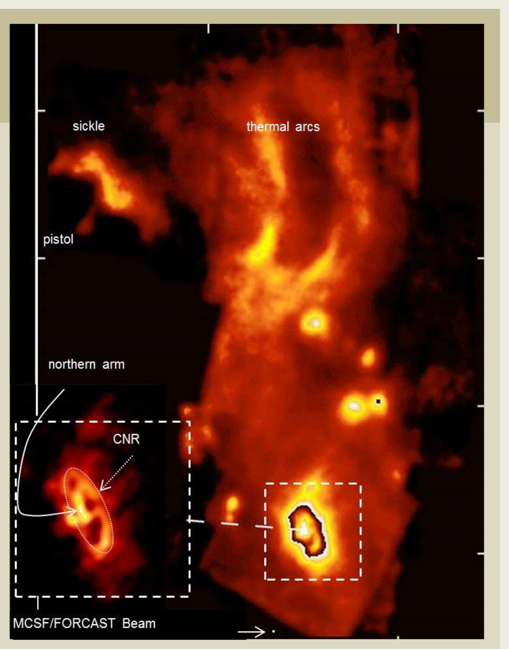
Actual Size MCSF.

Introduction:

We have designed and evaluated a Miniature Cryogenic Scanning Fabry-Perot (MCSF) interferometer for the 25-40 μm wavelength regime. A monolithic notch flexure design delivers our required tight tolerances, maintaining parallelism of the etalon to better than 0.2 μm while allowing us to scan over ~2 mm with a positional accuracy of 0.1 μm. The scanning mechanism includes a cryogenic stepper motor that drives a miniature fine-adjustment screw via a worm gear assembly. No feedback parallelism adjustment is required. The MCSF will be employed in the FORCAST instrument on SOFIA in the future.

Motivation:

- Converts a camera into a high resolving power imaging spectrometer
  - Effective use of 2d arrays
  - High resolving power in a modest space envelope
  - Absolute spatial registry
  - Relaxed pointing requirements
  - Resolving power is tunable to expected line width
  - Large bandwidths can be obtained through scanning
- Investigations of the Galactic Center
  - Circumnuclear Ring (CNR)
    - What feeds the CNR?
    - Is it a transient phenomena?
  - Radio arches
- Investigations of external galaxies
  - Star formation trigger and feedback mechanisms
  - Morphology
- Investigations of protostars and protoplanetary disks



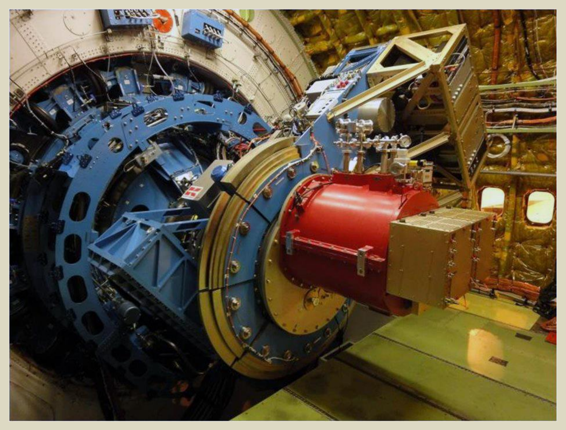
KWIC/KAO 37.7 μm image of the Galactic center at 8.5" resolution.[1]

- Advantages of mid-IR and longer wavelengths:
  - Reduced extinction
  - Multitude of molecular and fine-structure transition lines
- With the MCSF in FORCAST:
  - Map regions such as the GC in the [SIII] (33 μm), [SiII] (35 μm), [NeIII] (36 μm) and [OIV] (26 μm)
    - Probe hardness of radiation field
    - Reveal age of star forming regions
  - Imaging spectroscopy of nearby galaxies

