Structural Analysis of a Magnetically Actuated Silicon Nitride Micro-Shutter for Space Applications

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Next Generation Space Telescope (NGST)

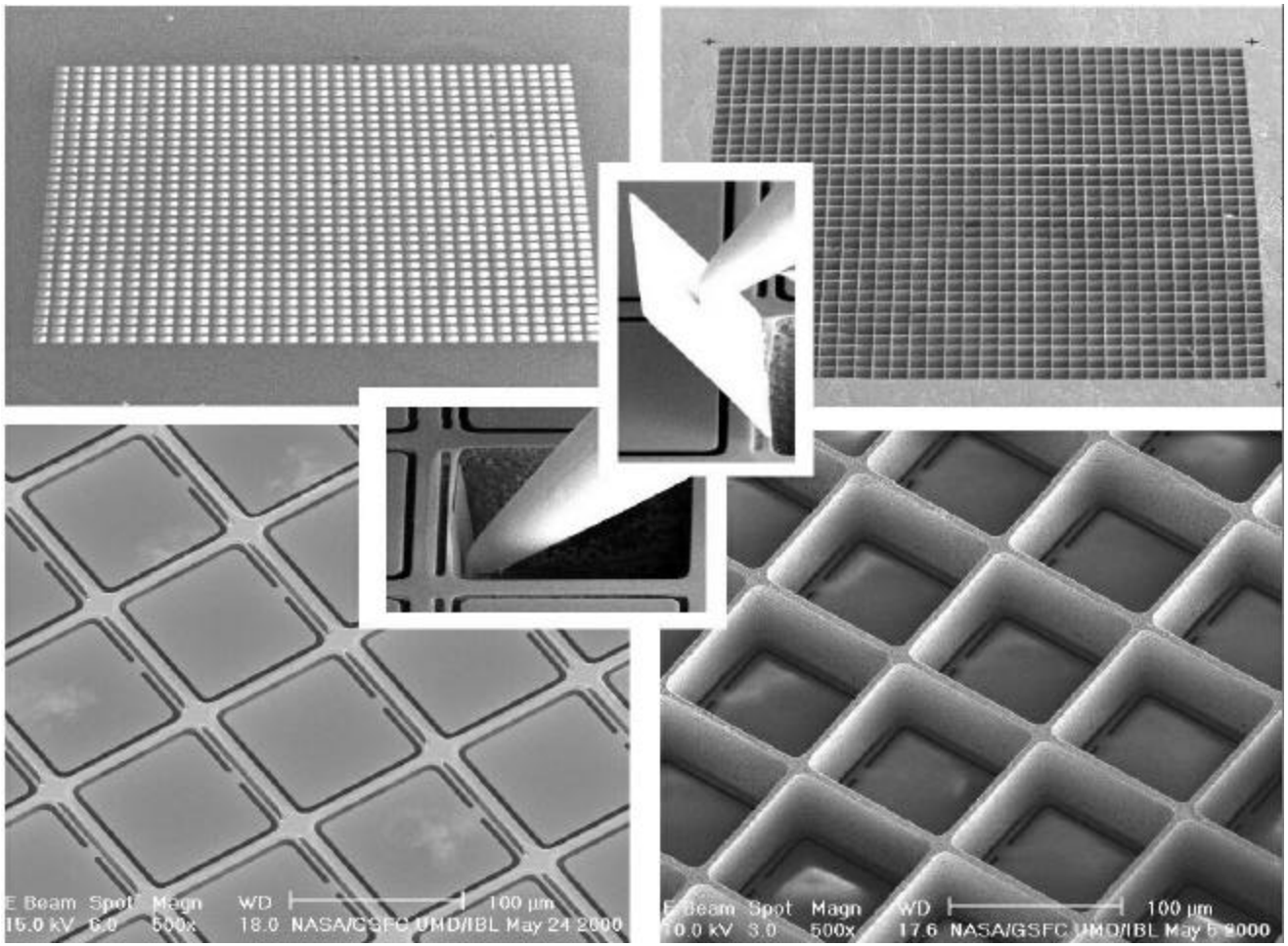
- **N**ext **G**eneration **S**pace **T**elescope
  - Mission: Investigate Galactic Origins
  - Key Instrument: NIR MOS
    - Near Infrared Multi-Object Spectrometer
  - MOS Requirement:

    Addressable "Field Selector"

