Thermal actuator update

Fabrication and testing of CFM with flexures

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LIGO-E1900226

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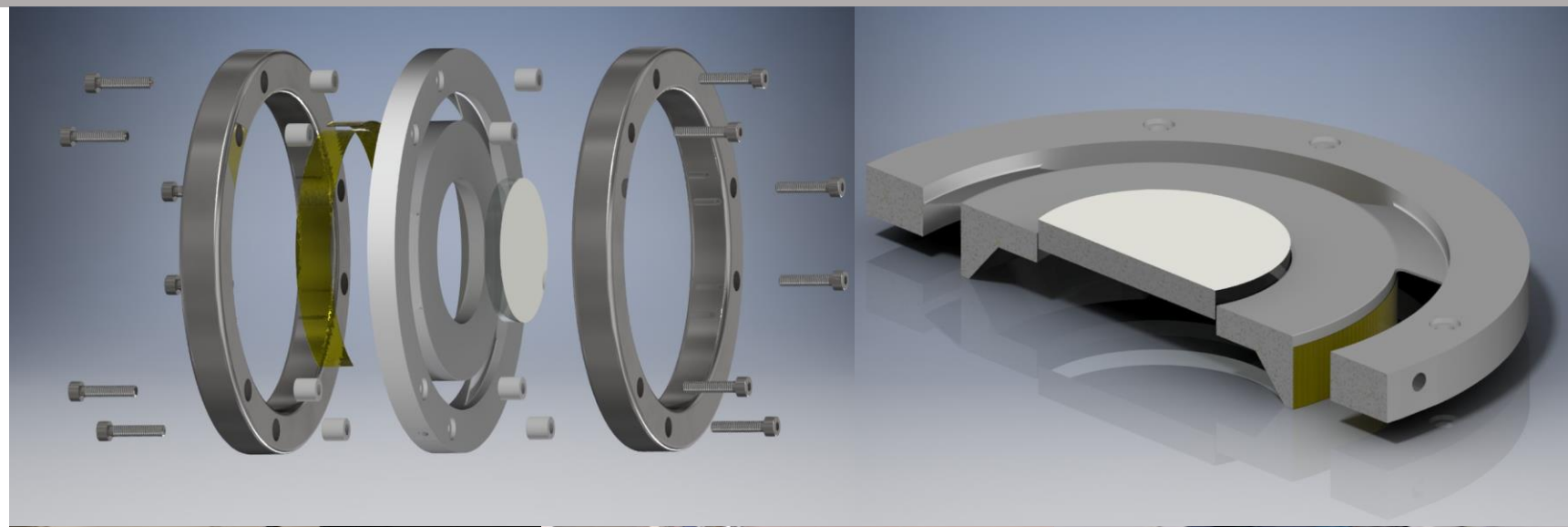
1. 1kg-CFM design with flexures

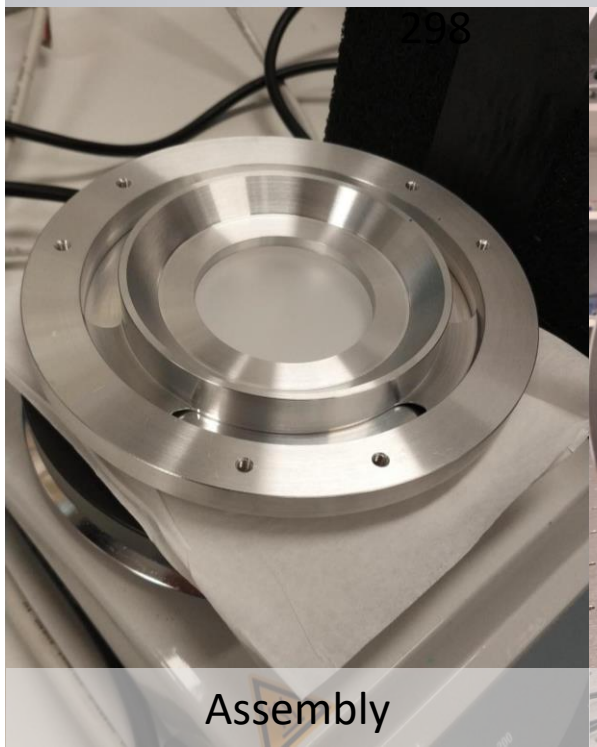
1kg-CFM design concept (*top images*):