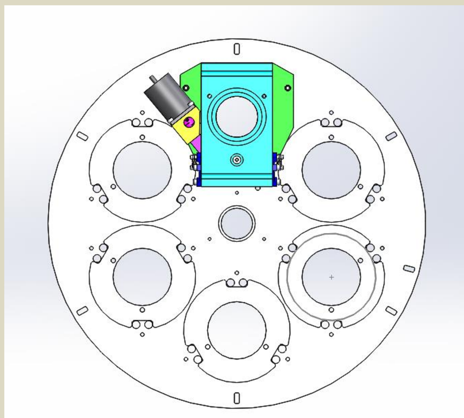
FORCAST [2,3]:

SOFIA in flight.[5]

- Facility instrument on SOFIA[4]
- Dual-channel mid-IR camera
  - Short wavelength camera (SWC) 10-25 μm employing 256x256 Si:As (BIB) array
  - Long wavelength camera (LWC) 25-40 μm employing 256x256 Si:Sb (BIB) array
  - Both cameras can observe simultaneously
  - Field of view: 3.2' x 3.4'
- MCSF will be mounted in filter wheel in LWC
  - Cooled to 4K
  - At Lyot stop
  - 2.5 cm clear aperture
- MCSF will maintain performance in dynamic aircraft environment
- R ~ several thousand



FORCAST instrument on SOFIA.[5]



The MCSF on FORCAST filter wheel.

Stress and Push Point Analysis:

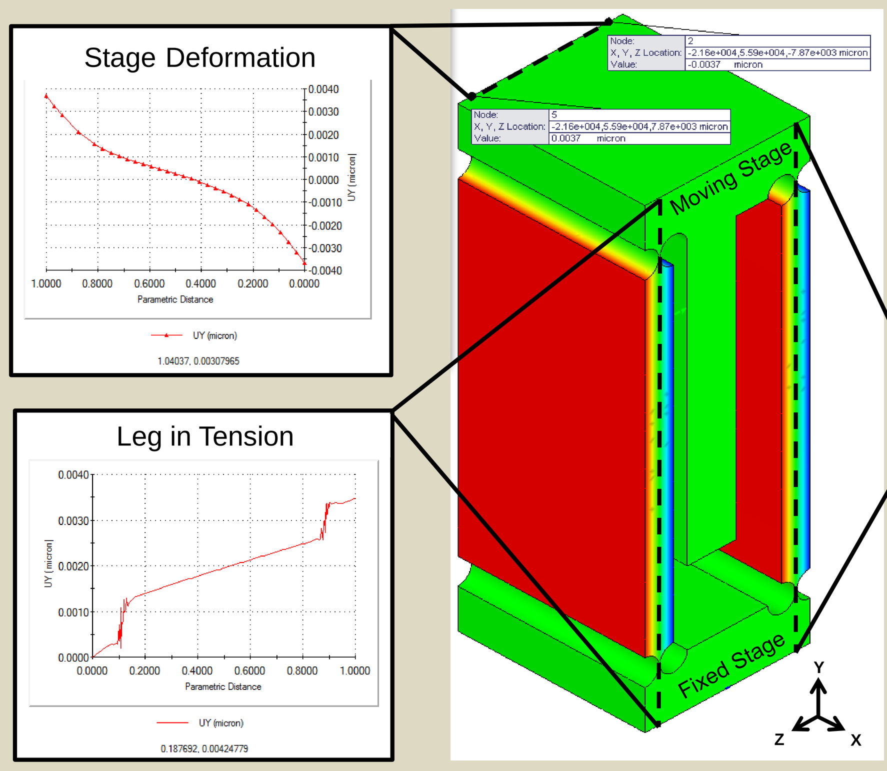


Figure 1: "Tension" and "compression" as seen in parametric distance along y-direction of flex vanes of simplified monolithic flexure and yielding in the y-direction of the moving stage ("deformation").