Micro-shutter Attributes and Requirements

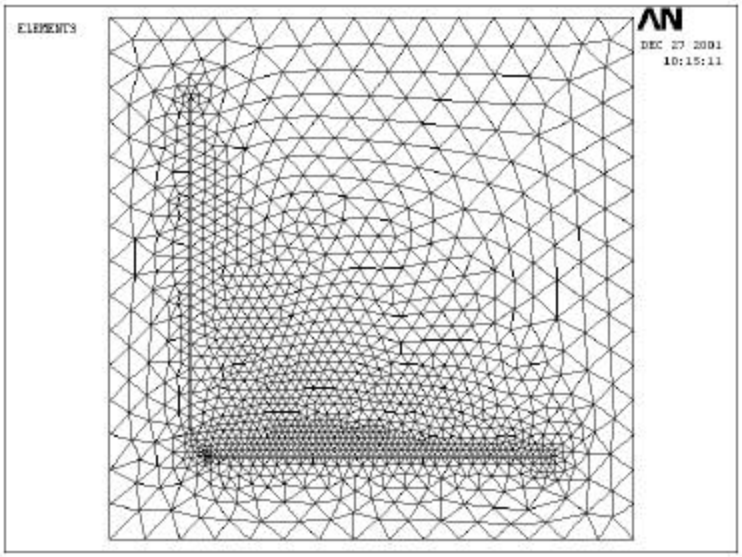
- Pixel Size Requirement: 100µm x 100µm
- Torsion Strap: 90µm x 3µm x 0.5µm thick
- Mirror Material: Silicon Nitride
  - silicon nitride is linear until fracture
- Operational Temperature: 30°K
- Rotation
  - micro-shutter will rotate 90° to the open position
  - micro-shutter will be closed in the off position

Micro-shutter Array

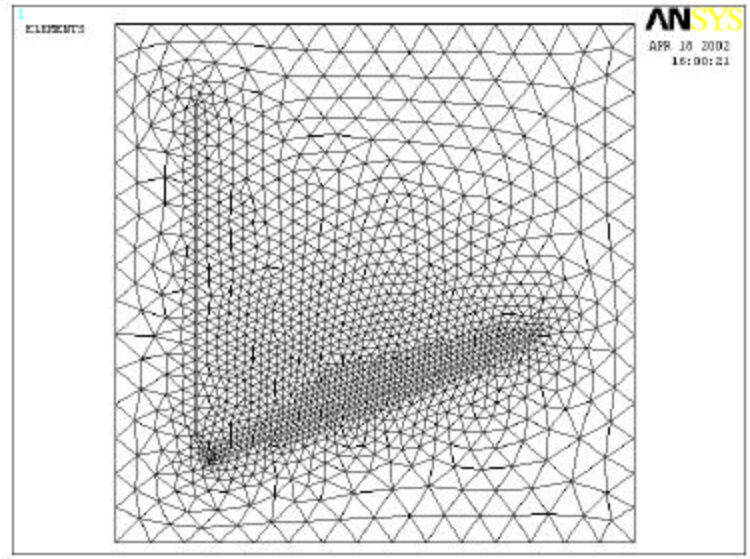


Electrostatic Analysis

- 2D Structural/Electrostatic FEM Using ANSYS/Multiphysics v5.7



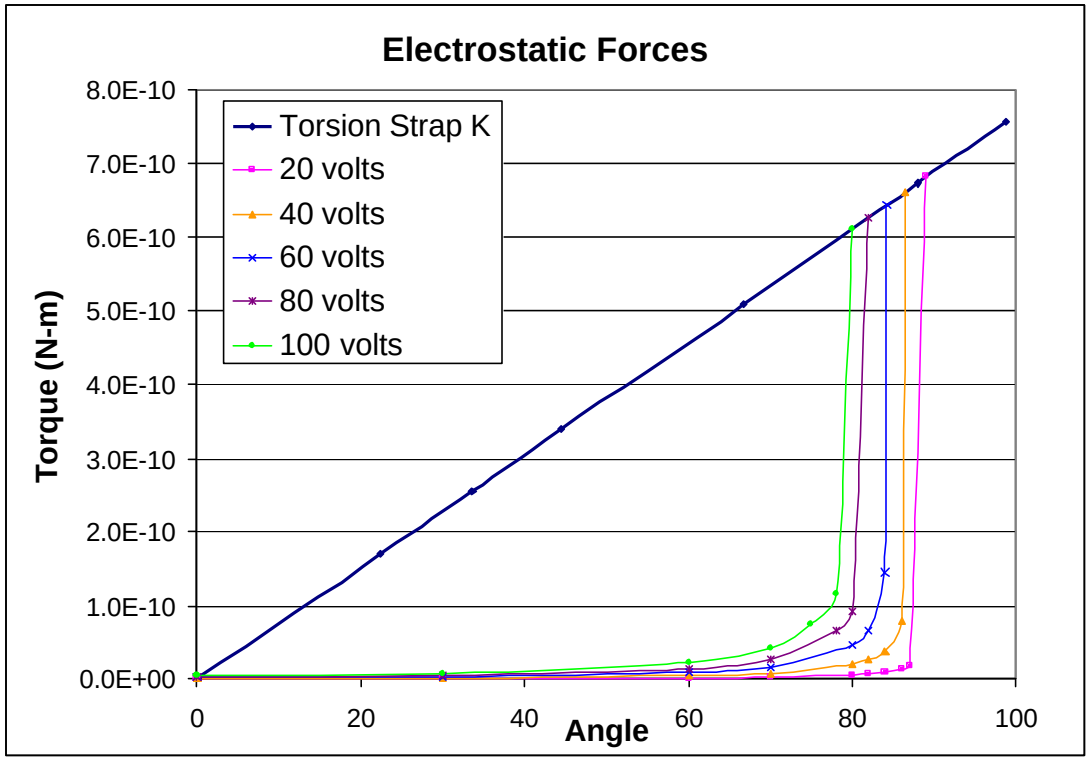
0 Volts



625 Volts

Electrostatic Analysis

- ANSYS Predicts 625+ Volts Required for 90º Actuation
  - ? Limit ~ 100 V
- Parametric Study for Determining Max. Rotation with Limiting Actuation Voltage:



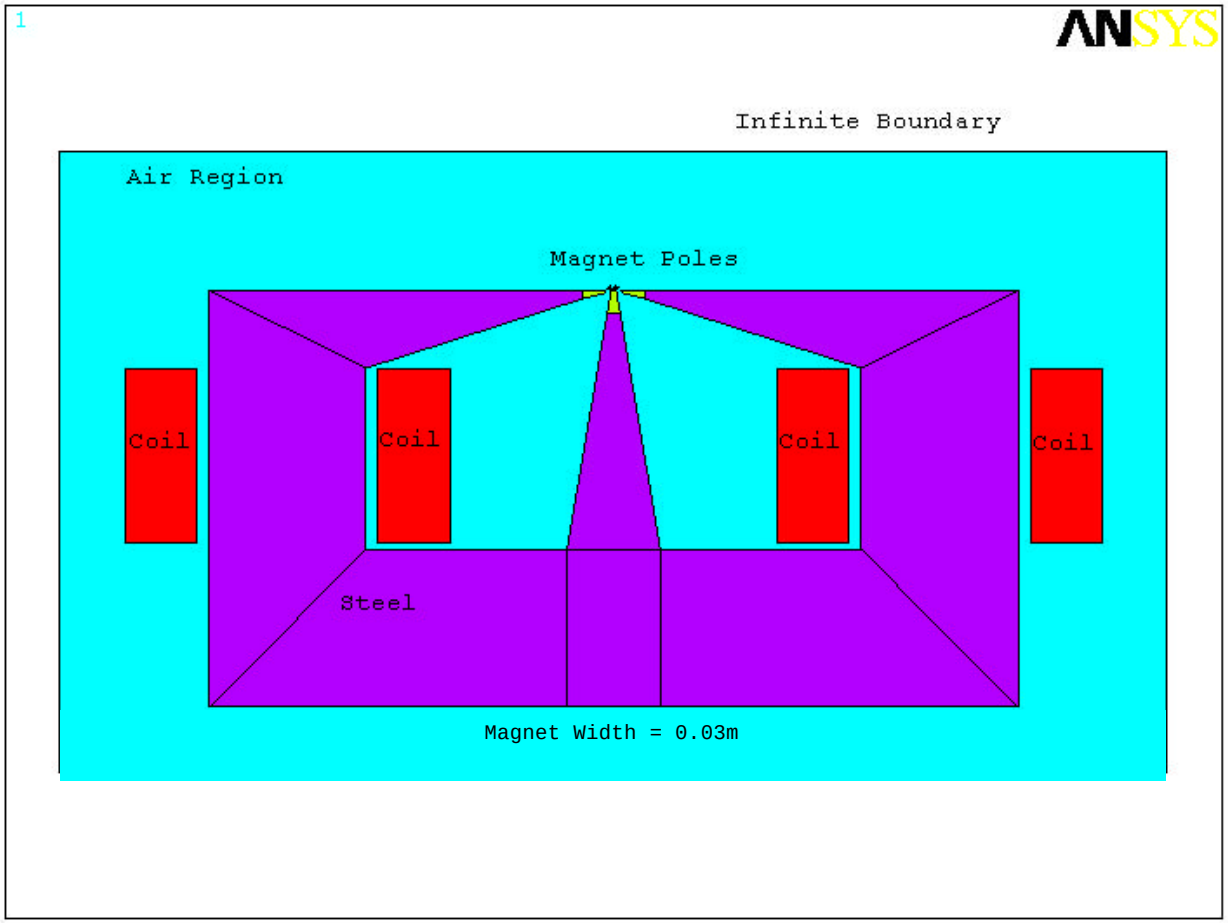
•100 V Limit Allows for 10º rotation, from 80º to 90 º

