Disk Support Ring and Mounts CDR

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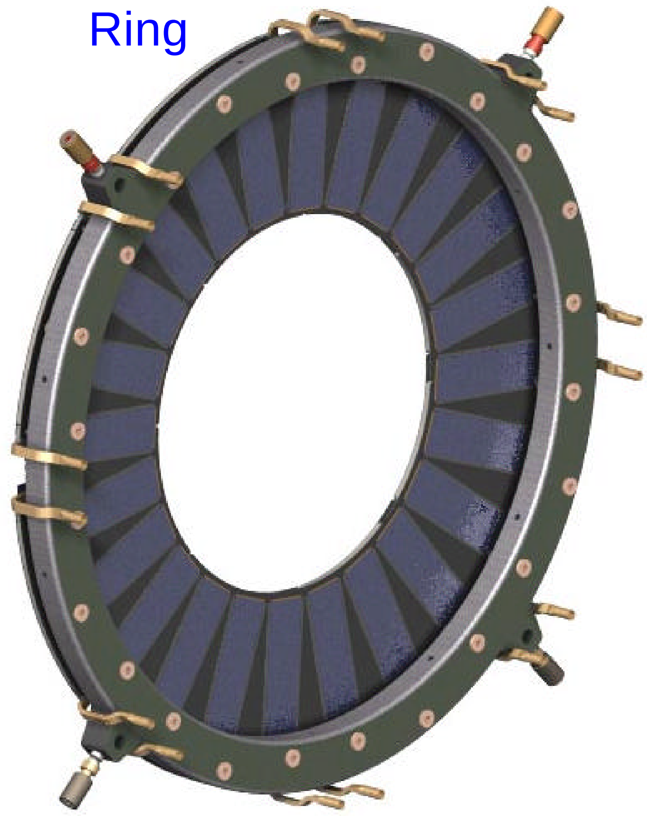
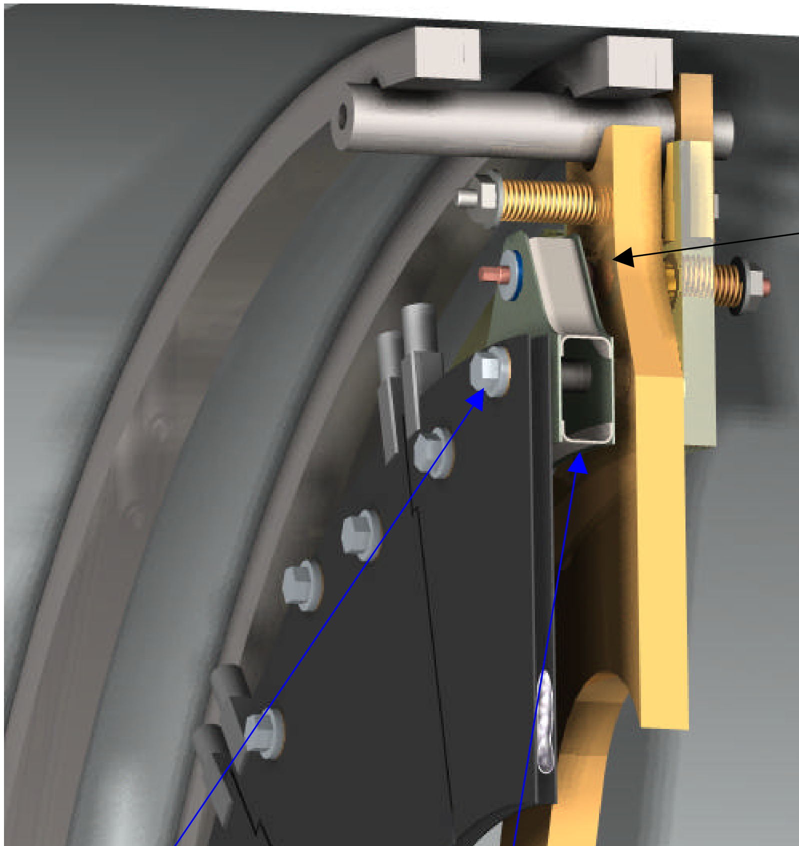


Ring History

- Background
  - Prototype development
    - Centered on 500mm dia. Global Support Structure design point
    - Two rings constructed and thermally tested with sectors
    - Original design called for 12 sectors per disk, and 3 mounts per ring
    - All test results to be discussed were obtained on the larger diameter ring
      - Individual ring test
      - Ring/mount test mounted in Global Support frame section
  - FEA design studies
    - Made initially for larger diameter ring
    - Recently FEA studies were completed for the new, smaller diameter ring with increased number of supports
  - Design
    - Detail drawings for the new ring are complete
    - Cost information is being established

Early Development

Sector Mounting Ring
Initial Prototype Setup



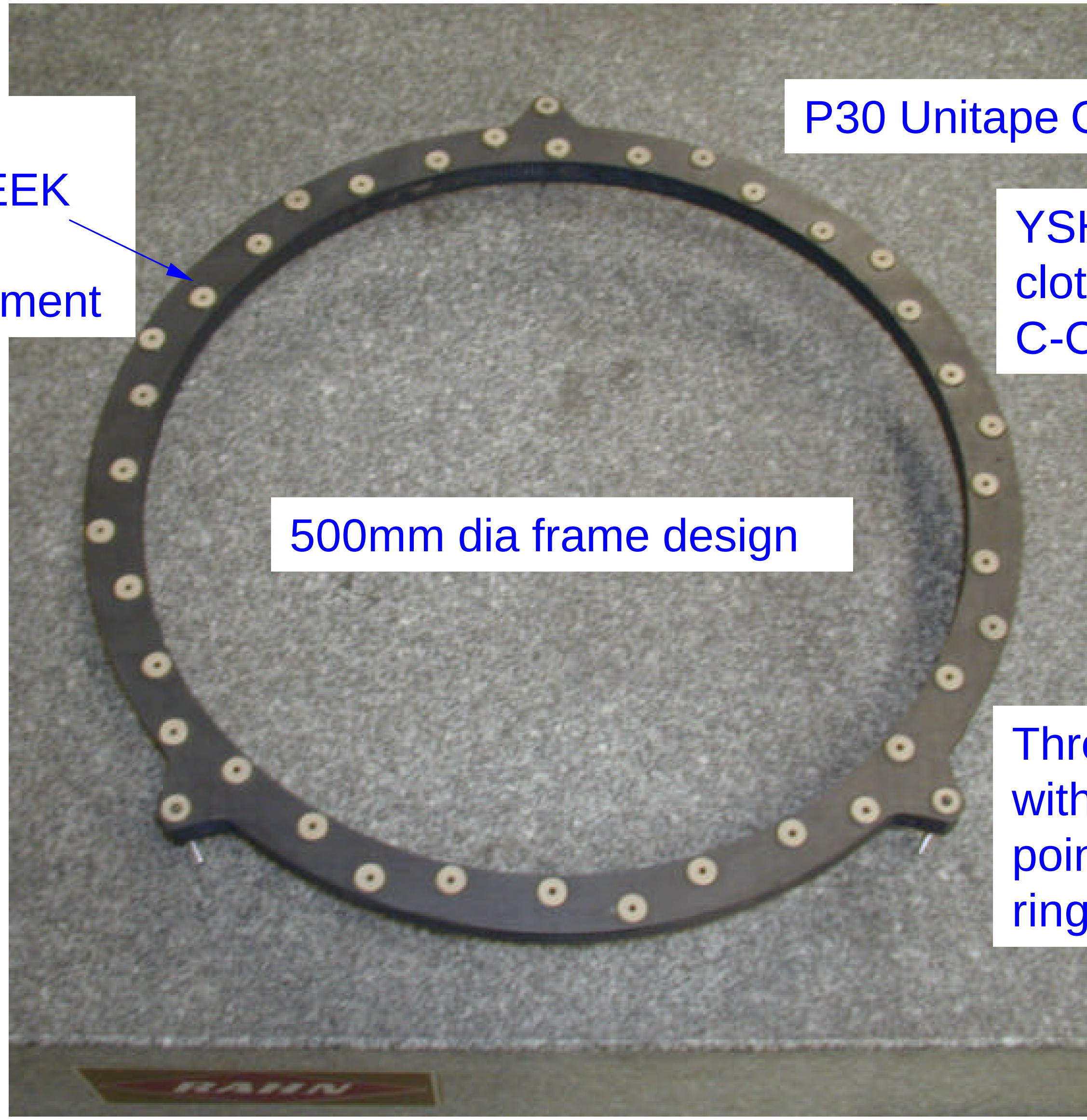
Test set-up, low CTE equipment (Invar)

C-Channel

Precision locating screws

Basic objective was to evaluate thermal stability and stiffness of composite ring and ring support

