FE Study of Thermal Stability of the Multiple Fresnel Zone Plates Precision Alignment Apparatus for Hard X-Ray Focusing

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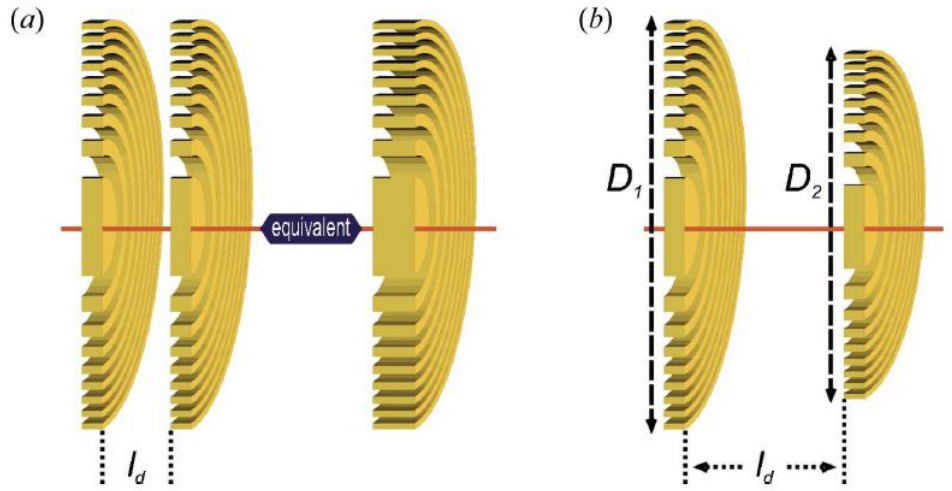
Outline

- Background
- Thermal Analysis
  - Z2-33
    - Environmental effect
    - Operational effect
  - Z2-34
    - Environmental effect
  - Z2-37
    - Environmental effect
    - Operational effect
    - Thermal stability over time: compensation
- Summary

Background

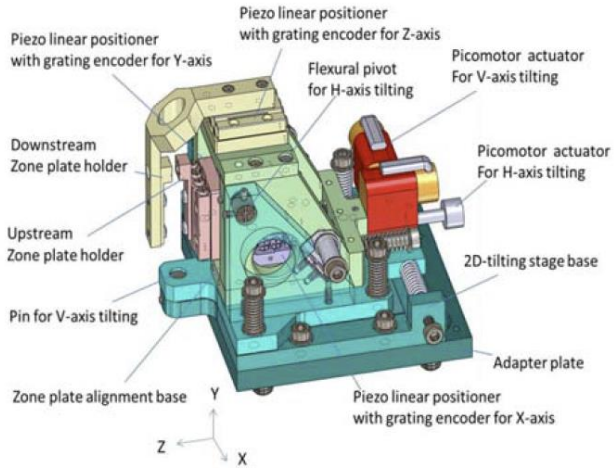
- Efficiency of FZPs depends on the aspect ratio of the height to the zone width
- Efficiency can be increased by stacking of multiple zone plates in the intermediate-field



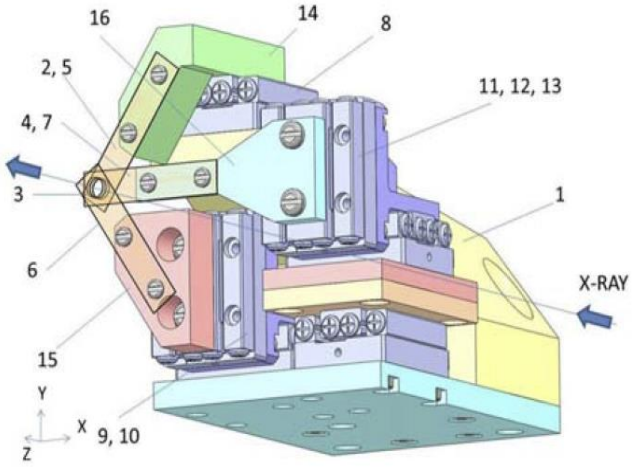
Stacking of two zone plates
J. Vila-Comamala et al. 2012

Background

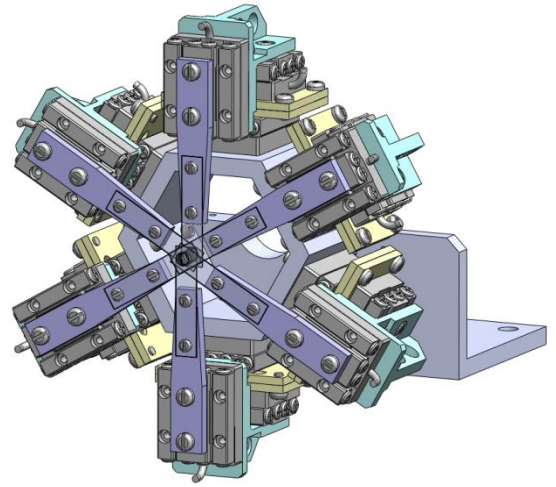
- Precision zone plate alignment apparatuses have been designed and tested at APS