Mechanical Operation

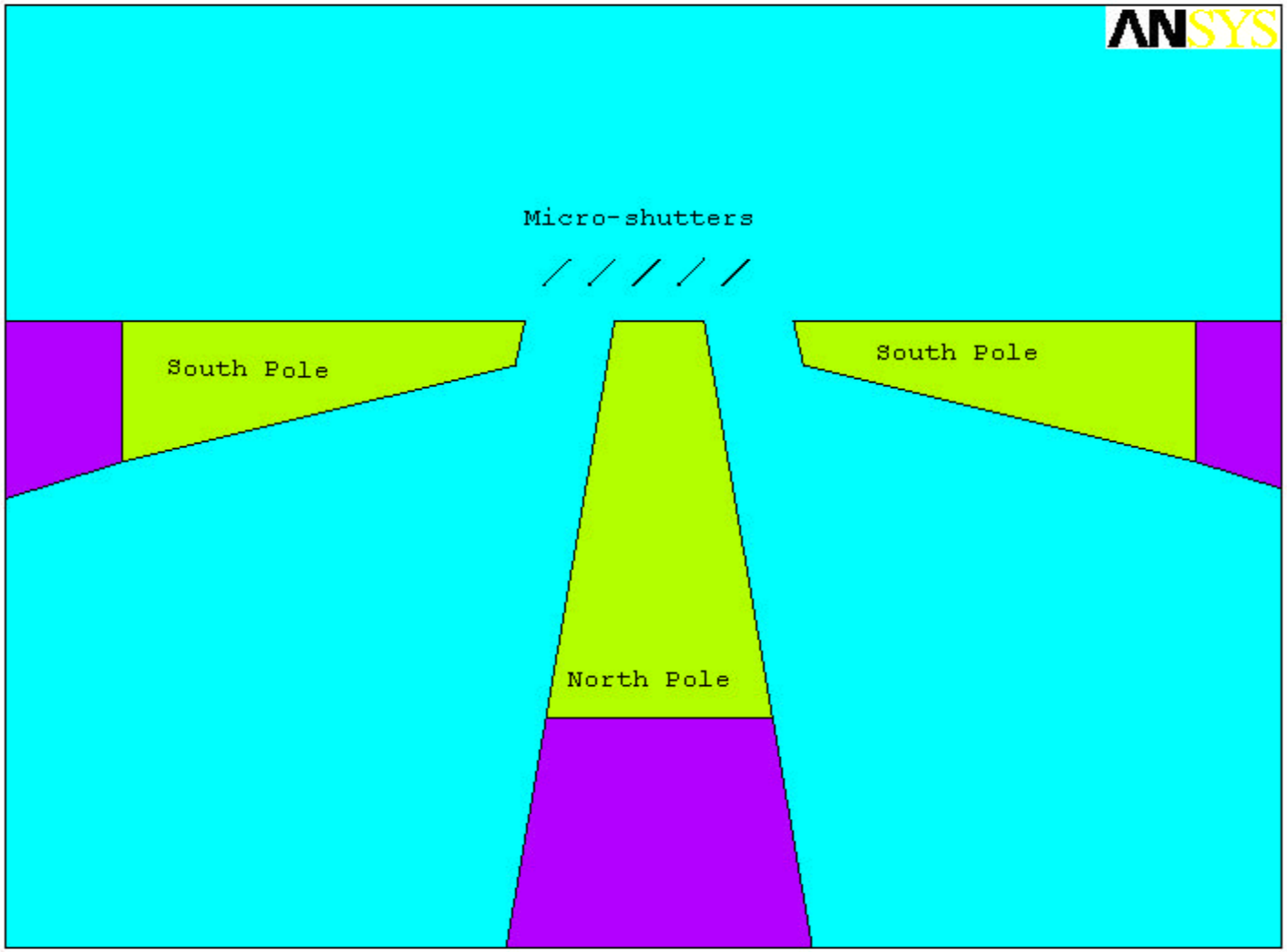
- Produced by Timothy Carnahan, GSFC Code 542