12-Sector Ring



Precision machined PEEK bushings for sector attachment

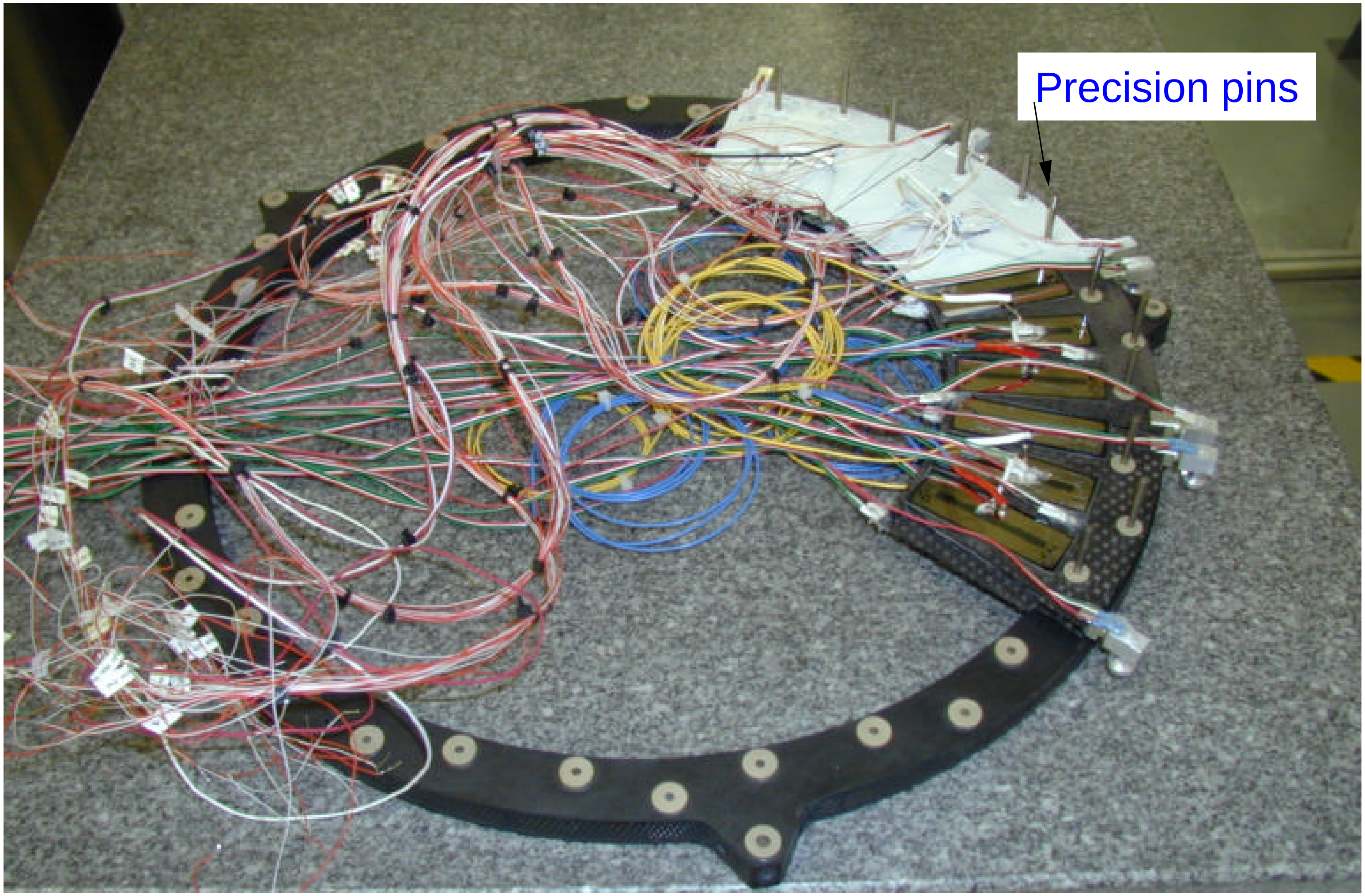
P30 Unitape C-C facings

YSH50 woven cloth/CE resin C-Channels

500mm dia frame design

Three point support with suspension point behind the ring

Trial Setup

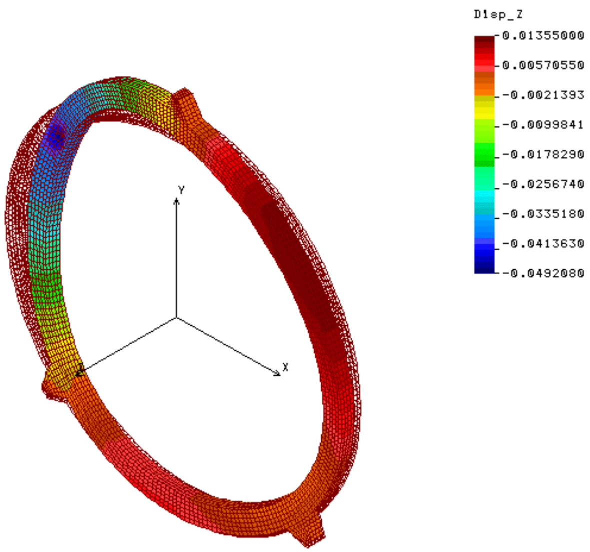


Able to install precision pins (light press fit), in three positions for sectors, in all of twelve positions

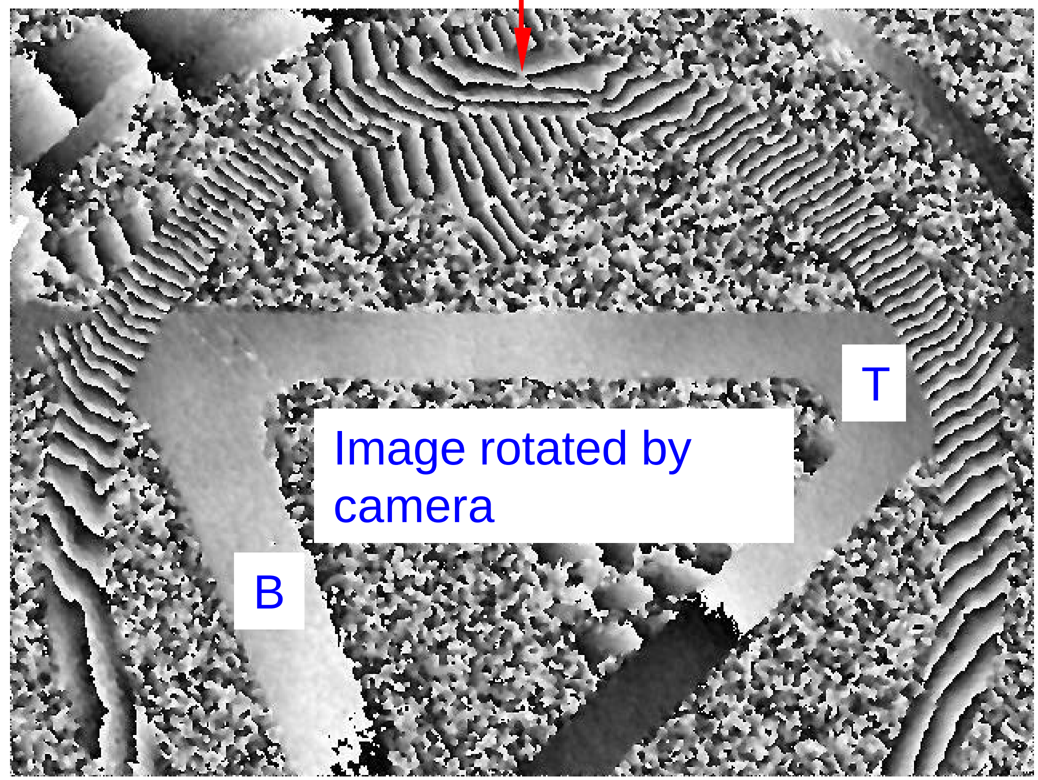
Development Results

- Quality of ring fabrication for *12-sector design (ring #2)*
  - Bond fixture used in assembling ring was machined from graphite plate
    - HYTEC inspection indicated ring precision hole pattern was achieved, but flatness was not
      - Major improvement in dimensional quality, but ring flatness remains an unsolved problem
    - LBNL inspected tooling plate, slight out-of-planarity
    - Observations from LBNL data:
      - 39 precision hole pattern, location tolerance of 12.5µm was achieved
      - Several (~20%) counter-bores to allow space for *head* of PEEK inserts were out of planarity by 50µm, whereas drawing specified 25µm
        - » Explains only a small part of the ring flatness problem
- C-Channel dimensional quality improved significantly, but slight out of flatness was evident before bonding ring
  - C-Channel may be causing the ring to cup. Further prototyping is needed

Static Results



Load application from back in ring center



Load 2N from front
46.9μm=23.45 μm/N

Ring appears to deflect 70.7% of that predicted by FEA

Experimental TVH result average of three tests: 163μm/kg=16.6 μm/N

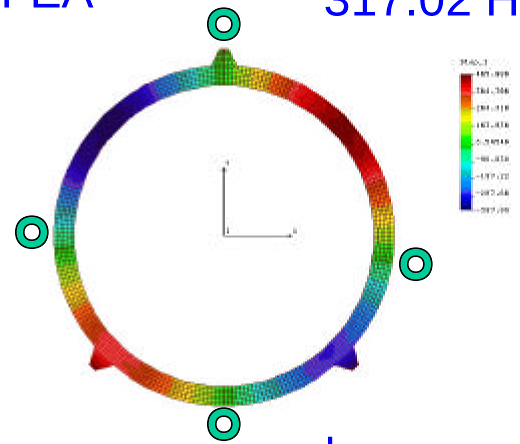
Test load nominally 56g

(2N= 204g=0.45lbf)

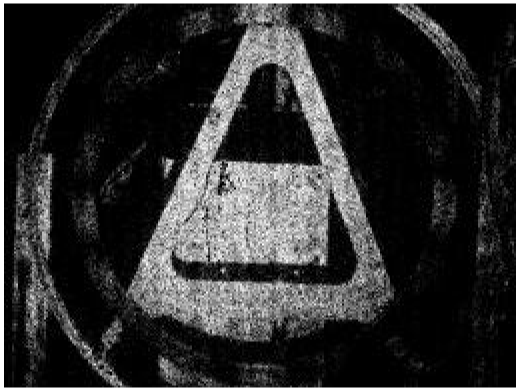
Vibration Tests

- Vibration testing-*Free Free*
  - Removed ring from Invar plate and suspended ring removing any form restraint—to degree practical
  - Measured first two modes holographically
  - Modes
    - 1st 317.02Hz predicted versus 330Hz measured, *3.1%*
    - 2nd 335.9Hz predicted versus 352Hz measured, *4.6%*
- Observations
  - Predicted and measured mode shapes agreed, and the estimated frequencies agreed within 3-5%.
  - Confirms the FEA model approach fro designing composite ring.