- Improve thermal isolation
- Decouple COM motion and pitch change
- Allow increase in mass

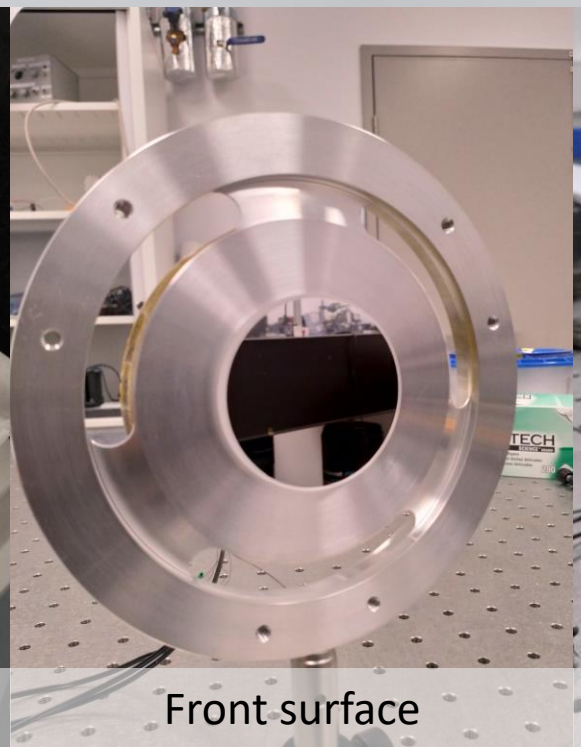
Fabrication of CFM with flexures (*bottom images*):

- Inner ring:
  - OD: 90 mm
  - ID: 50.75 mm
- Outer ring:
  - OD: 140 mm
  - ID: 110 mm
- Flexure:
  - thickness: 0.55 mm
  - length: 10 mm
  - Anchored angle: ≈ 18.5 deg
  - angle subtended: 40 degrees
- Mass: 298 g

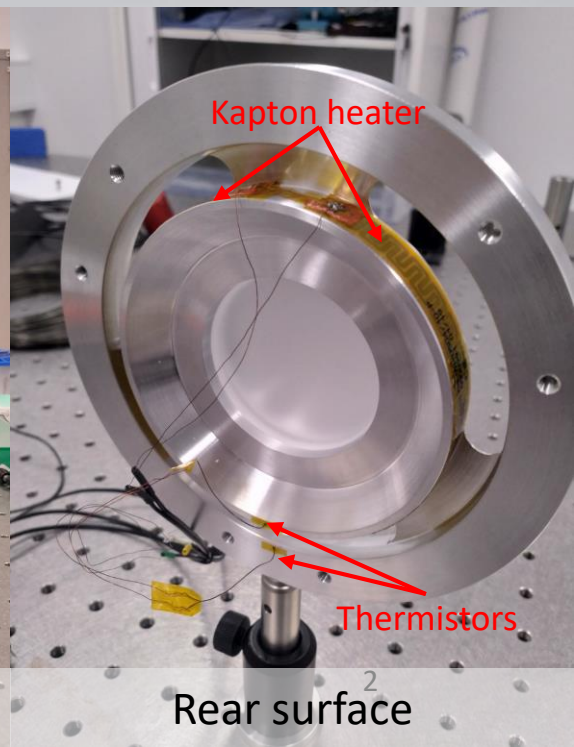




Assembly



Front surface



Rear surface

2. Measured deformation - Defocus

- Max defocus (so far): 50 mD (Fig 3).
- Thermal time constant ≈ 40 minutes (Fig 1).
- Glitches expected to reduce as cycling through more heat cycles
- Smaller inner ring OD → lower dS/dT (see E1900073)
  - COMSOL FEA predicts approx. 4.32 mD/K for 90 mm OD actuating ring (Fig 2)
  - FEA agrees with measured dS/dT (4.31 mD/K)

Testing: 2 cycles so far, approx. 8 hour each cycle with 70% duty cycle:

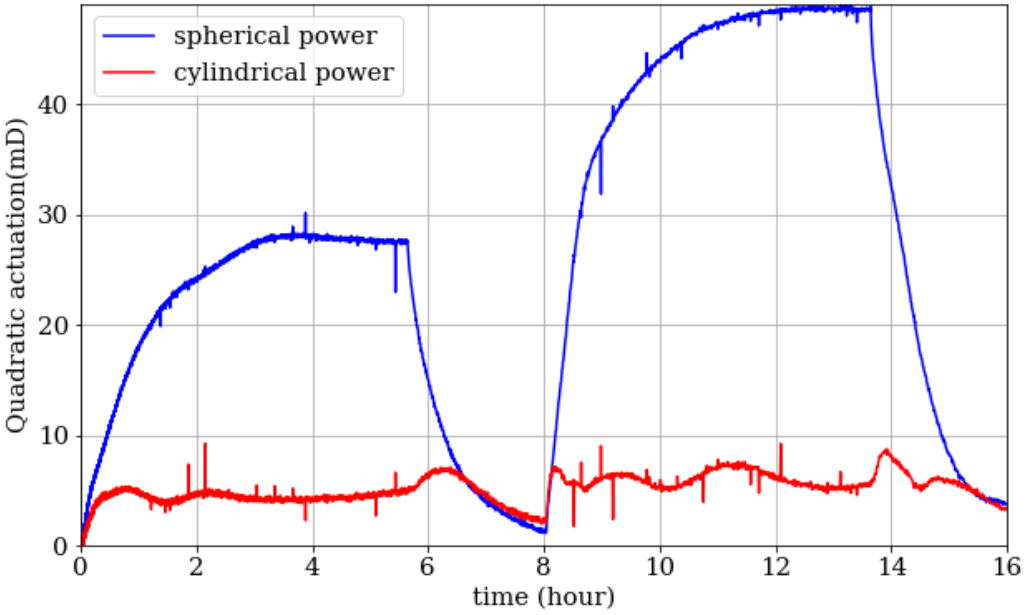
- P_{in1} = 588 mW
- P_{in2} = 1.22 W
- **Mirror mounted directly on optical post**

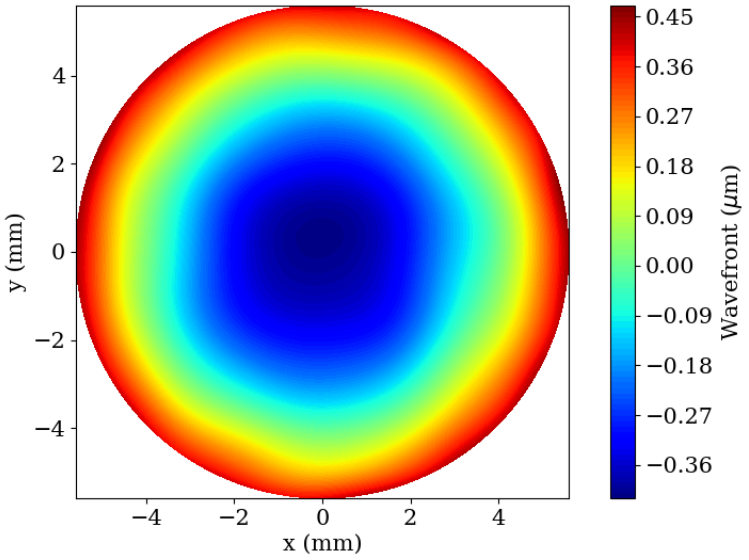
From top – clockwise:

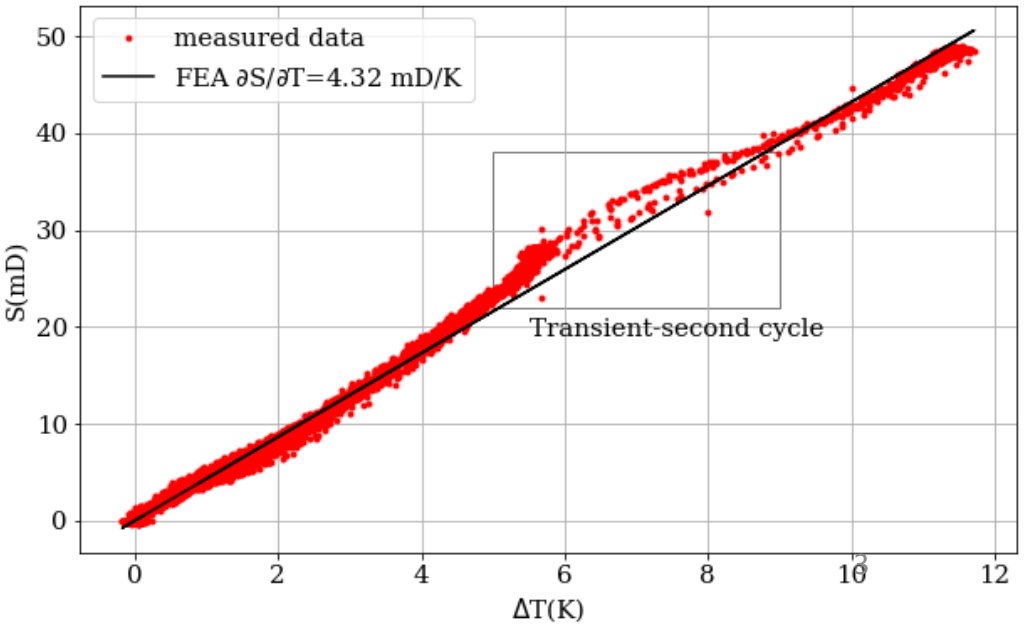
Fig1: Time series of defocus + cylindrical power

Fig2: Change in defocus as function of change in temperature of inner ring , compared to dS/dT predicted by COMSOL FEA for inner ring OD of 90 mm.

Fig3: Full wavefront map at maximum actuation during second cycle (≈ 50 mD)







2. Measured deformation – Higher order aberration

- Mainly quadratic deformation
- No obvious effect of three flexures on wavefront deformation
- 121 nm P-V higher order aberration (HOA) at 50 mD defocus. Ongoing testing to verify HOA at higher actuation
- Higher order mode scattering due to HOA computed from full overlap integral between residual wavefront and target TEM_{00} mode (T1800480)
- High-order mode scattering < 0.4% for beam radius <2.7 mm (Fig. 3)

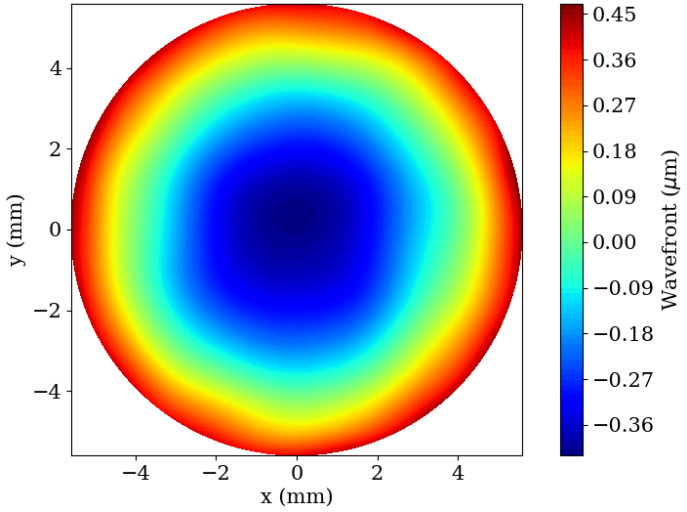


Fig1: Full wavefront map at maximum actuation during second cycle (≈ 50 mD)