Electromagnetic Analysis

- Proposed Tripole Electromagnet

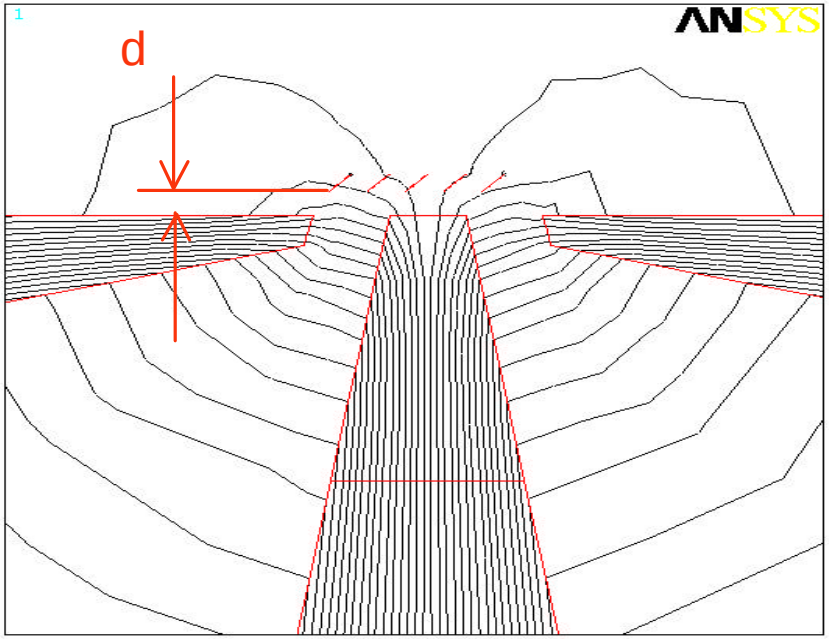


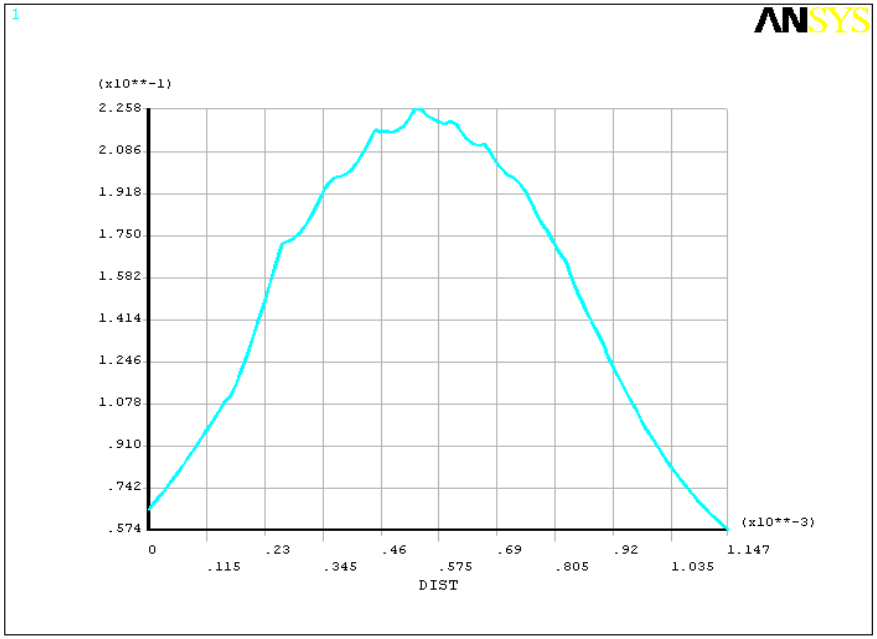
Micro-shutter Size Relative to Magnetic Poles



Electromagnetic Analysis

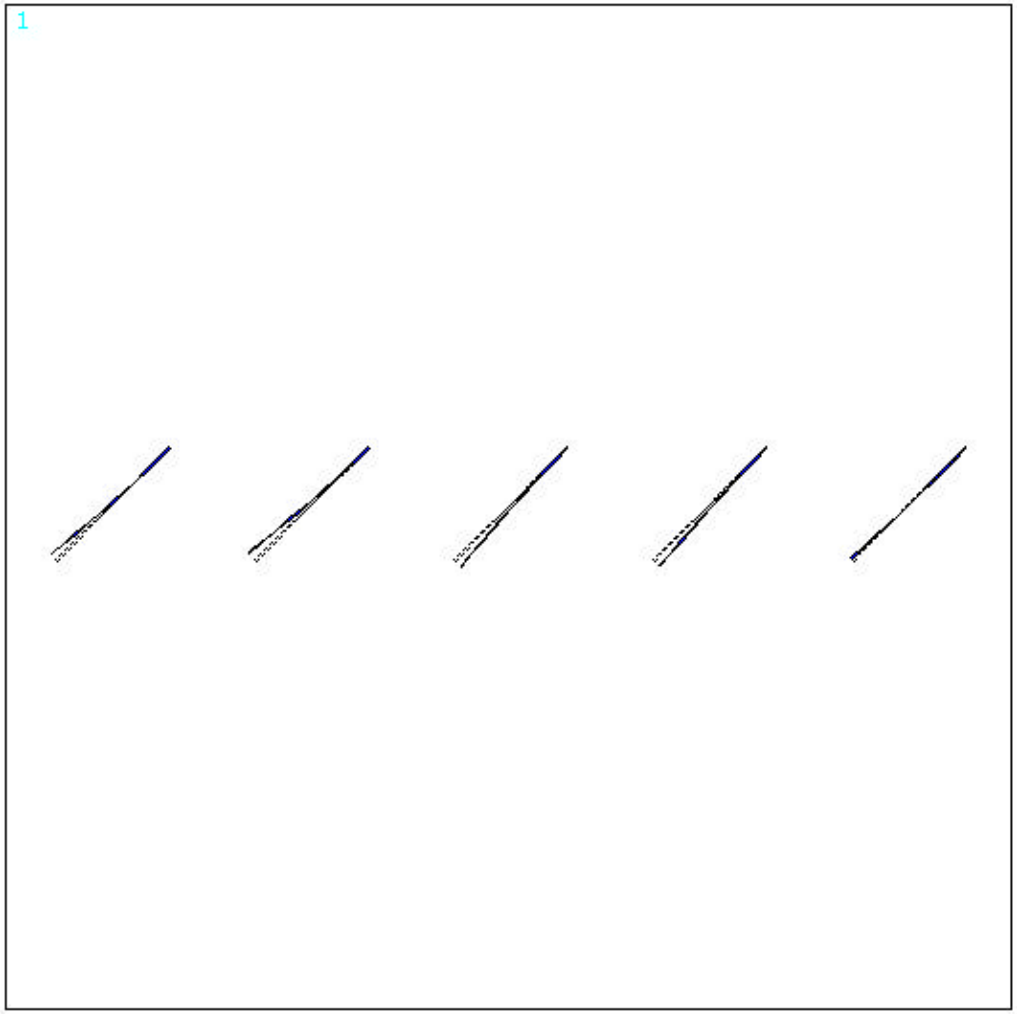
- d=distance between shutters and magnet; 40µm = d = 120µm
- peak magnetic flux density = 0.23 tesla at magnet centerline