FEA 317.02 Hz



nodes



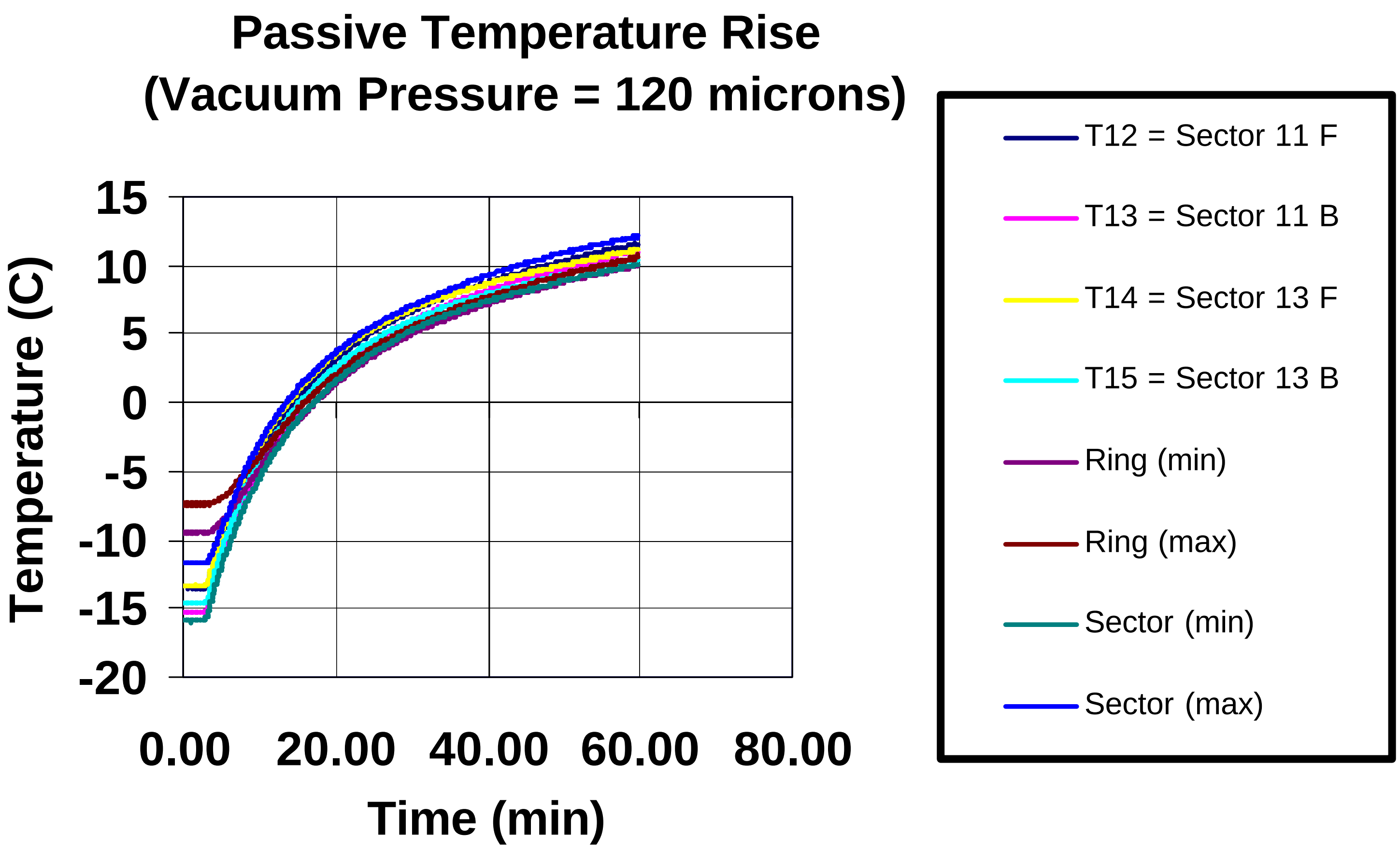
Experimental TVH results-330 Hz

Thermal Testing

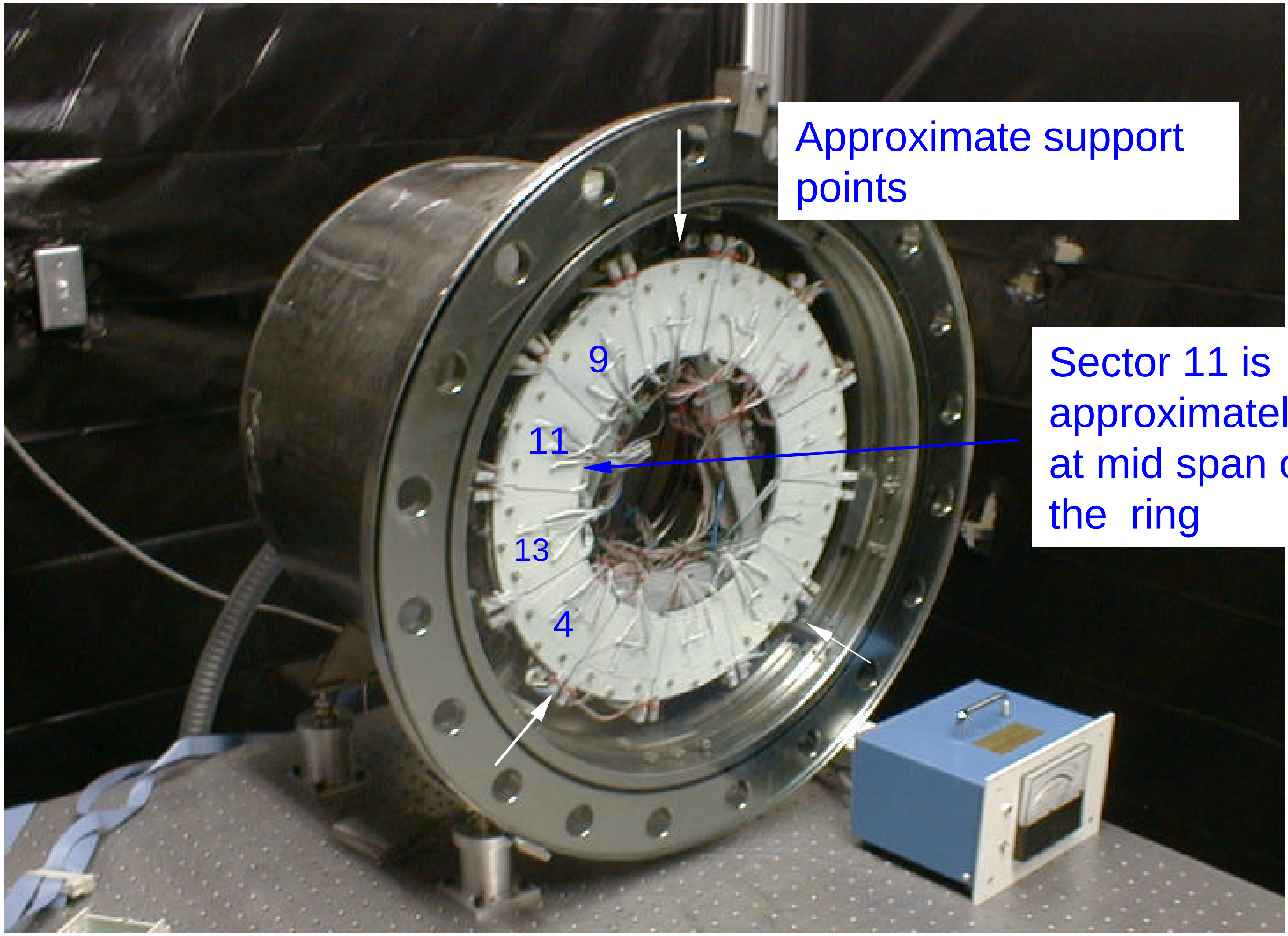
- Method for determining out-of-plane motion
  - Cool-assembly via sectors to -15°C, while in a vacuum chamber
  - Turn coolant circulation pump-off
  - Monitored change in shape as assembly temperature increased
    - Attempted to measure shape changes when ring and sector temperatures are nearly equal
    - Spread in all RTD's < 5 °C
  - Temperature would rise about 1 degrees per minute from external heating
    - Heating largely radiation from surroundings
- Side aspects of initial tests
  - Effects of different materials used in sector and ring construction
    - Measured by out-of-plane shape changes

Thermal Testing

Attempt made to control the sectors and ring temperature within a narrow band during period when holographic data was taken