Z2-33



Z2-34



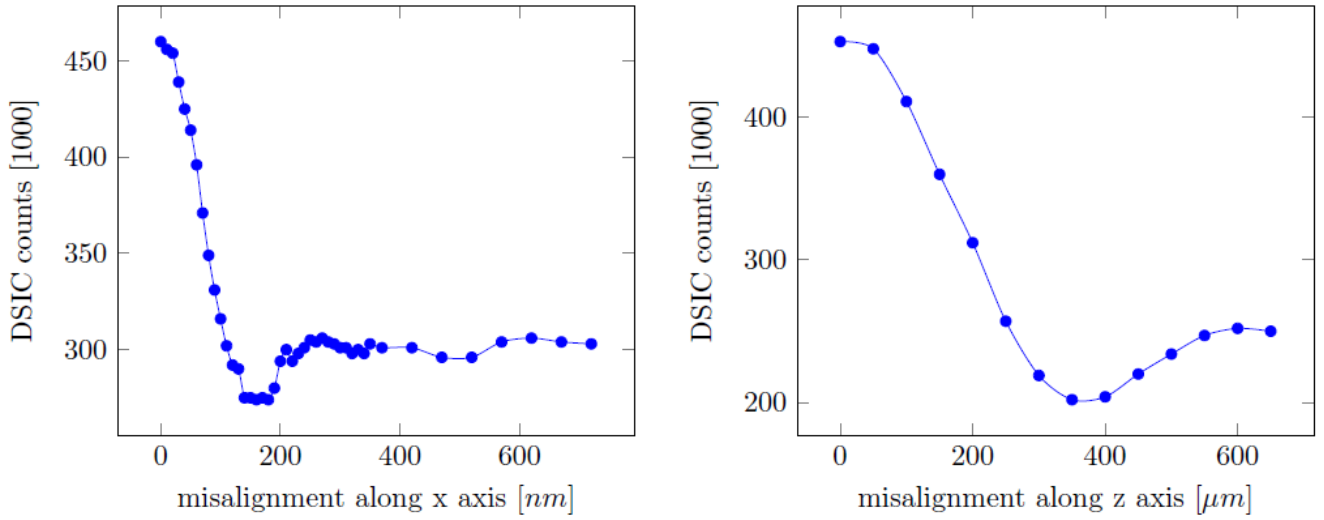
Z2-37

D. Shu et al. U. S. Patent application in progress for ANL-IN-13-092

Background

Challenges:

- High precision in alignment
- Stability of the apparatuses
- Relative stability between FZPs for over 8 hours
  - Less than 30nm misalignment



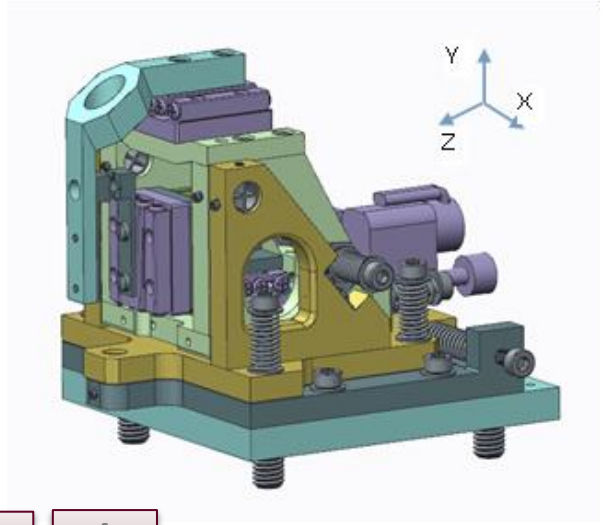
Efficiency decrease due to misalignment
S. Gleber et al.

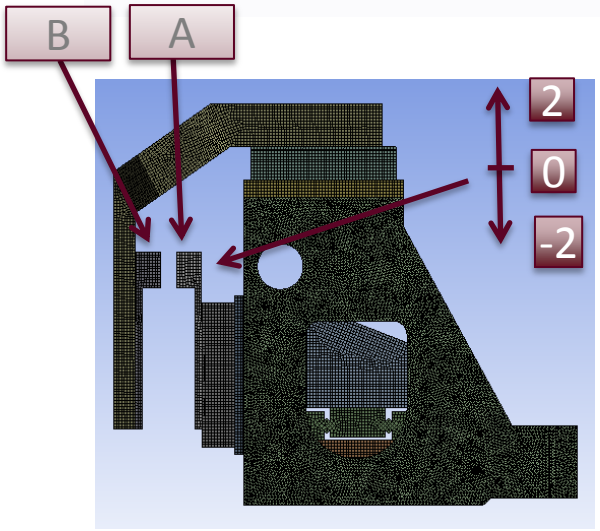
Finite Element Study

- **Environmental effect**
  - Temperature change vs. Displacement
- **Operational effect**
  - Constant Heat load from motors in the stages
  - Transient thermal of motor operations
- **Thermal stability**
  - Compensation for thermal displacement

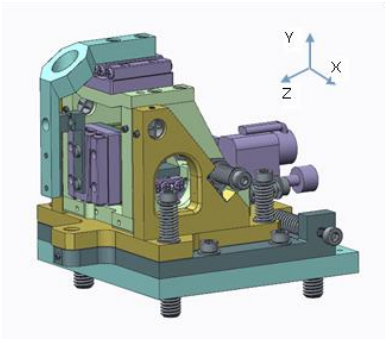
Finite Element Study - Z2-33 Model

- Two zone plates stacking
- Symmetric Structure
- Al6061 was used to make the prototype
- Holder material can be changed to minimize the relative shift