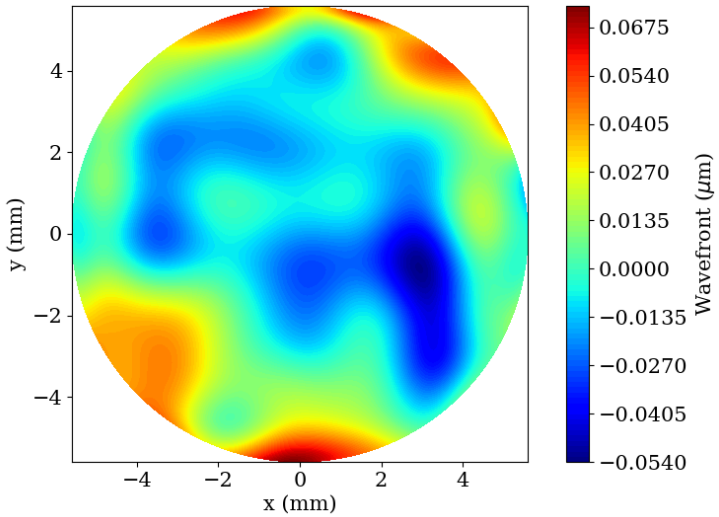


Fig2:Residual wavefront after removal of quadratic component

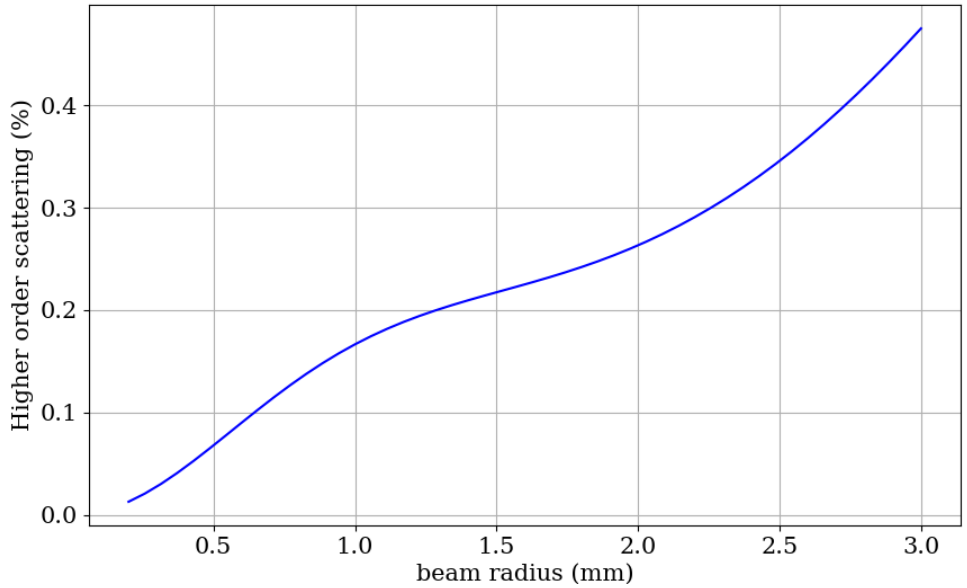


Fig3: Higher order mode scattering due higher order aberration (Fig2)