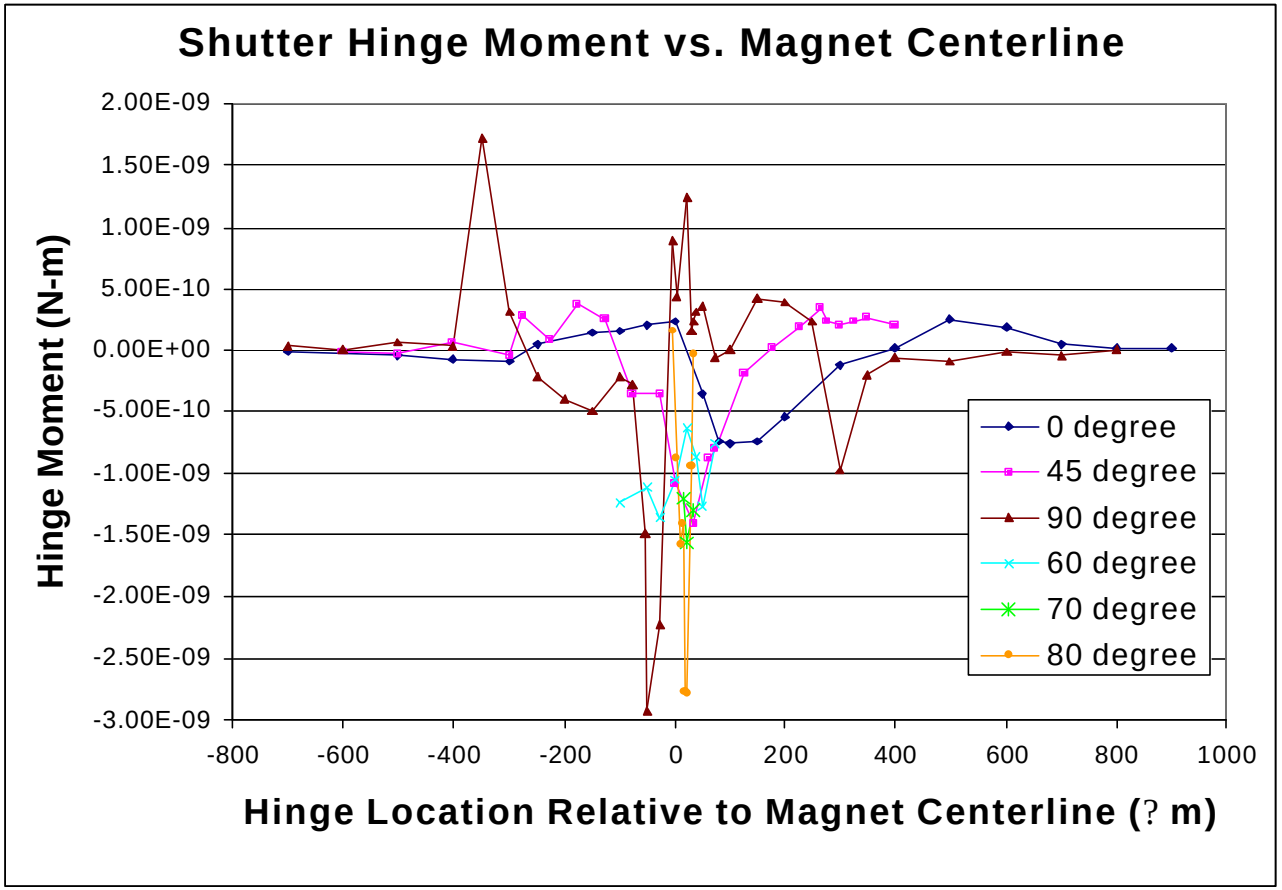
Deflected Micro-shutters

- Magnetic forces are Applied to the Micro-Shutters.
- The force deflects and rotates the Shutters.