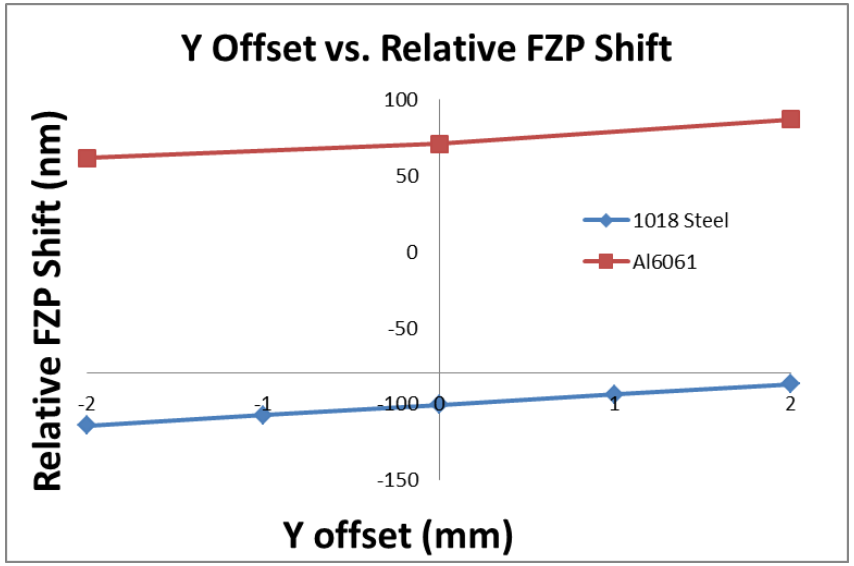


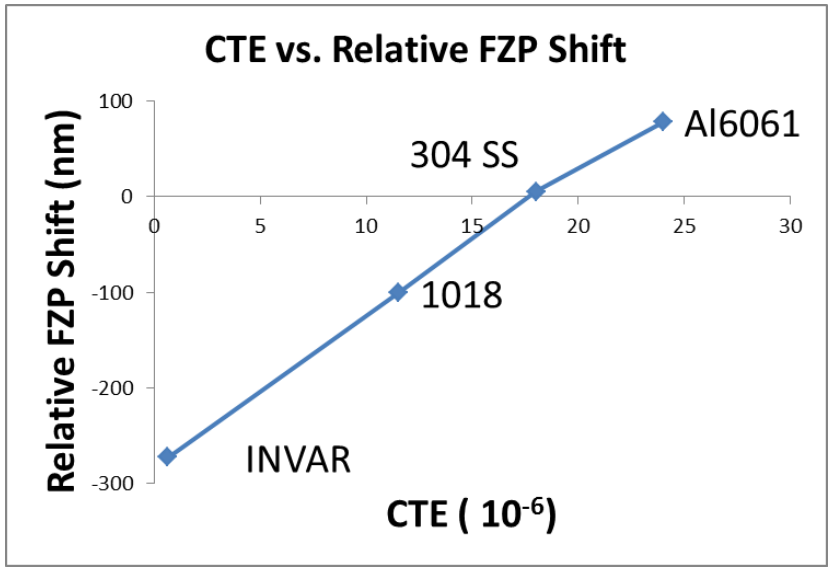
Finite Element Study - Z2-33 Results



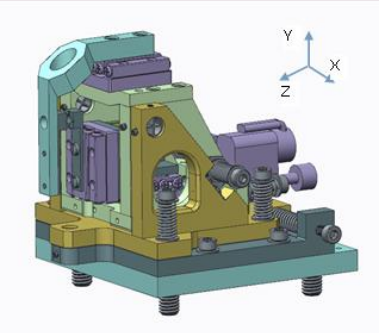
Temperature variation effect

- Temperature variation cause FZPs to shift relative to each other
- Linear relationship between Y offset and relative FZP shift
- Close to linear relationship between CTE and relative FZP shift
- Can be used to select the optimum location for FZPs