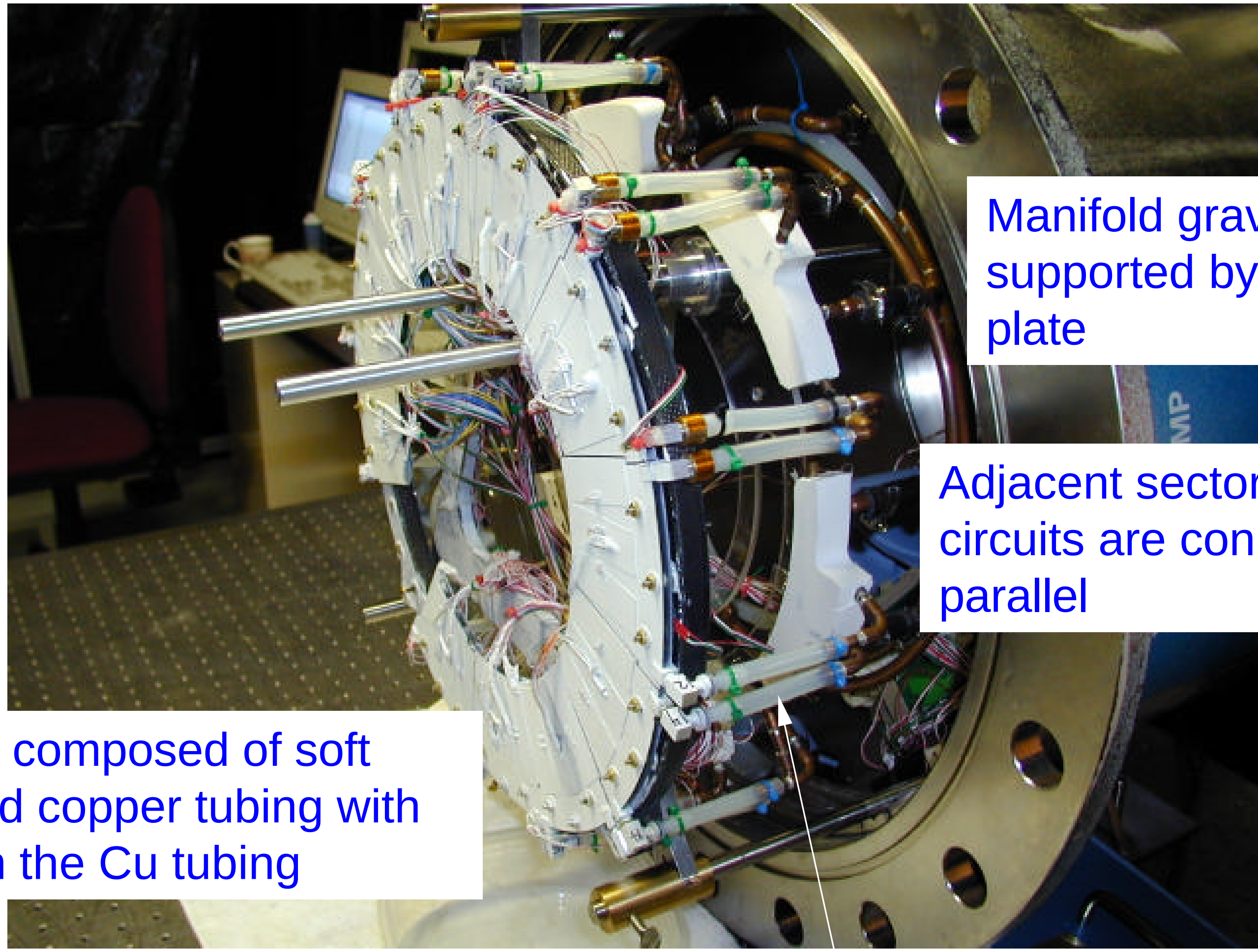
Disk Support Ring



12 Sector Assembly Preparation for TVH Evaluation

Manifold Issues

2-Sectors are supplied fluid in parallel---tank has one inlet and one outlet



Manifold gravity load supported by Invar plate

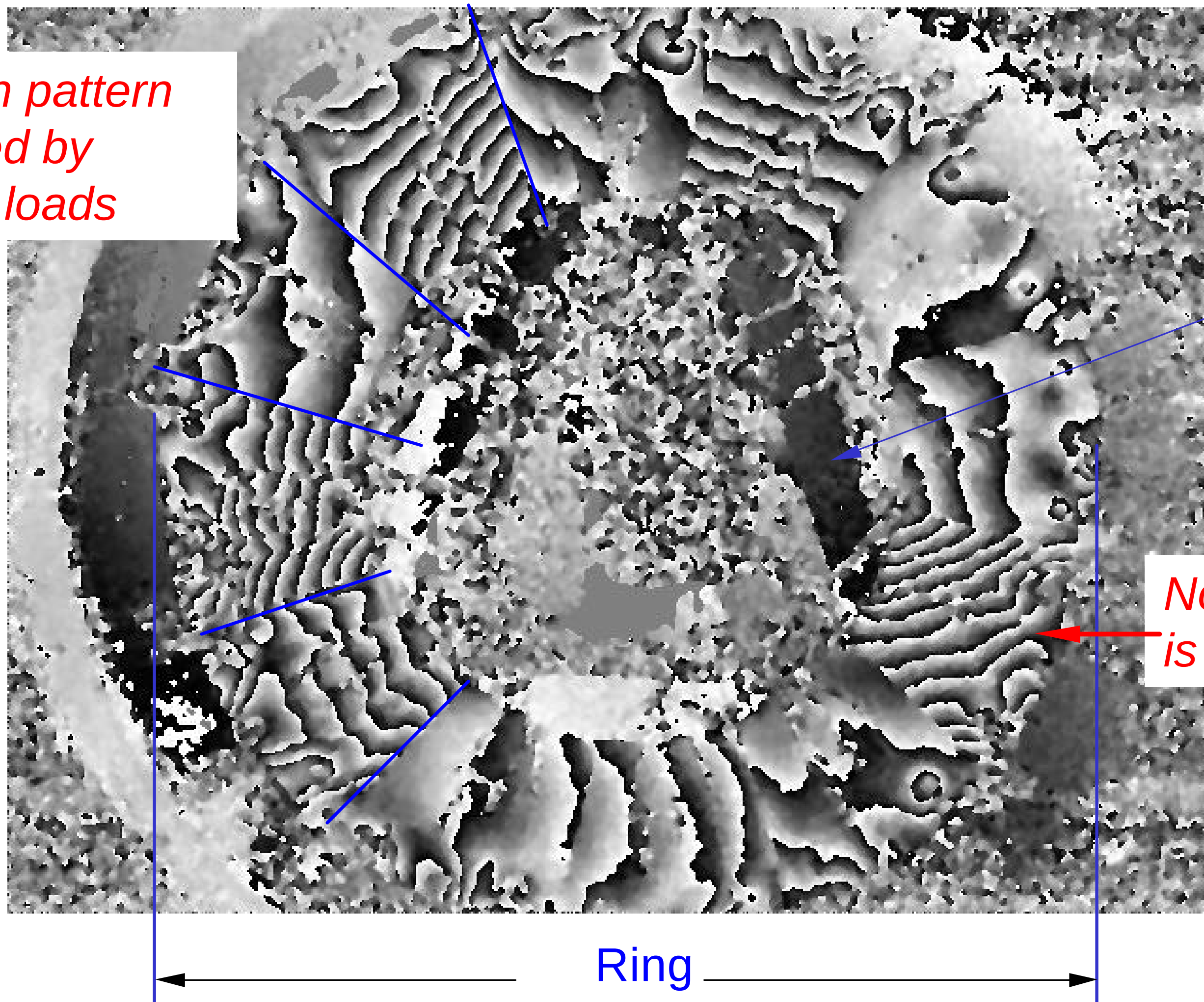
Adjacent sector flow circuits are connected In parallel

Manifold is composed of soft silicone and copper tubing with flow split in the Cu tubing

Compliant tubing to isolate sectors from interconnections, *results in axial pressure load (hopefully constant)*