3. Temperature isolation

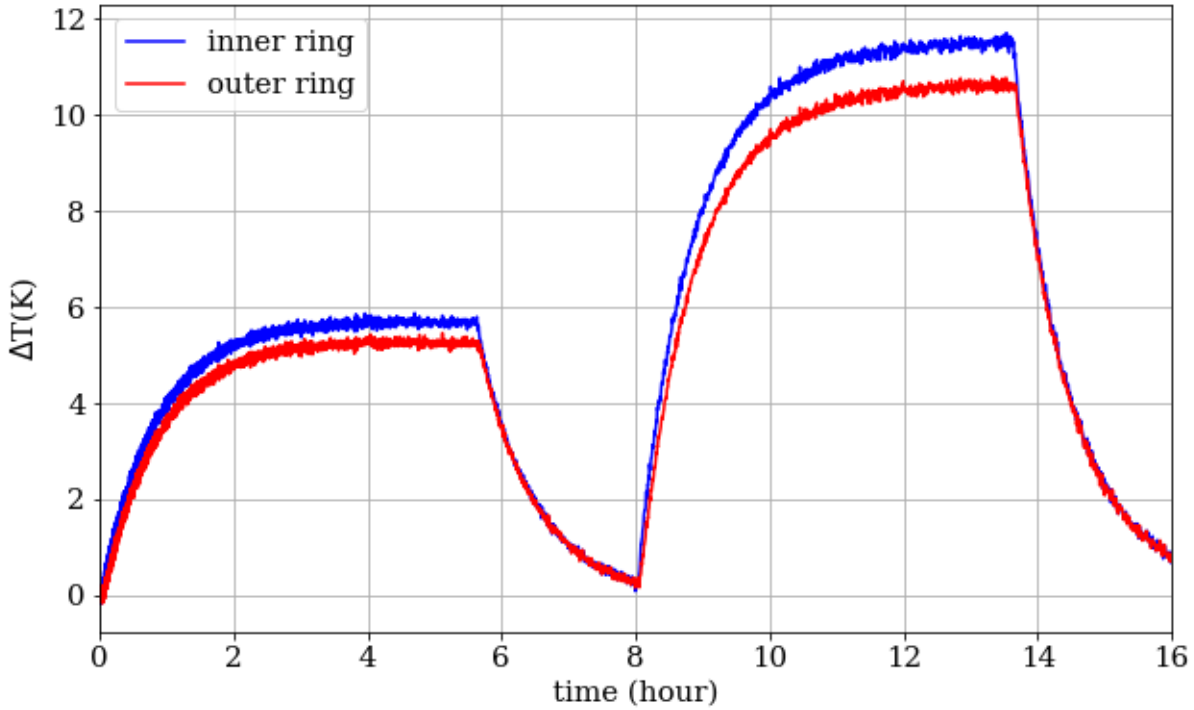


Fig1: Time series of temperature recorded by thermistors on inner and outer rings

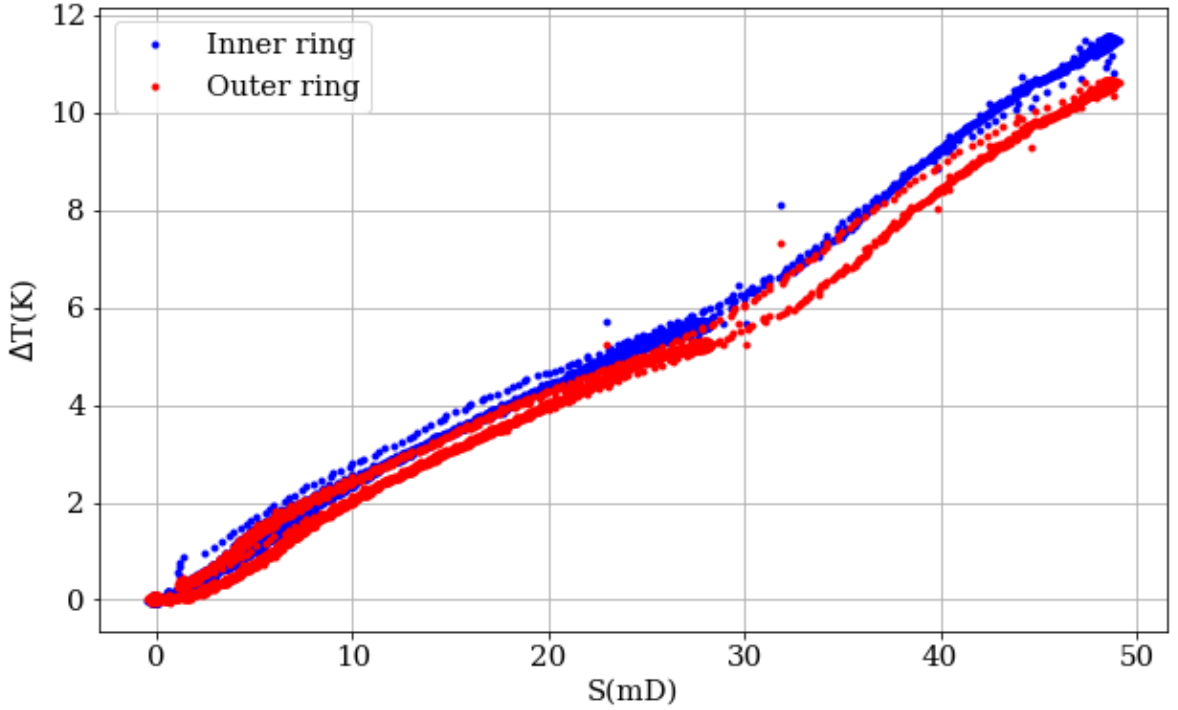


Fig2: Temperatures on inner and outer rings plotted against change in defocus

- At thermal equilibrium, outer ring ΔT approx. 90% that of inner ring → greater difference at higher temperature
- **Heater ON:** temperature determined mainly by heat conduction. Flexures limits heat conduction →lower temperature at outer ring
- **Heater OFF:** dominated by radiative heater transfer. Higher emissivities of fused silica + heater surface → faster radiative cooling of inner ring at beginning until thermalize with outer ring → Asymmetry in heating and cooling
- Currently verifying results with FEA.