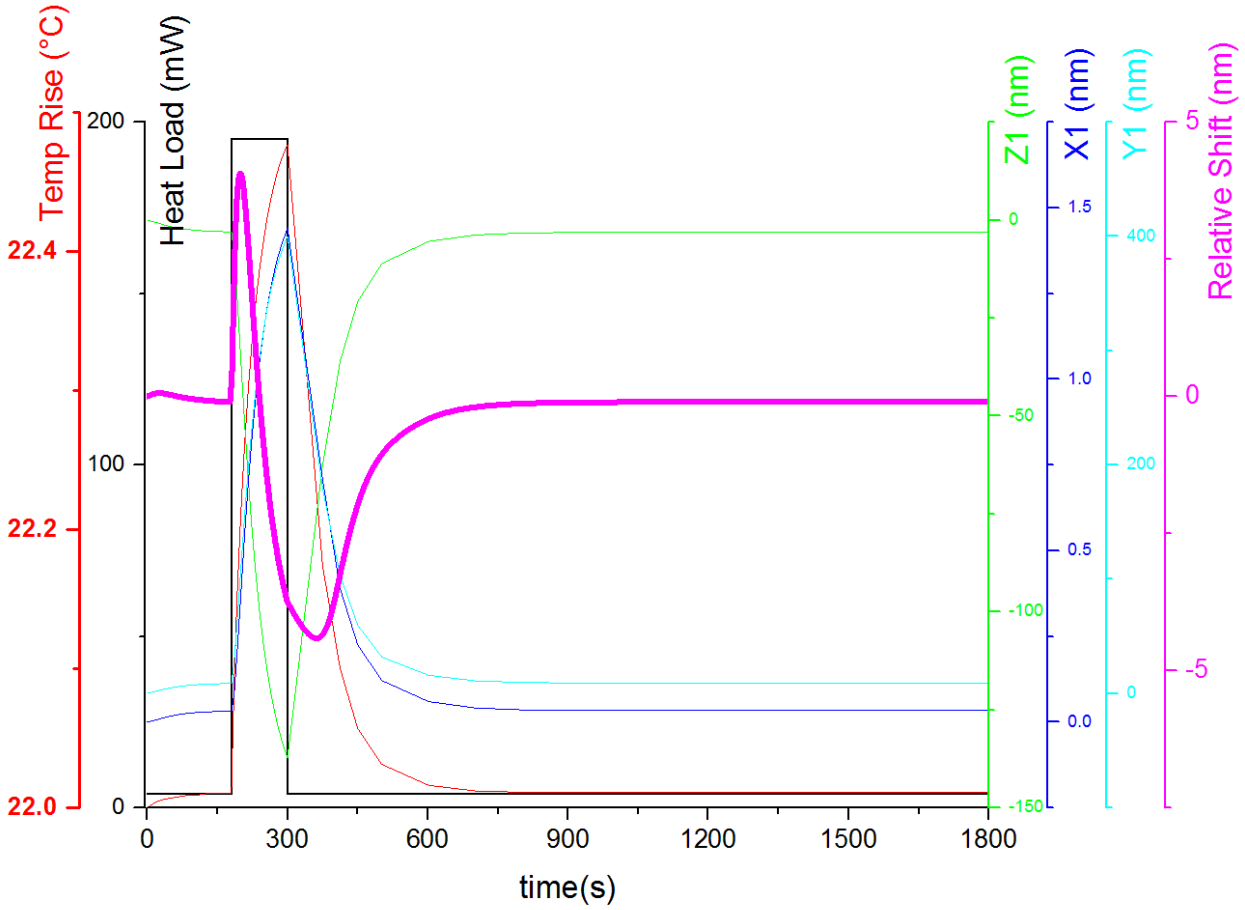


Finite Element Study - Z2-33 Results



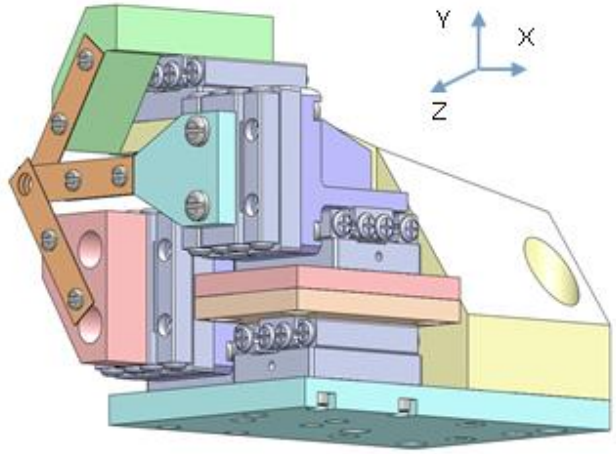
Operational Effect

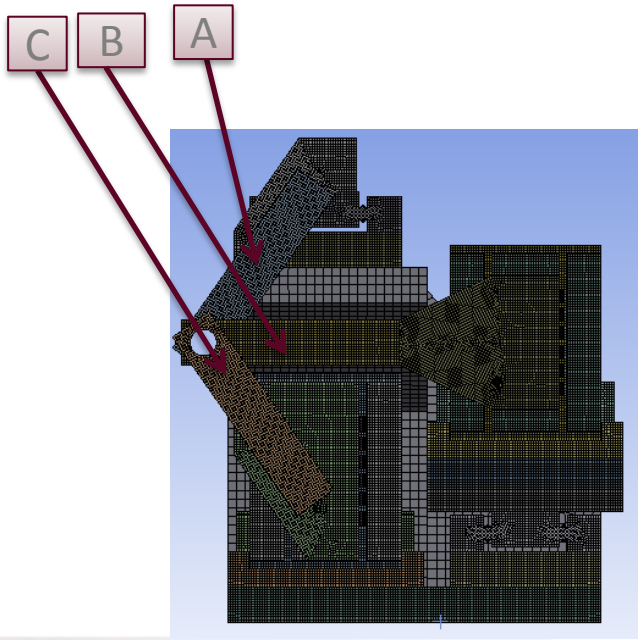
- All three stages have constant power dissipation of 4mW from motor when not moving and 195mW when move
- Instant temperature rise with motor operation
- Cool down in about 10 minutes in air convection
- The relative FZP shift changes with temperature change



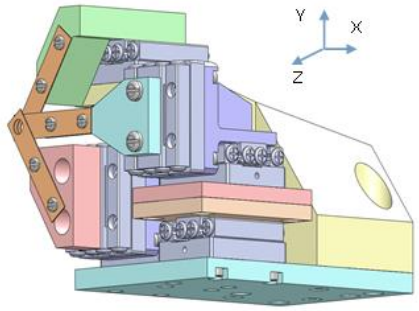
Finite Element Study - Z2-34 Model

- Three zone plates stacking
- Non-Symmetric Structure
- Invar was used to make the prototype