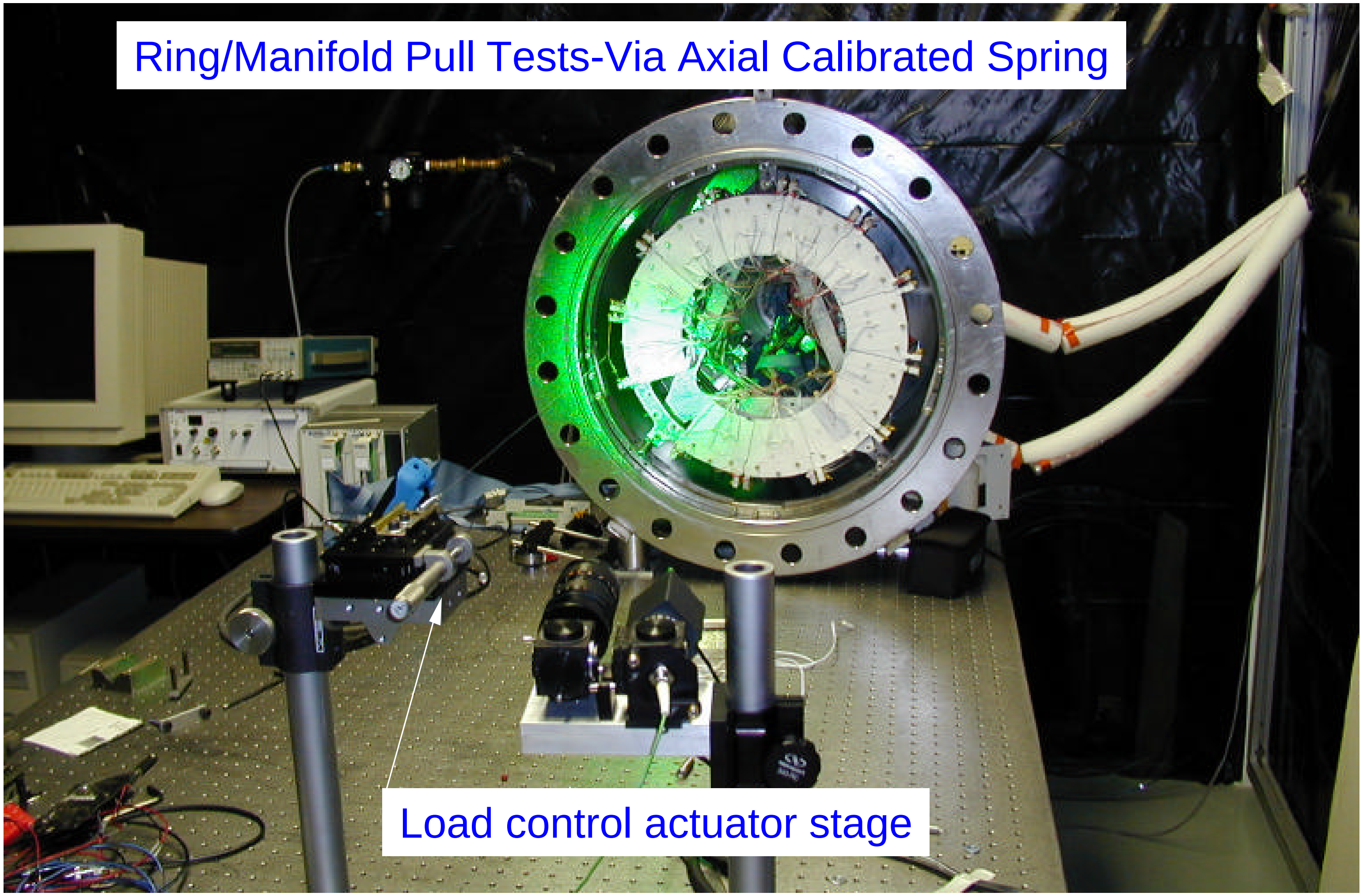
Assembly Thermal Test

Sample of Full Field of View
~1 Degree C Temperature Change



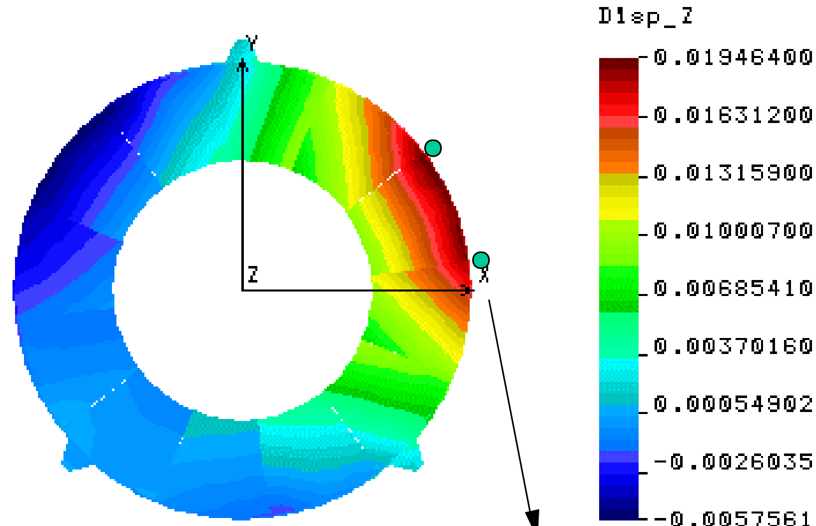
Ring Loads

Static load testing instituted to quantify disk stiffness

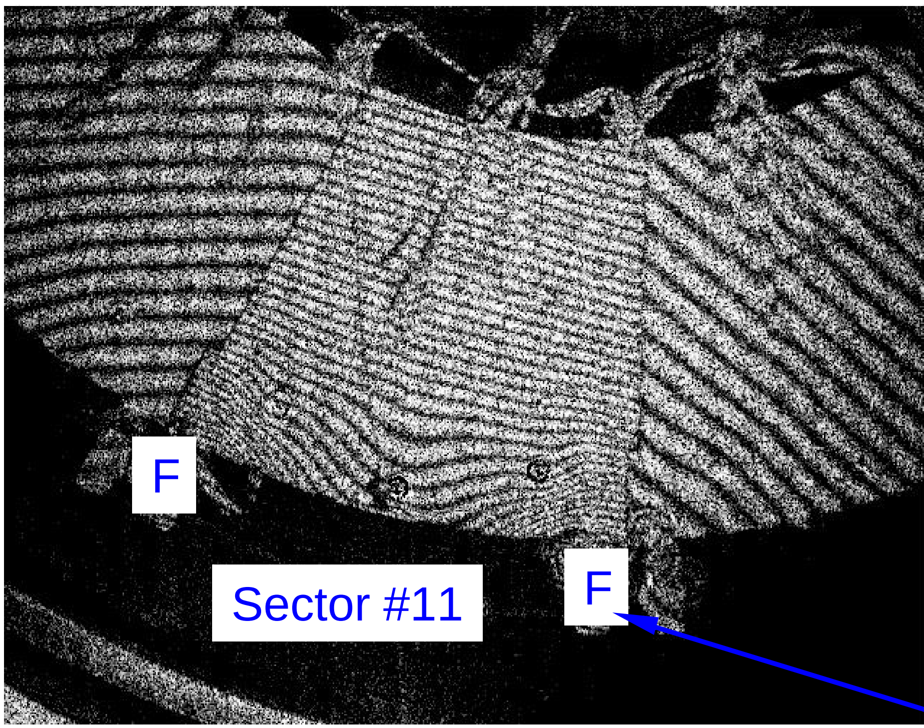


Data Validation

23.8µm/N tilt extracted from ring FEA. Note load was applied at mid-span on outer edge of ring, does not include the entire offset like in test (*sector tilt is about 77.3% of that predicted by FEA*)



Load points at edge of ring, 0.396N total



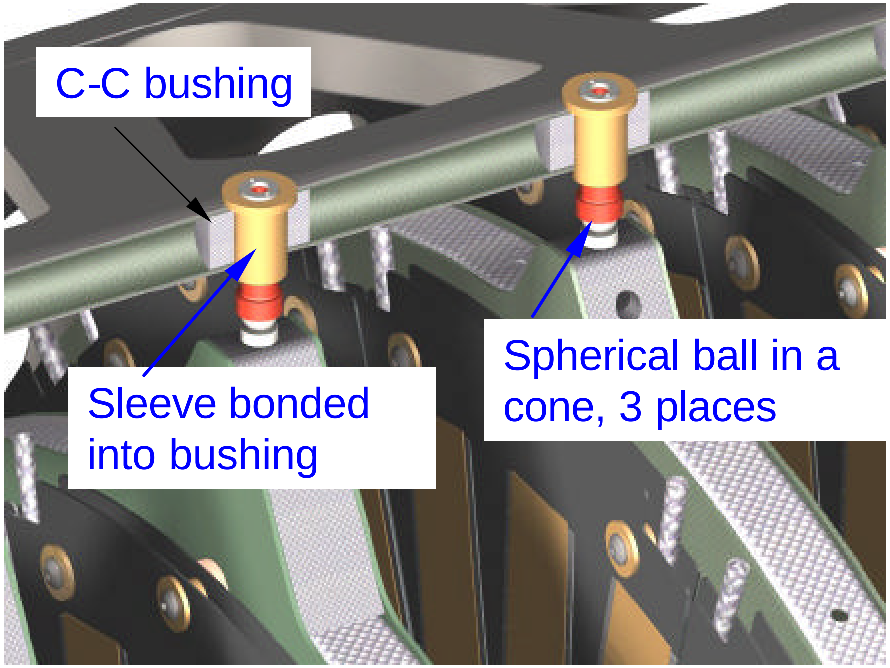
18.4µm/N tilt across the sector, outside mid-edge to *inner* edge obtained by TVH

F-denotes area of load application in test

Ring Mounting

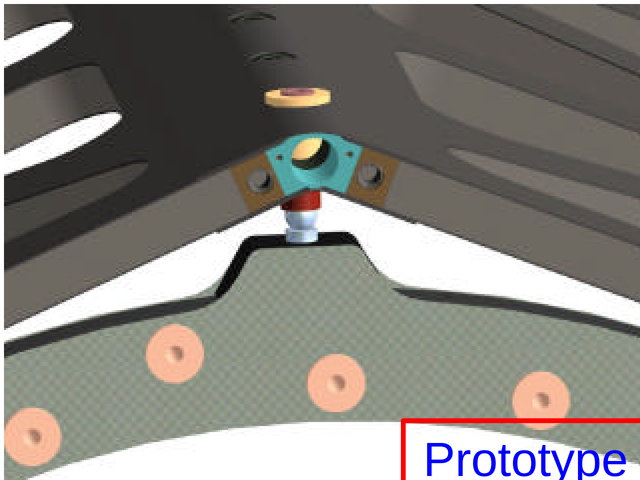
- Improved Radial Mount Concept
  - Connection of ring to the frame is accomplished with an adjustable mount made from PEEK material
  - Adjustment feature is used in the initial set up to facilitate the proper radial positioning of the disk
    - Adjustable mount is bonded to the outer frame of the Global Support structure
    - Differential screw feature is used to disengage the mount conical seat from the spherical ball
      - Upon re-assembly of the disk, alignment is achieved by adjusting the differential screw to its travel limit
- Objective: Ensure little or no compliance from mount would be introduced