4. Mirror – mounting motion decoupling

- Pitch change of reflected beam: 50 µrad @ 50 mD
- No flexure case (actuating ring mounted directly on post): 700 µrad @ 50 mD (see E1900154)

→ An order of magnitude lower

- Looks promising for decoupling COM variation and pitch of mirror in suspension system

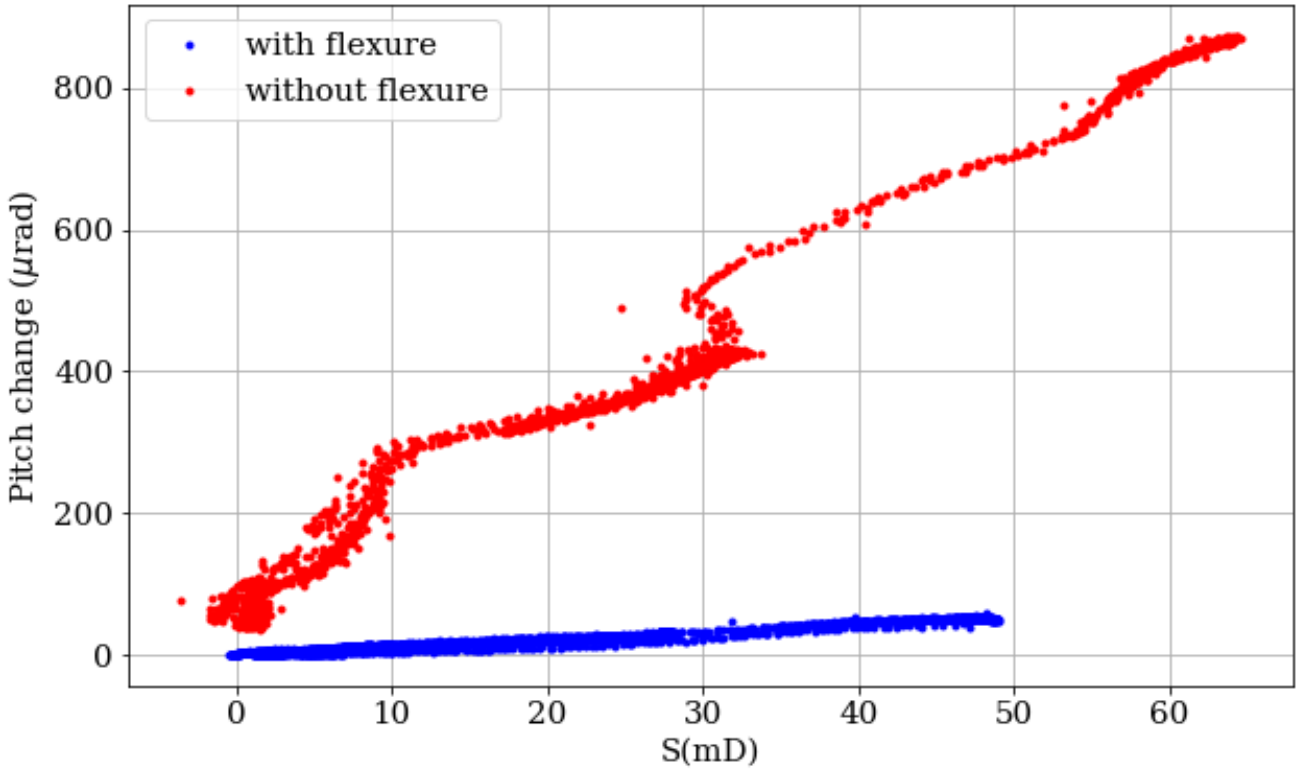


Fig: Comparison of change in pitch with change in defocus between a standard CFM (red) and flexure CFM prototype (blue)

5. Next step

Current prototype:

- Continue testing with more heat cycles
- Evaluate higher order aberration at larger actuation
- Verification with FEA model
- Measure static deformation

Design of next prototype:

- Greater OD of inner ring → increase dSdT
- Optimize flexures for thermal performance including thermal time constant and thermal isolation
- A prototype with high emissivity coating to improve thermal time constant
- Attachment of supporting rings to increase total mass