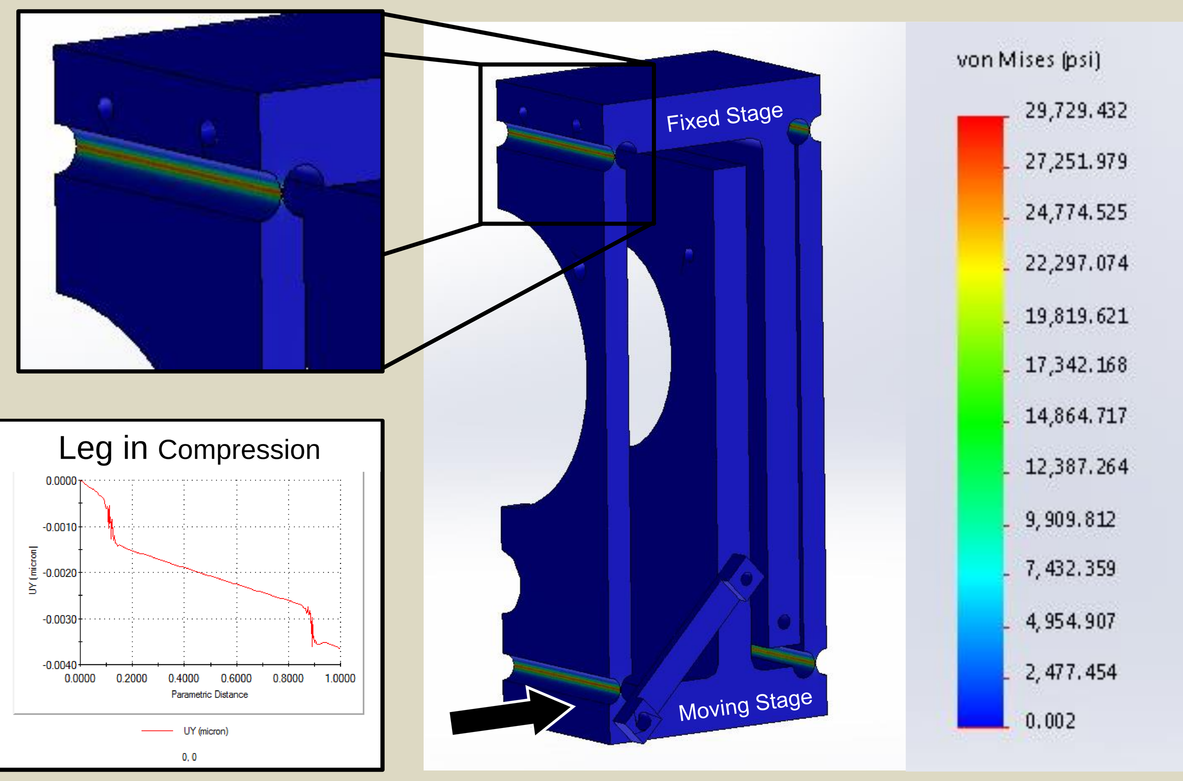


Figure 2: FEA Stress plot zoomed onto flex vane web. Maximum stress was found to be within limits for aluminum.

- Examining the monolithic flexure FEA model (Figure 1):
  - Finite Element Analysis performed to understand behavior of notch flexure with mechanical properties of 6061-T6 Al
- Evaluating stresses in notch flexure (Figure 2):
  - Notch flexure stresses found to be below yield stress of 6061-T6 aluminum
- Determining optimum push point (Figure 3):
  - Error angle minimized at a push point of 14.7mm above flexure midline