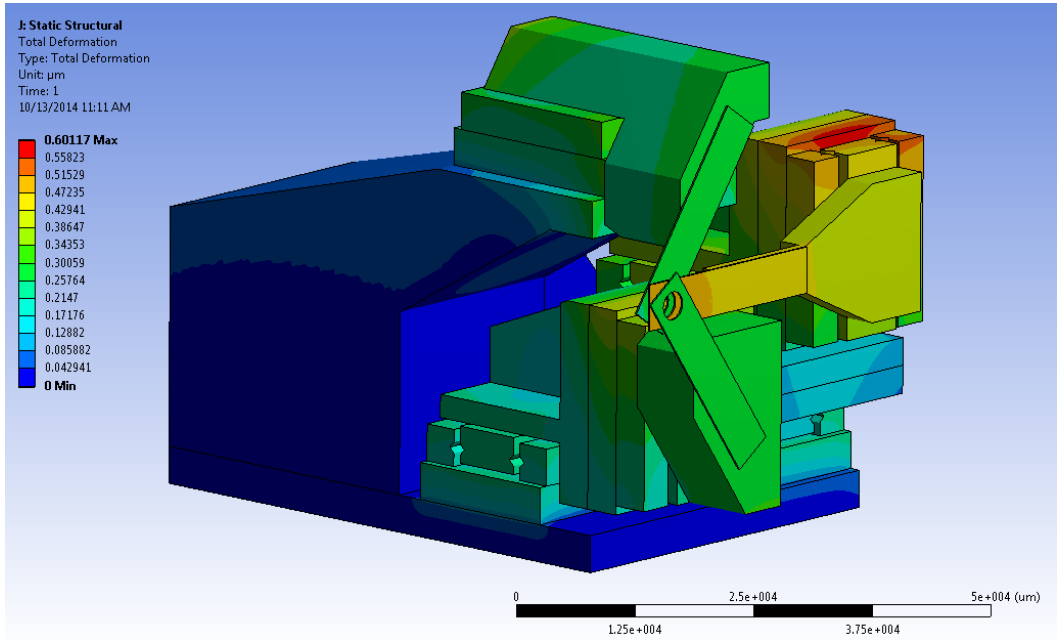




Finite Element Study - Z2-34 Result

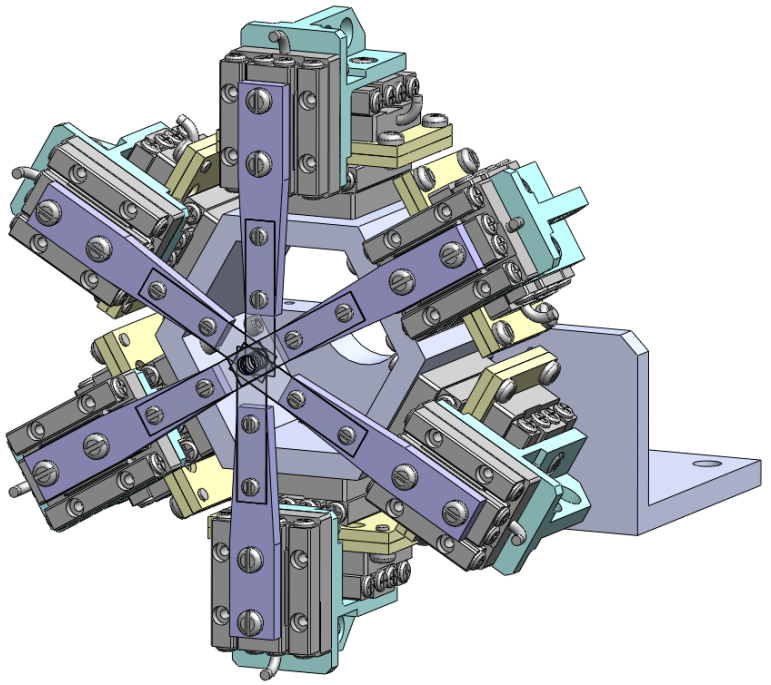


- Sensitive to temperature variation, so the temperature control of the environment is very critical
- Shift in X direction: 110nm
- Shift in Y direction: 270nm