View rotated for convenience

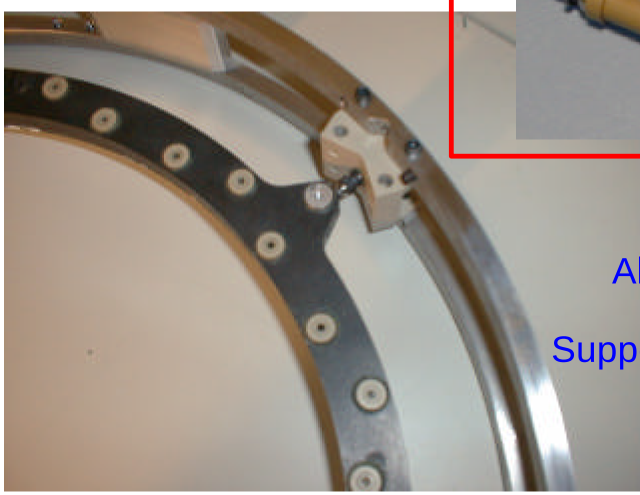


Mount Concepts

Support Ring Radial Mount



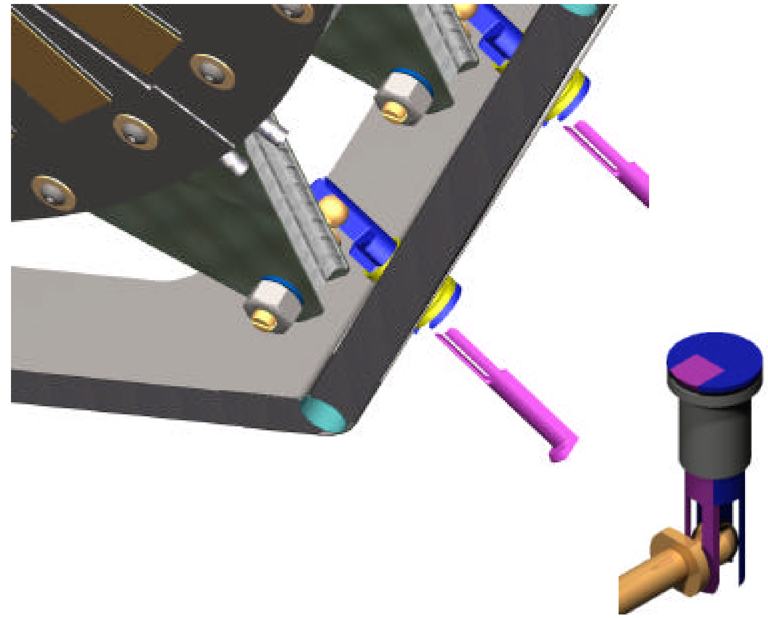
Prototype as tested



Alignment pin

Support ring

Radial Groove Support Ring Concept simulated by mounting in the Invar plate



Prototype-tested

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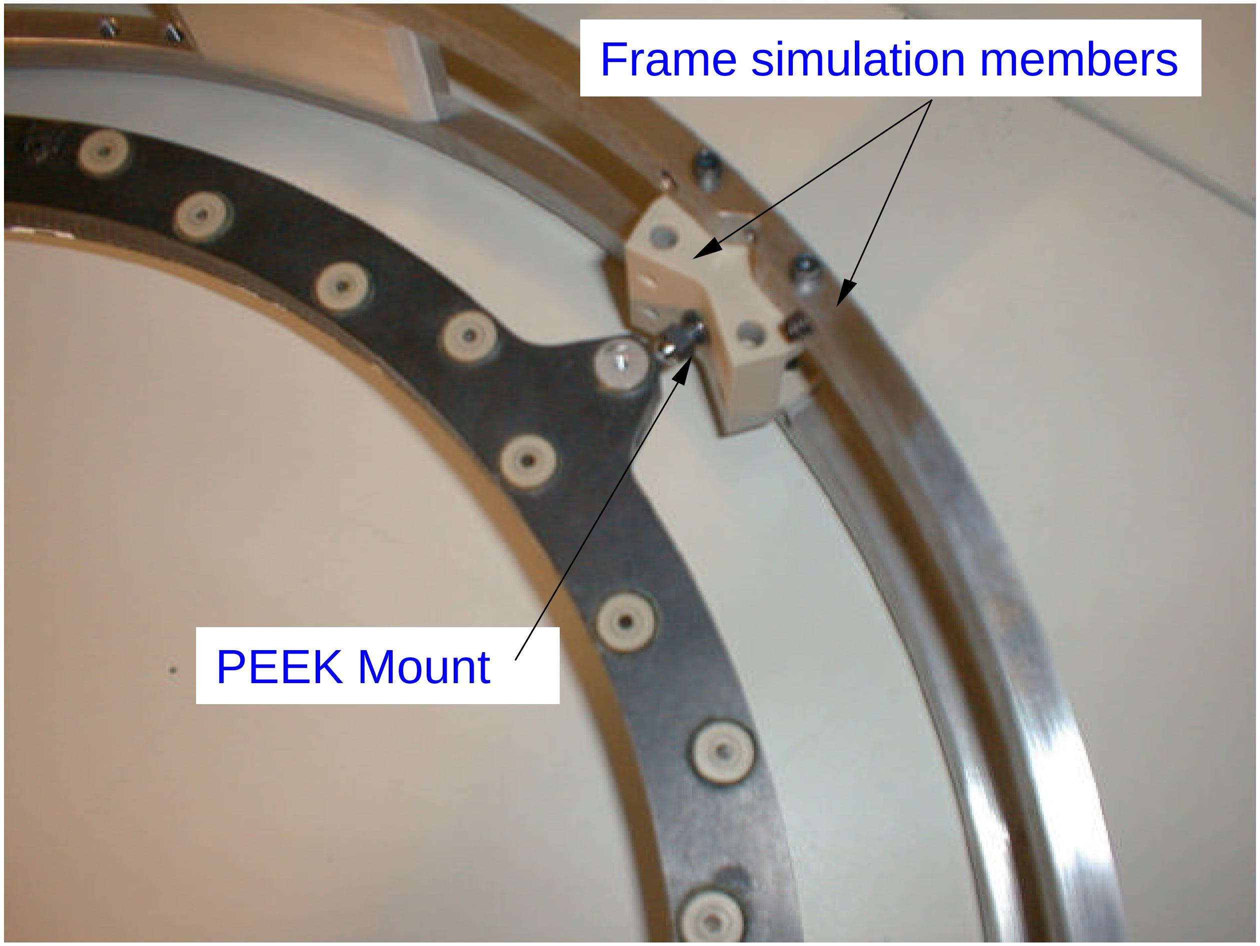
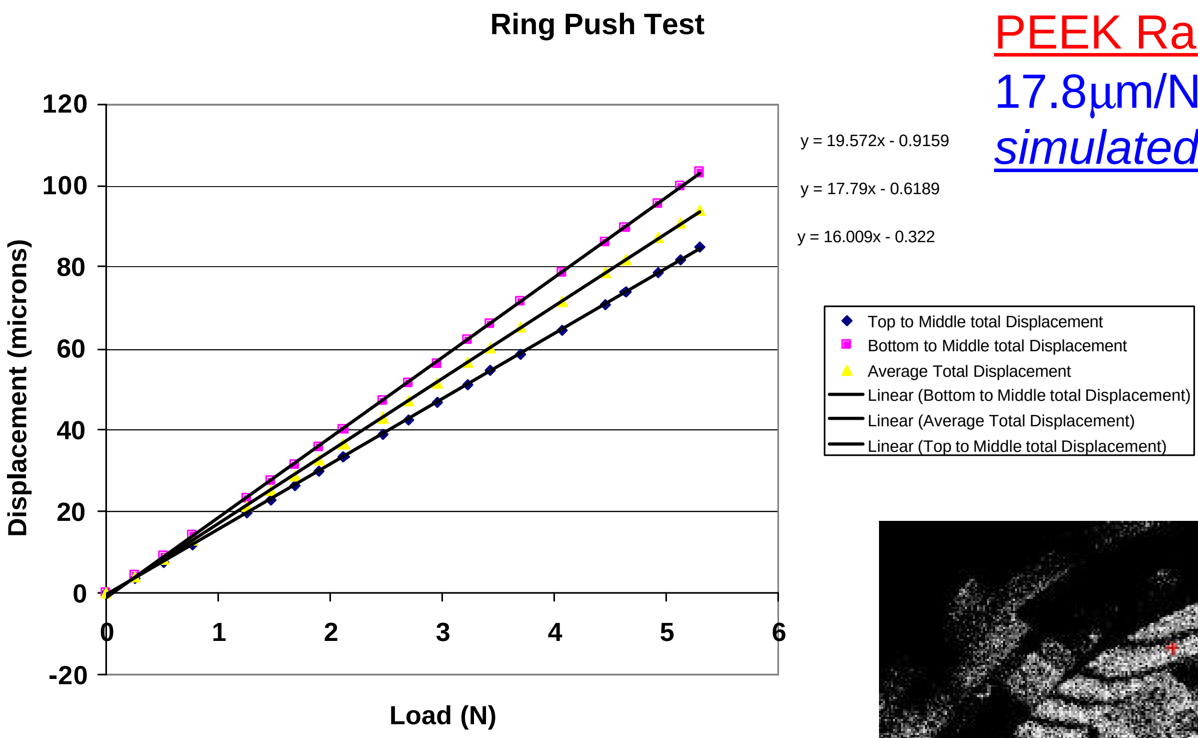
Test Setup