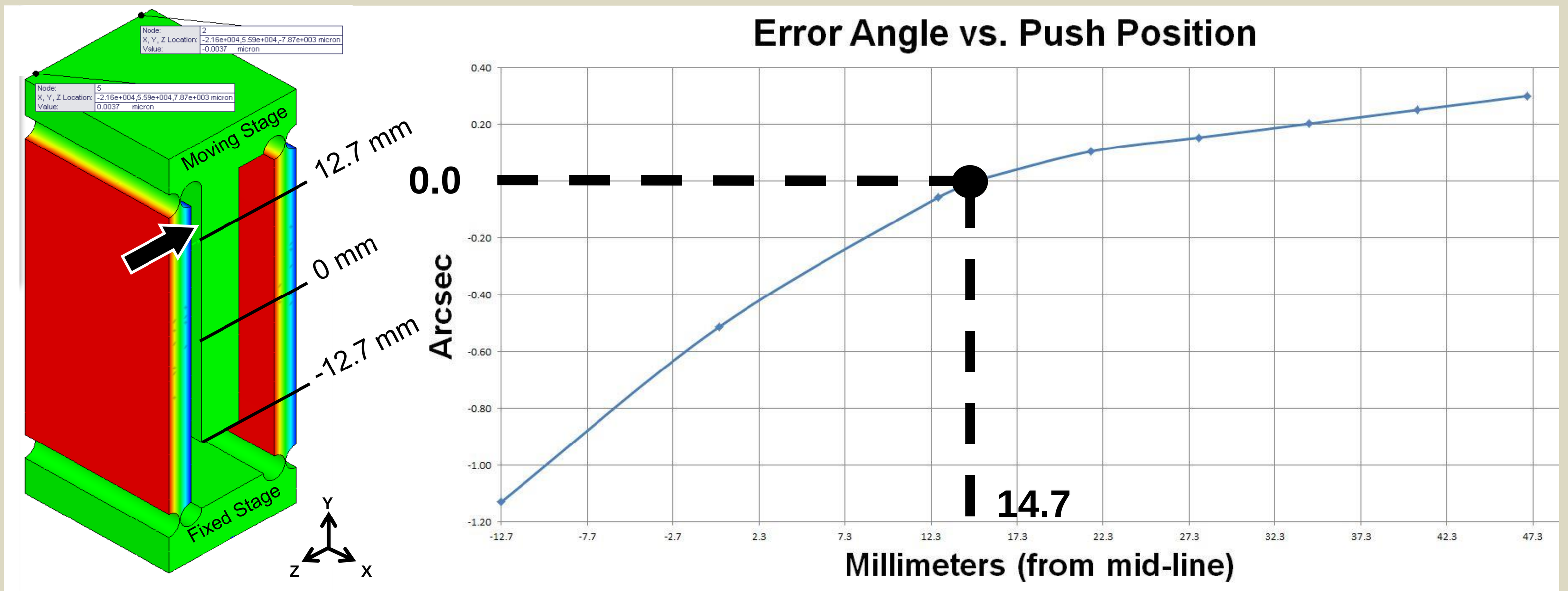
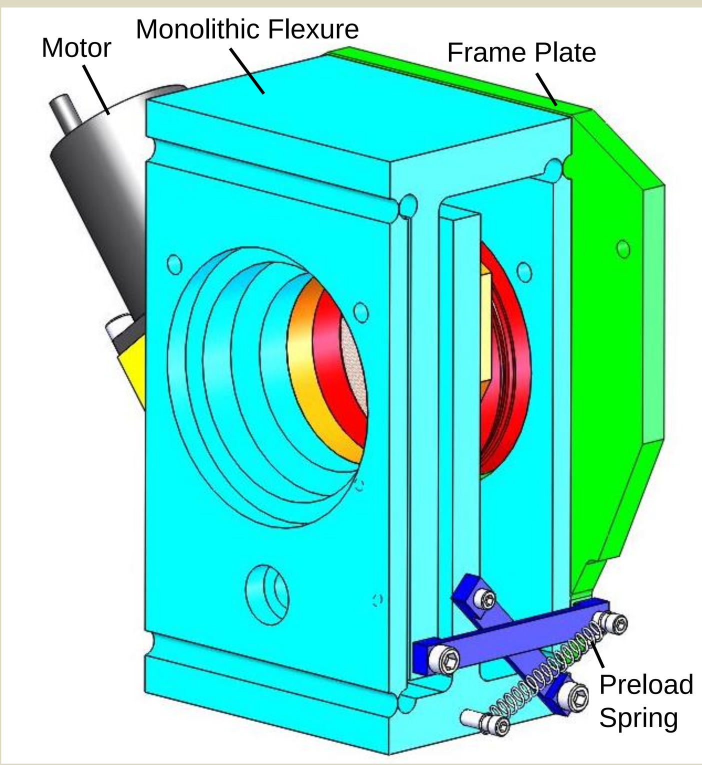