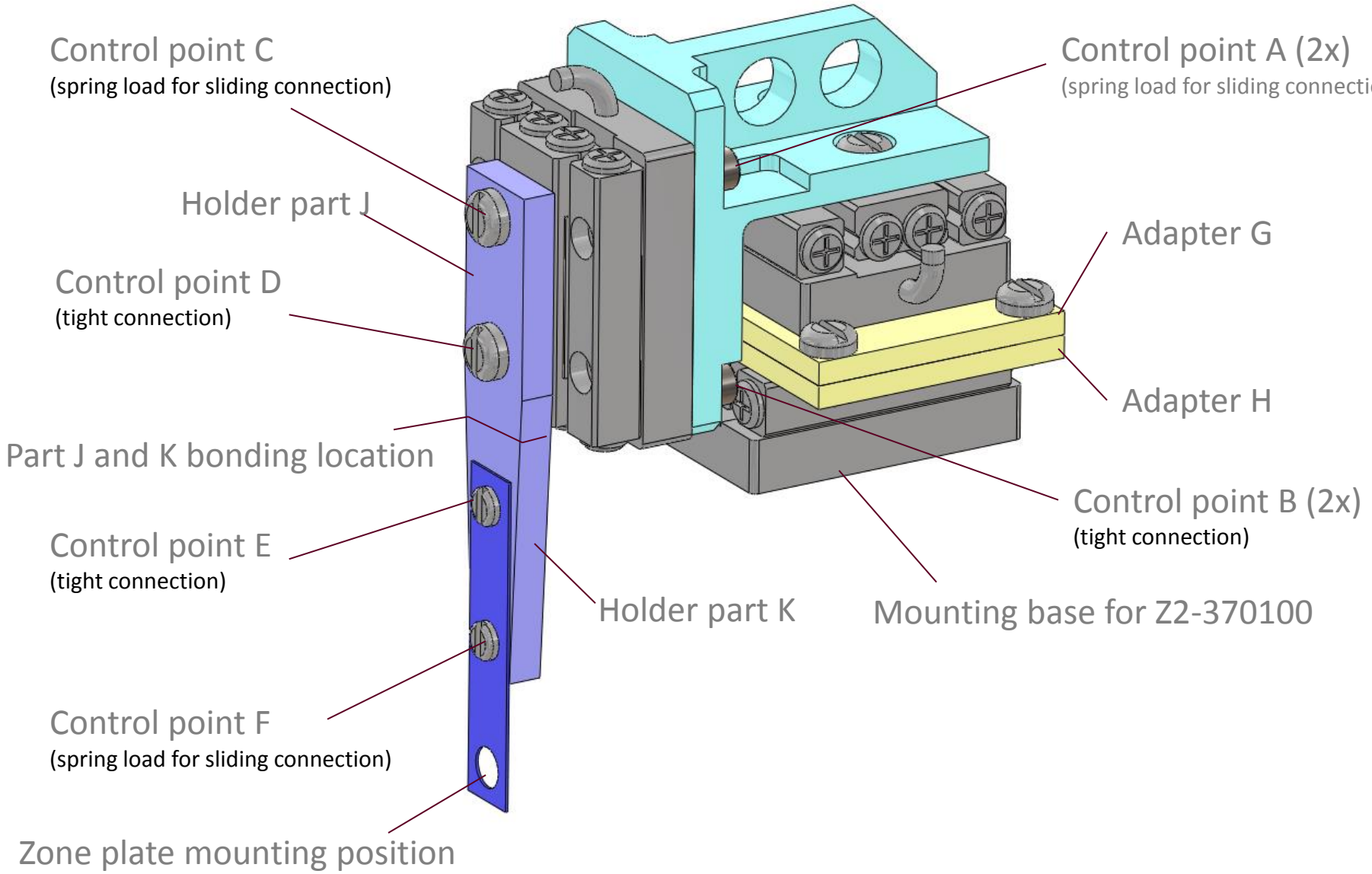


Finite Element Study - Z2-37 Model

- Six zone plates stacking
- Symmetric Structure
- Identical arms mounted on a hexagon invar base
- Materials for the mounting plates and linkage components can be selected to compensate the thermal deplacement
- FZP location can be adjusted to compensate the thermal displacement