New Radial Mount Concept



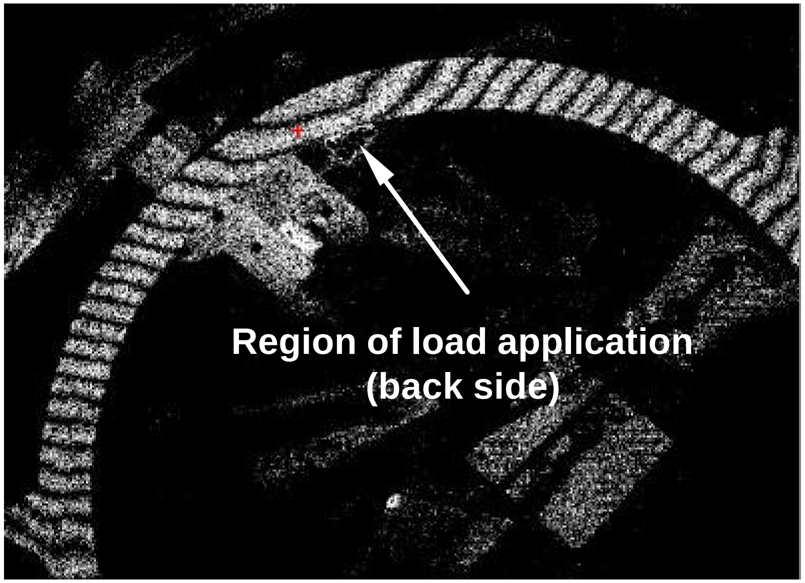
Static Normal Load



<u>PEEK Radial Mount/Ring stiffness</u>

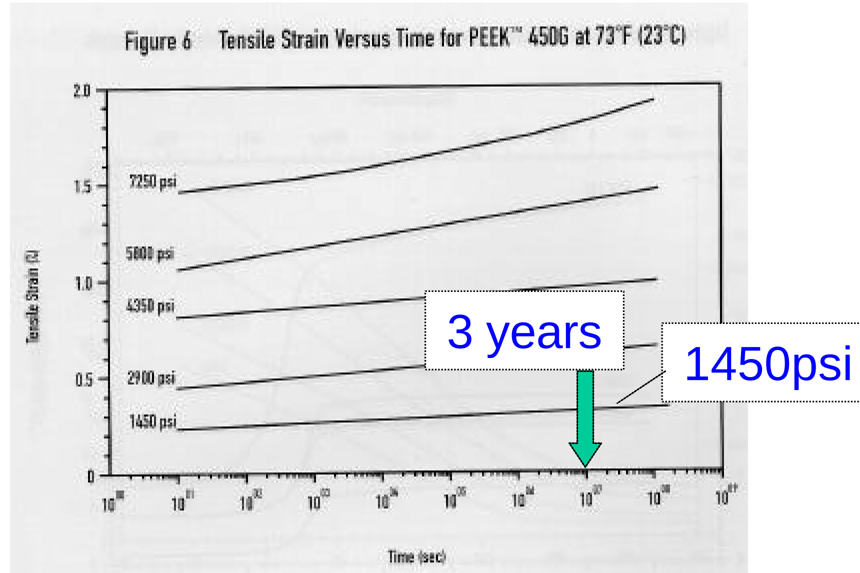
17.8µm/N--- includes connection to <u>*simulated*</u> frame

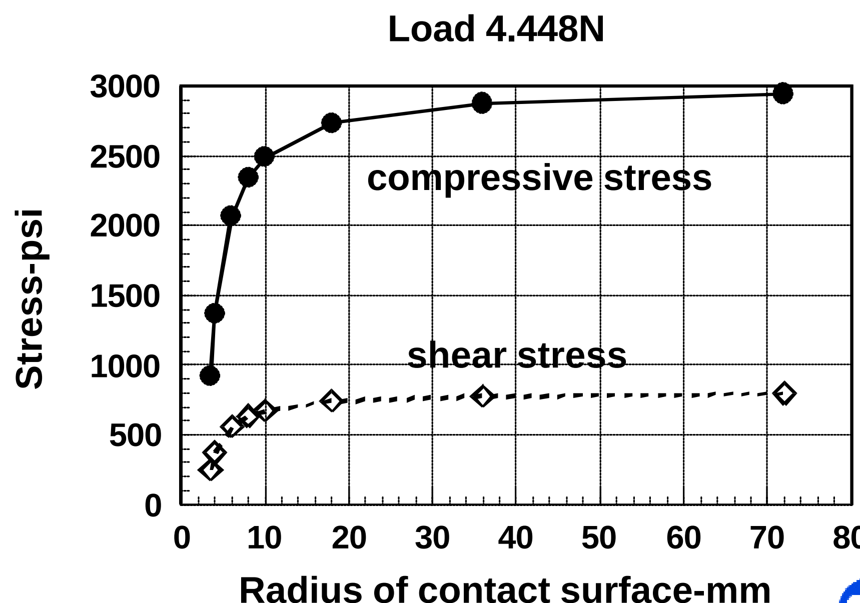
Invar screw mount <u>lacked a simulation of the connection</u> to the frame. Stiffness with the Invar screw mount was 16.6 µm/N.



Mount Creep

- **Potential Creep from High Contact Stress**
  - Spherical ball resides in a conical seat
  - Conical seat is PEEK material
    - Fiber filled, for improved creep properties
  - Concern that creep in mount will cause instability to develop in disk position
- **Problem is alleviated by the conical seat quickly conforming to ball spherical surface**
  - Graph at right shows how contact stress decays dramatically as conical surface at contact point develops conforming curvature
    - Plastic nature of the material
    - Anticipate stresses to be less than 1000psi (6.9MPa)
    - Estimate of seat deformation is 0.03mm
  - Filled PEEK at 1450psi stress will creep 36% over 3 years, assuming no further stress reduction





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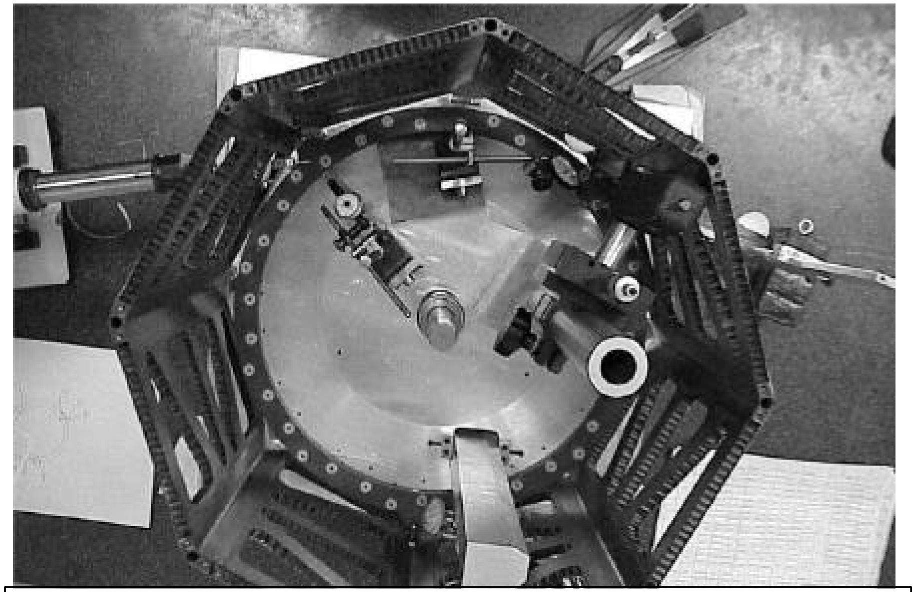
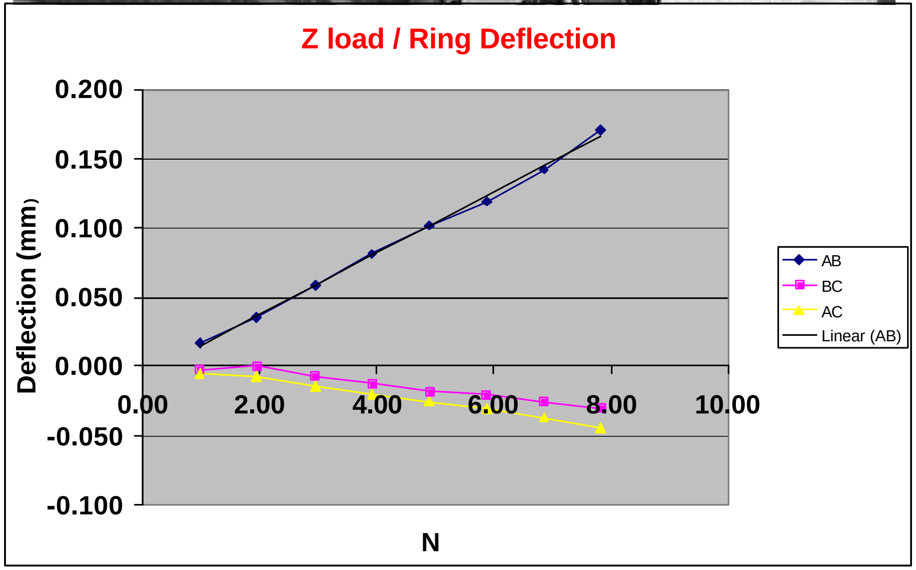
Ring/Mount/Frame Test

- Ring mounted in Global Support frame section by Fred Goozen at LBNL
  - Tooling designed for precisely boring the frame and locating the three radial mounts for supporting the ring
  - Frame is supported on 8 columns, at the frame attachments points
  - Mounts are bonded in the frame corners (longitudinal tubes)
- Load testing
  - Static load applied at mid point between ring support points, duplicating technique used in previous holographic testing of ring
  - Load/deflection curve fit shows 22µm/N slope
    - Previous HYTEC test of ring outside of composite frame yielded 17 µm/N
    - Small increase in compliance is ascribed to the mount/frame combination





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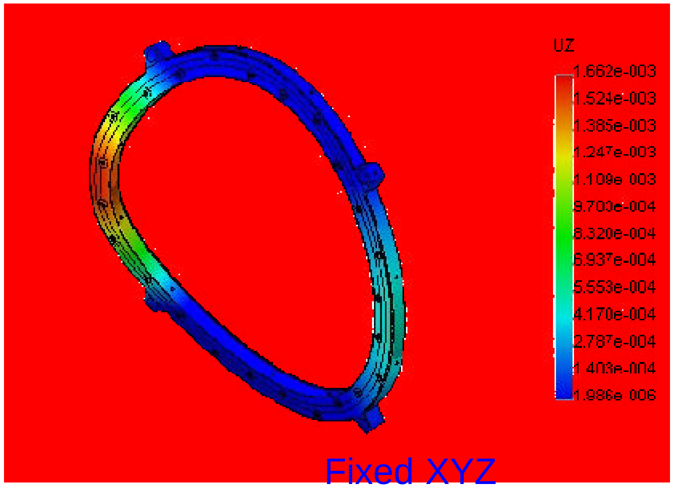
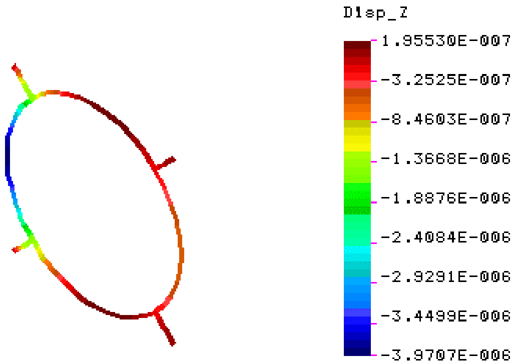
Assembled Stiffness