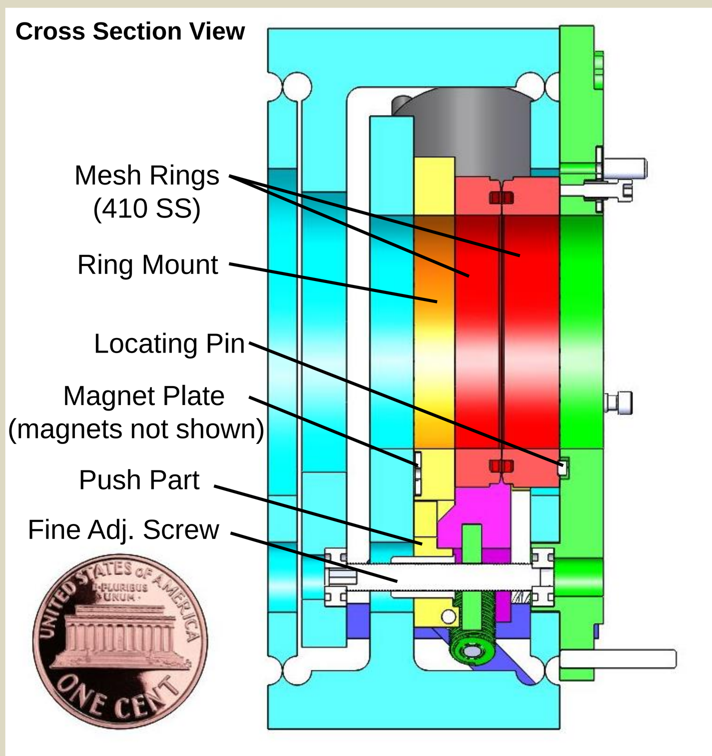
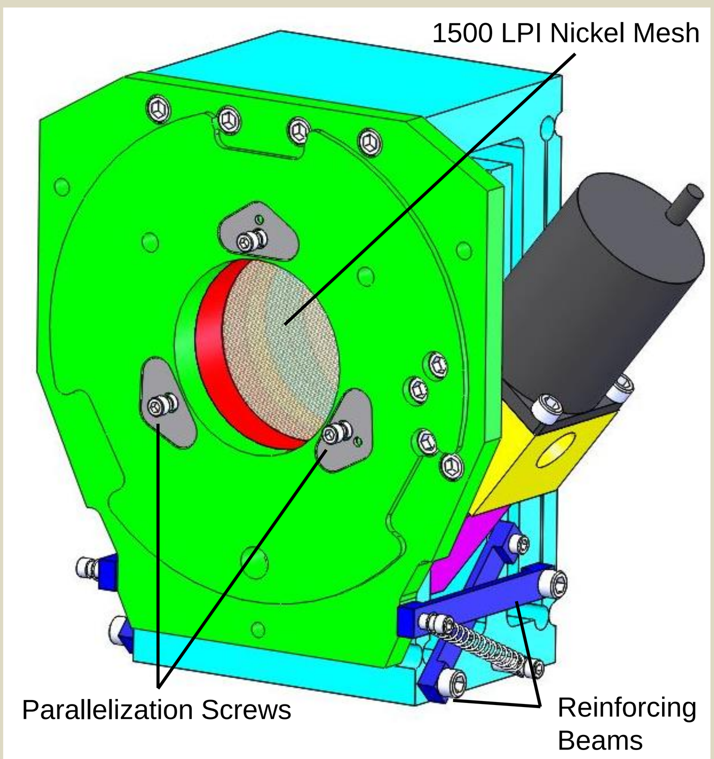