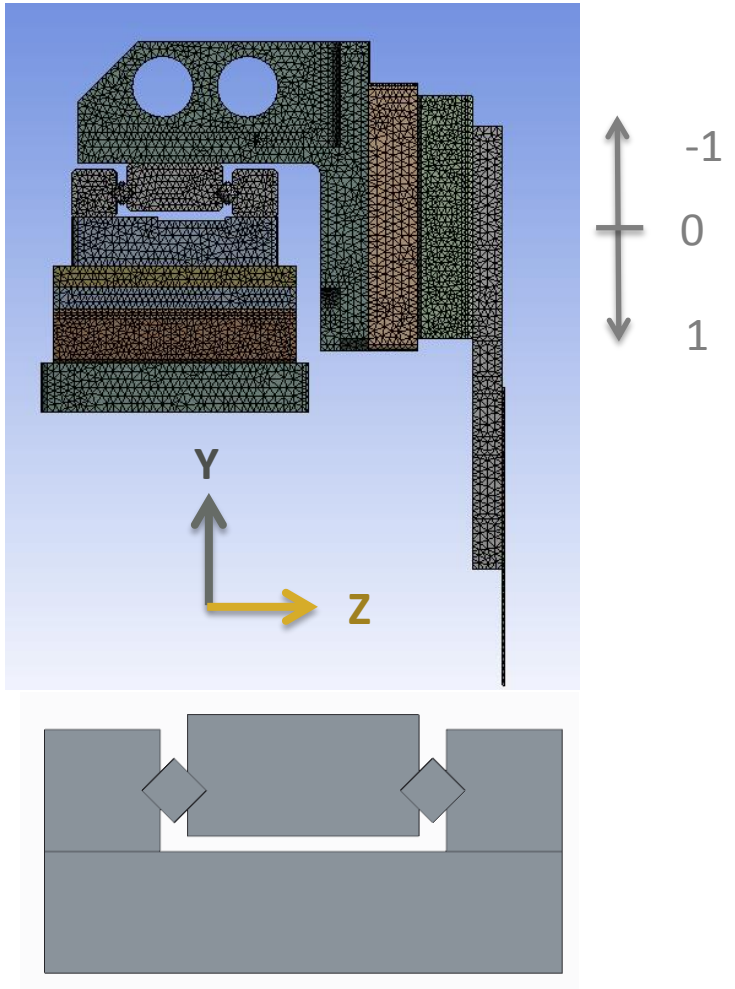


Finite Element Study - Z2-37 Model



Finite Element Study - Z2-37 Model

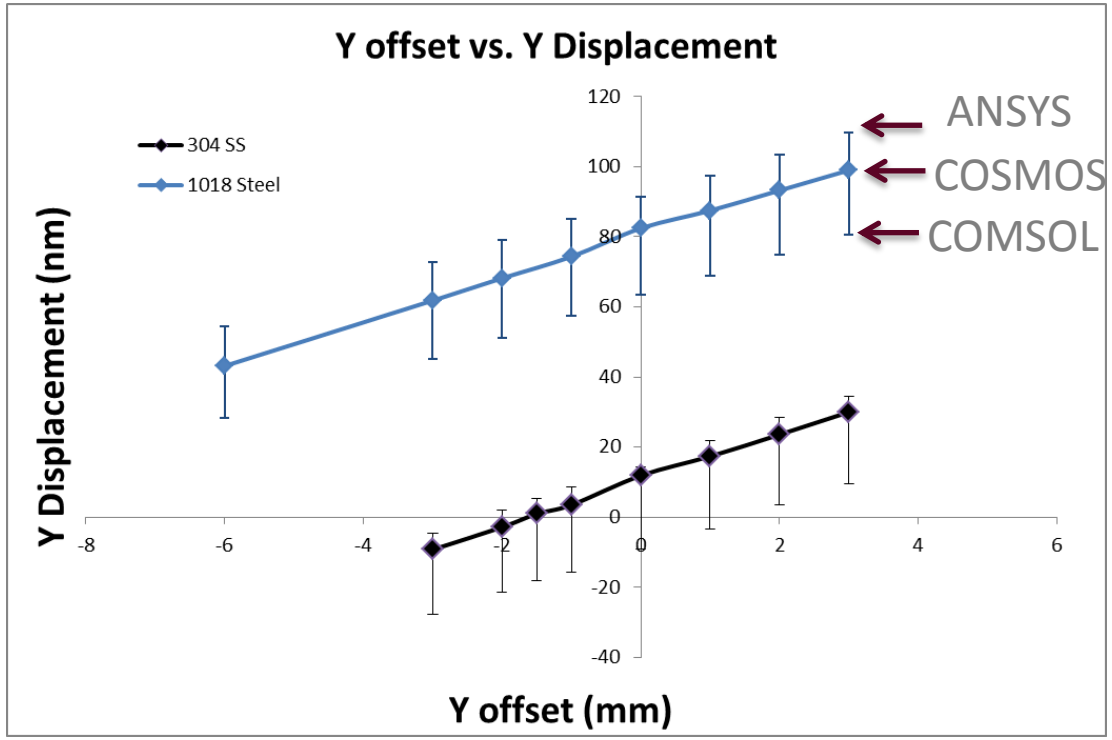
- Individual module
- Stage with cross-roller bearings
- Boundary condition
  - Air convection cooling
  - Constant temperature at far end surface
- Load
  - Case 1: Uniform temperature rise at different Y positions
  - Case 2: Transient temperature rise and deformation due to heat load from motors
  - Case 3: Material selection for thermal compensation



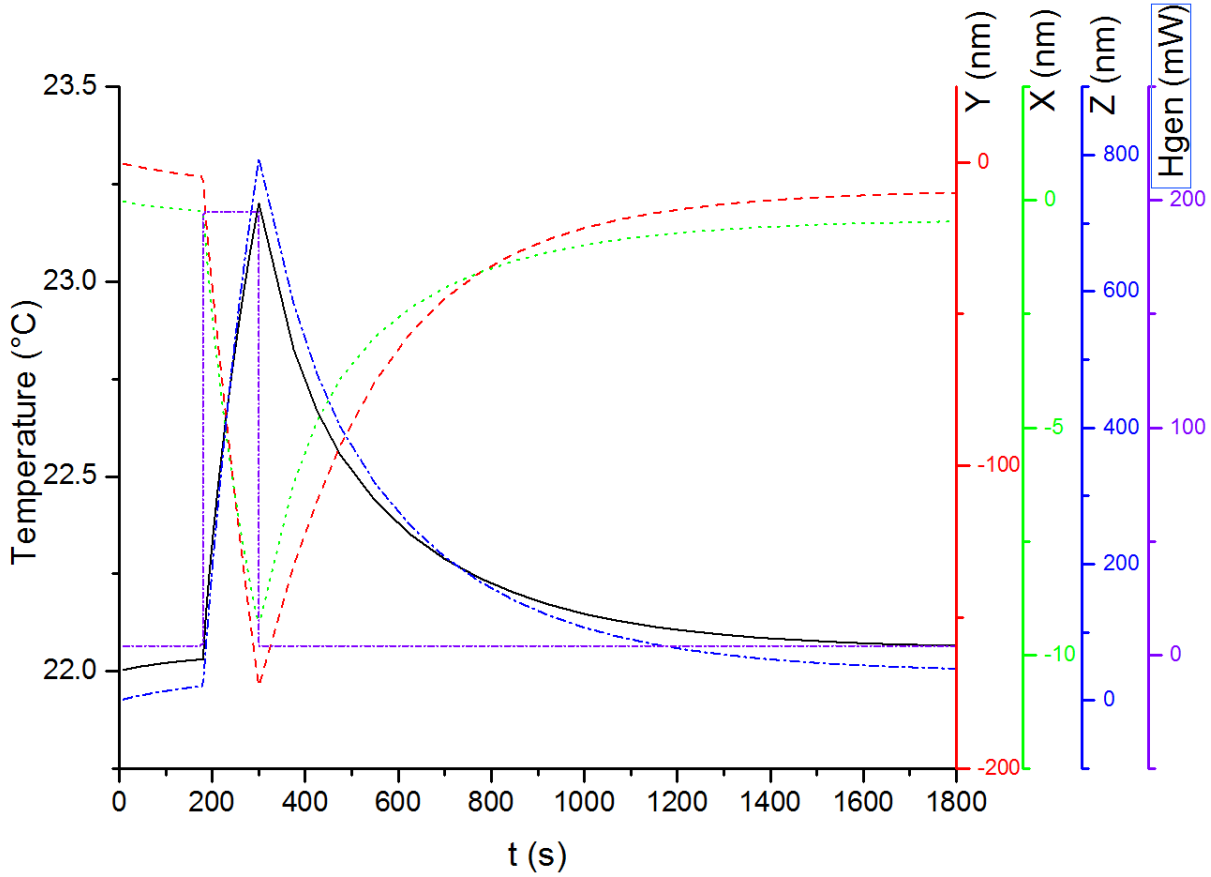
SmarAct stage with cross-roller bearings