- *FEA of ring at Frame Level-8 Sector Design*
  - Upper FE model is a shell model of the 432mm frame ring
    - Support point connecting to mount is fixed
    - Stiffness, 1N load normal to ring 1.66μm/N
  - Lower FE model is a beam model representation in the Global support model
    - Representation for the mounts *and the connection compliance to the sandwich frame*
    - Stiffness, 1N load normal to ring 3.97μm/N
- *New 4-Mount/Ring Design is theoretically roughly 10 times stiffer than 3-Mount/Ring Design*
  - *Possible that new frame model is overestimating compliance*





Connects to frame model

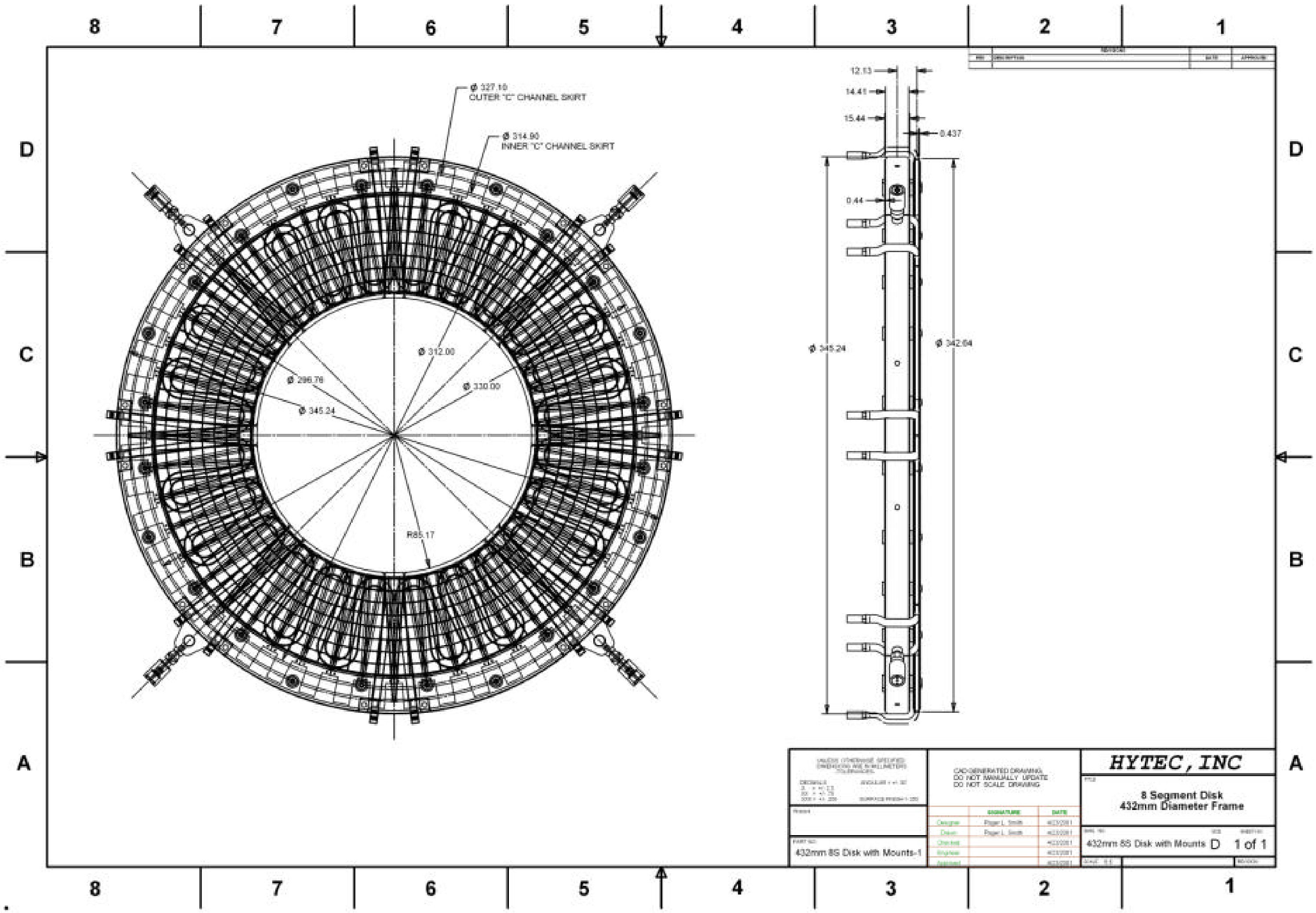
Development Summary

- Salient points of Prototype Development
  - FEA approach to simulating ring design produced results that correlated well with measurements
  - Conducted rather extensive testing of ring and mounts, *and interaction with frame*
    - *Tests included the actual proposed PEEK ring support mounts and the frame construction details*
  - Based on the FEA and testing, a decision was made to increase number of support points from 3 to 4
    - Extraneous service loading on ring is not well known, this situation pushed the decision
  - Dimensional quality of the ring
    - Reasonably good, but improvements are desired in the area of the C-Channel and the ring flatness
    - Decision made to control the sector mounting pattern to provide interchangeability between any sector, and sector position
  - Method of precisely locating and bonding the ring mounts in the Global Support frame has been demonstrated by LBNL
    - An average of 27 measurements taken on the ring in the vicinity of the three mount positions and they were found to be planar within 43 µm
      - A modified set up and bonding procedure for the mounts is planned in the interest of achieving closer to 25 µm
    - This milestone eliminates considerable uncertainty in construction of the disk region
    - Further tests will be conducted to measure the dimensional consistency in mounting, demounting, and remounting a ring assembly.

8-Sector Ring

- Redesign Progress for Ring
  - Ring construction drawings (and FEA studies) are complete
  - Tooling drawings for forming C-Channel are in complete
    - Plan on making ¼ ring segments and reversing molding to improve on dimensional quality
  - Ring bonding fixture concept
    - Change to method for locating bushings
      - Tight positional tolerance is being assigned to the sector three hole mounting pattern, permitting a slight relaxation of the global hole pattern
      - Will use a *"mistress gage"* with sector three hole pattern as a master, which will *ensure interchangeability* between sectors
- Prototypes of the new ring are planned
  - Starting with new C-Channel design (reverse mold)
  - With confirmation of the C-Channel dimensional aspects, a production ring sample will be made
  - Anticipate confirmation of ring construction by year end
- Ring Mounting
  - Further tests are planned to verify repeatability of placement

8-Sector Design



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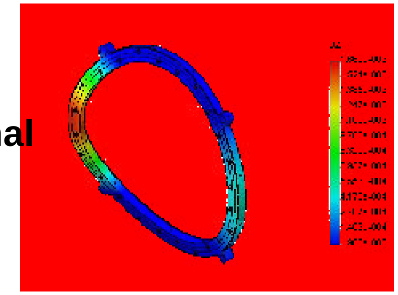
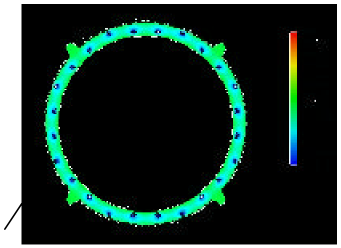
Ring Analysis

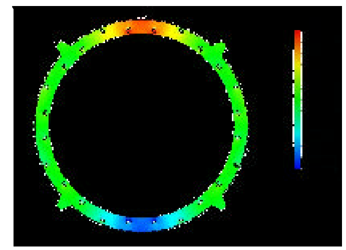
- 8-Sector Ring FEA studies to qualify reduced dia design
  - *Z-Stiffness*, normal to ring measured at mid span, **1.7μm/N versus 23.5 μm/N** for larger dia ring with 3 supports (same for PEEK and C-C bushings)
  - *R-stiffness*, 4 radial loads simulating differential expansion with frame, **0.12 μm/N** (0.55 μm/lbf) (same for PEEK and C-C bushings)
  - *Z-Thermal distortion*, for 40°C temperature change the nominal out-of-plane distortion is:
    - **PEEK** inserts-**19.3μm**
    - **3D CC-0.38 μm**
  - *R-thermal distortion,* again for 40°C temperature change the nominal X-Y distortion is the same for either bushing (apparent α=-0.87ppm/°C) :
    - Assuming no thermal change in the frame, the ring distortion becomes **6μm** for both PEEK and 3D CC
  - Rϕ- sector position change, potential for ϕ- shift of 6 **μm**
- *Construction recommendations,* change from PEEK to 3D CC bushings, beneficial effect on out of plane distortion

Force normal

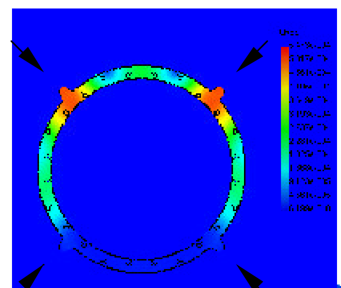




40°C ΔT



4-radial forces



Remaining Issues

- Stiffness
  - In spite of insufficient experience base with actual service loads, it is believed that going to a 4-point support will provide adequate stability for the disk assembly
  - Fall back position
    - Ring mount concept can be expanded to 8-point if judged absolutely necessary
      - Theoretical increase, another factor of 8 in out-plane-stiffness
- Construction precision *improved by 3-factors*
  - First, smaller ring will improve as-bonded dimensional quality
  - Second, additional steps being taken to achieve complete interchangeabiliy at sector level
  - Third, new C-Channel method of consolidation will improve ring quality
    - Method will be demonstrated before fall