Figure 3: Error angle vs. push position along tongue of simplified monolithic flexure's moving stage. The ideal push position, as measured from the midline of the monolithic flexure, is 14.7 mm above the midline of the flexure.

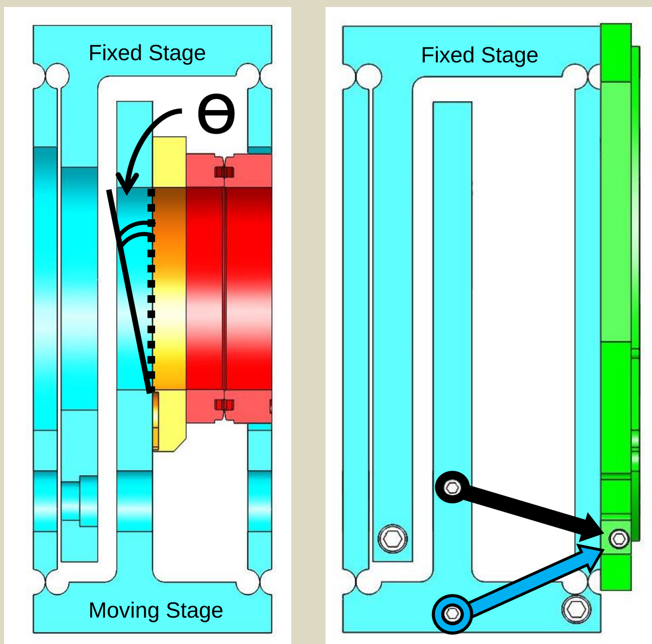
Design:



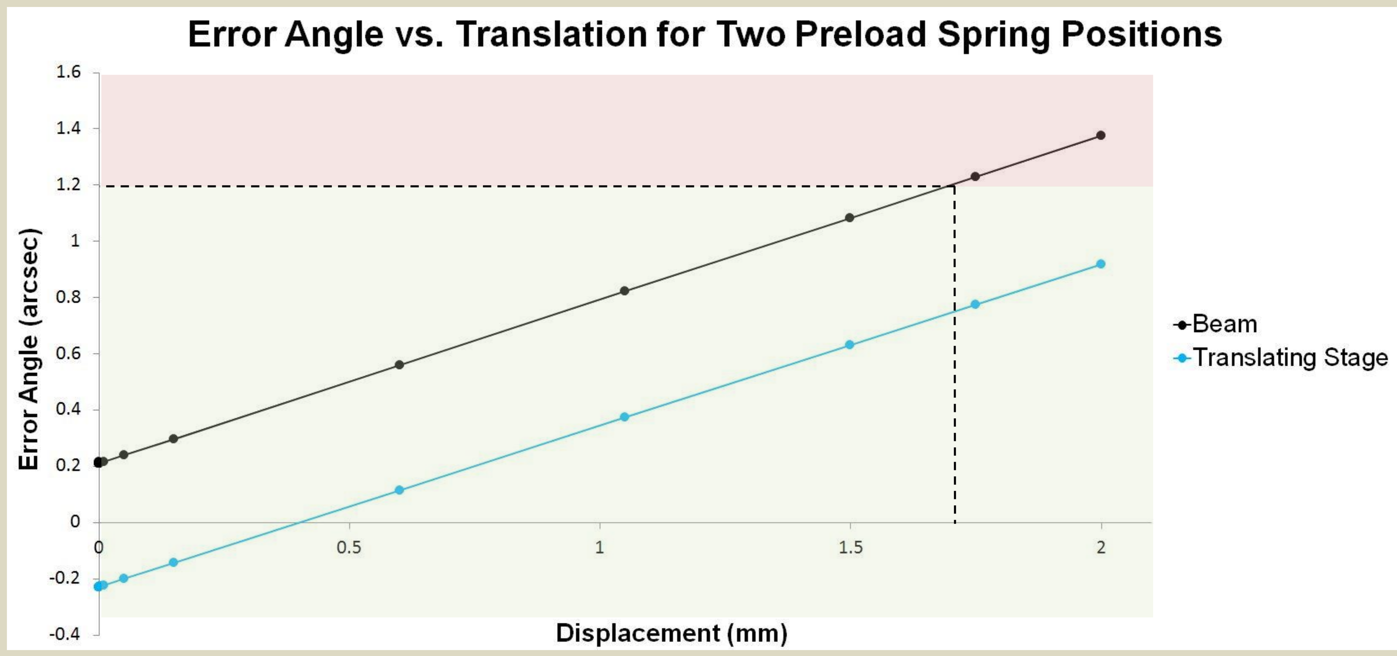




Systematic Error Analysis:



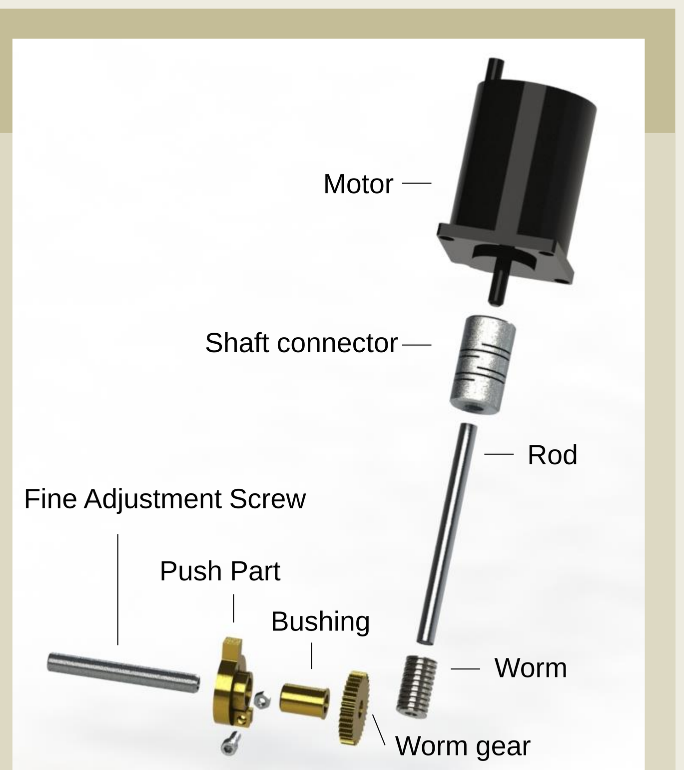
Left: "Error angle" from parallelism is measured from the translating mesh edge of the monolithic flexure (black dotted line). Right: Beam spring configuration (black) and translating stage configuration (blue) corresponding to error angle plot.



Error Angle in arcseconds vs. displacement distance in mm as measured in FEA simulation in SolidWorks for simplified MCSF model. Permissible operating range is found to be 1.5mm for beam spring configuration, corresponding to an error angle of 1.088 arcsec, and 2mm for translating stage configuration, corresponding to an error angle of 0.919 arcsec, both lying safely within our specifications.

Drive Train:

- Phytron VSS-19 cryogenic stepper motor (operating in full-step mode)
- Flexible shaft coupling
- Worm and worm gear
  - Gear ratio 36:1
- Ultra fine adjustment screw and bushing
  - 254 TPI, 100 micron pitch, from Base Optics
- Brass push part translates flexure
- "Push" system is countered by flexure and preload springs
- Step resolution: 1 step ≈ 14 nm translation
- Maintains position when motor is not powered



The Future:

- Fabricate and test prototype MCSF
  - Monolithic notch flexure will be fabricated via wire Electrical Discharge Machining (EDM)
- Design wiring layout of Phytron motor for filter-wheel mount
- Modify existing software for motor control specifically for FORCAST
- Integrate MCSF into FORCAST
- Deploy in SOFIA
- Possible adaptation for and implementation in future space based missions

References:
[1] Latvakoski, H.M., et al., "Kuiper Widefield Infrared Camera Far-Infrared Imaging of the Galactic Center: The Circumnuclear Disk Revealed ApJ, 511, 761 (1999).
[2] Adams, Joseph D.; Herter, Terry L.; Gull, George E.; et al., "FORCAST: a first light facility instrument for SOFIA," 2010, SPIE, 7735E, 62.
[3] Herter, T.L., et al., "First Science Observations with SOFIA/FORCAST: The FORCAST Mid-infrared Camera," ApJL, 749, L18 (2012).
[4] Young, E.T., et al., "Early Science with SOFIA, The Stratospheric Observatory for Infrared Astronomy," ApJL, 749, L17 (2012).
[5] NASA SOFIA Mission Page, 2013, HTML http://www.nasa.gov/mission_pages/SOFIA/12-122HQ.html#.U6NNZfldV6y

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