Finite Element Study - Z2-37 Results

- Temperature variation will cause FZP shift
- Y offset will affect shift
- Close to linear relation
- Three FEA software were used for the calculation
- Can be used to optimize the FZP location for minimum relative thermal displacement

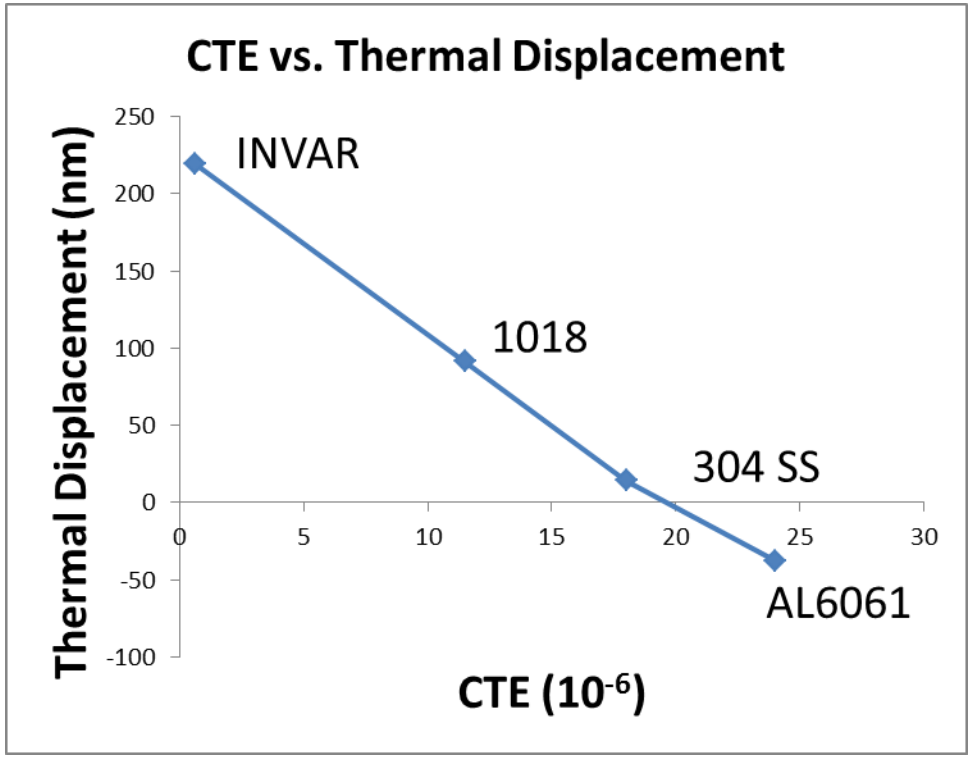


Finite Element Study - Results



- Result shows the operation of vertical stage
- Instant temperature rise with motor operation
- Cool down in about 20 minutes in air convection

Finite Element Study - Results



- Thermal displacement responds linearly with CTE of the holder material

Summary and Conclusions

- The FEA thermal and structural analyses of Z2-33, Z2-34, and Z2-37 were conducted
- The FZPs will shift relative to each other when environment temperature vary and when the motor perform movement
- Z2-33 and Z2-37 respond almost linearly to temperature variation
- The relative thermal shift between FZPs can be reduced through selecting appropriate holder material and/or Y offset
- Operation of motor in the stages will cause FZPs shift, the system need about 10 to 20 minutes to resume original position
- Every FE software has its own intrinsic errors. Three different package were used to perform the analysis and estimate the error
- Because the accuracy requirement is in submicron level, reduce the temperature variation in the experiment hutch is critical for the thermal stability of the apparatuses, this is especially true for nanoscale accuracy FZP stacking

Acknowledgements

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