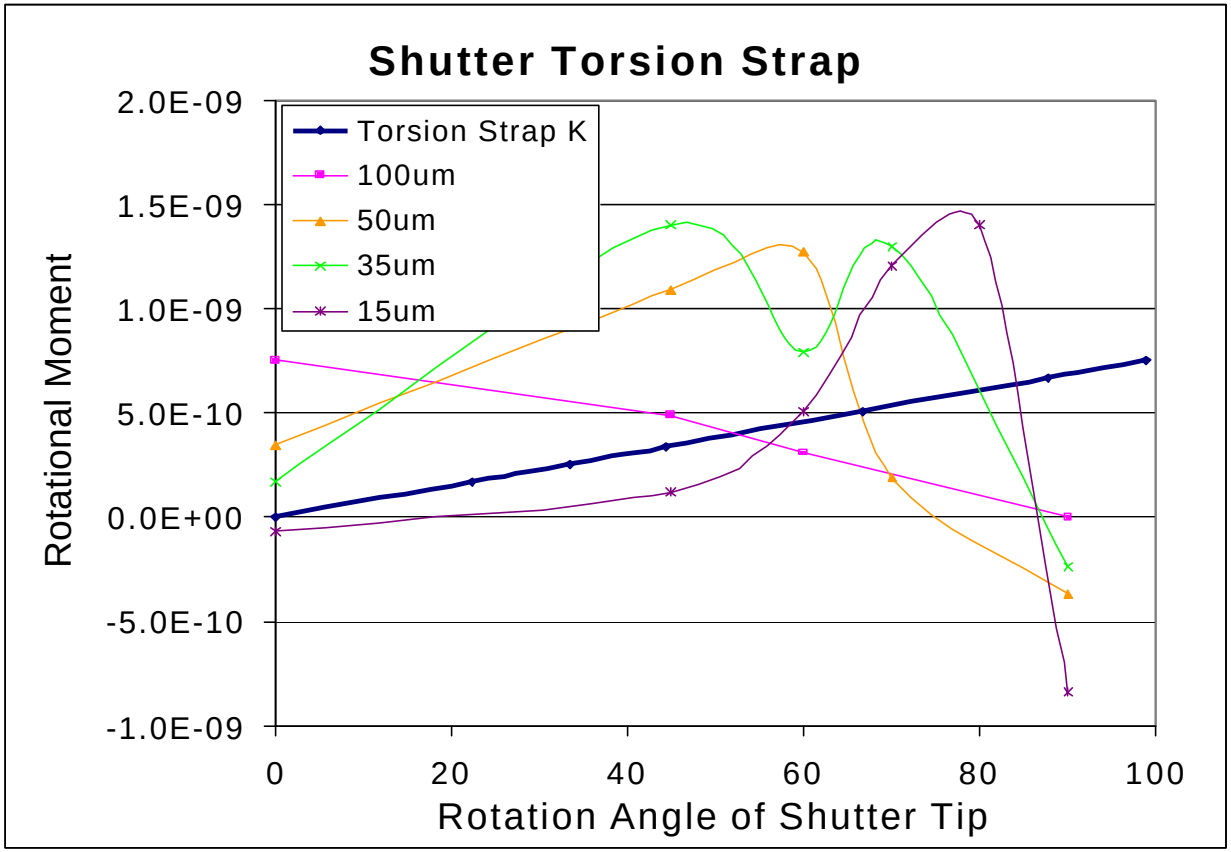
Electromagnetic Analysis

- Shutter Hinge Reaction Torque Relative to Magnet Centerline



Electromagnetic Analysis

- Shutter Hinge Reaction Torque (N-m) vs. Angular Deflection

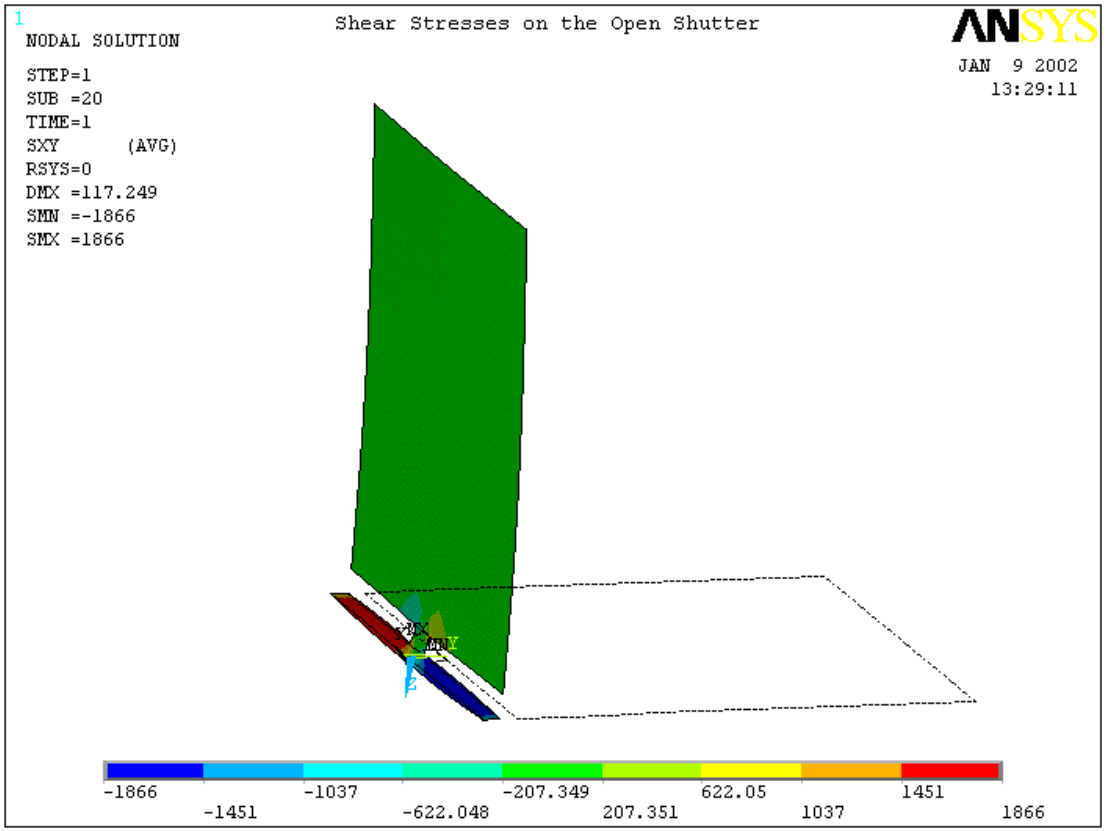


Model Correlation

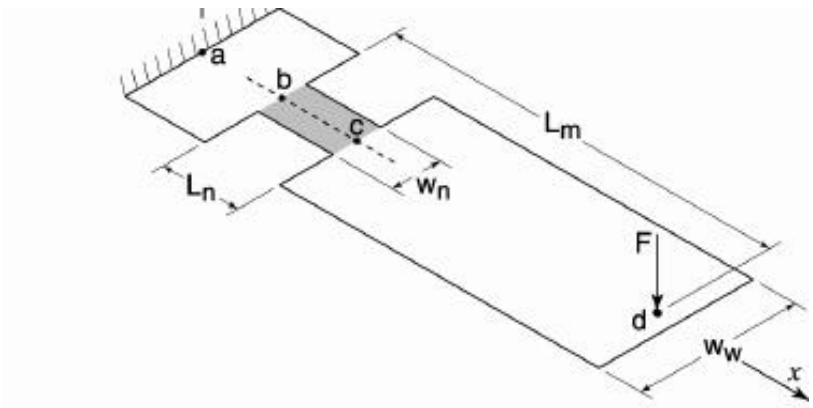
- Electromagnetic FEA Indicates Maximum Achievable Degree of Rotation = 86º
- Electrostatic Parametric Study Indicates Required Voltage to Capture Shutter (at 86º Position) = 43 V
  - Lab Tests Show “Capture” Voltage = 50 V
- Electrostatic FEA Indicates 15 V Required to Maintain 90º “Open” Position
  - Lab Tests Show “Release” Voltage = 23 V

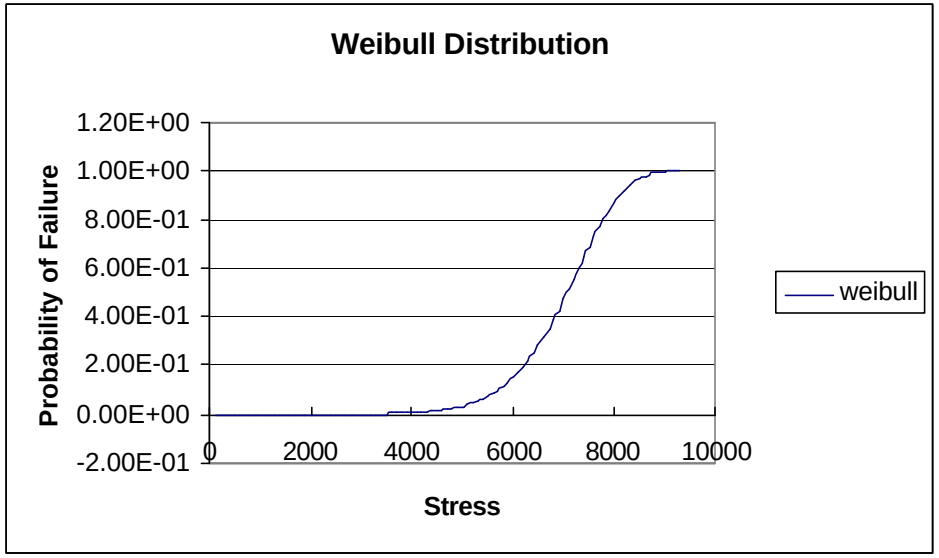
Stress Analysis

- 3D Structural FEM Using ANSYS/Multiphysics v5.7
- Assumed Silicon Nitride Fracture Strength = 6.4 GPa[1]
- Peak Resultant Stress = 1.5 GPa



Weibull Fracture Probability





- Many SiN cantilevered test samples were manufactured and tested.
- Probability of failure is dependent on the surface area of the test structure relative to the surface area of the device.
- $? _{test}/? _{torsion} = (\text{Surface Area}_{test}/\text{Surface Area}_{torsion})^{1/m}$
- Stresses in the 3? m x 0.5? m torsion strap are approximately 1500 MPa when the shutter is open.
- The Probability of Failure at 1500 Mpa is 9.48e-5. (**99.99% success rate**)

Conclusions

- FEA Predicts:
  - Electromagnetic Tripole Will Open a Magnetized Shutter to 90º Position
  - Shutter Electrostatically Captured When Opened >80º Using <100V
  - Shutter Maintained at 90º for 15V
- Test Data Correlates with Predicts
- Coupled-Field FEA May Be Used for Design Optimization

References

1) G. Coles, R. L. Edwards, W. Sharpe, The Johns Hopkins University. “Mechanical Properties of Silicon Nitride”. SEM Annual Conference. June 2001.

2) R. Fettig, J. Kuhn, S. H. Moseley, A. Kutyrev, J. Orlof, S. Lu. “Some Aspects on the Mechanical Analysis of Microshutters”. Micromachining and Fabrication, Vol. 3875. September 1999