Magneto-structural Simulation of a MEMS Micro-shutter

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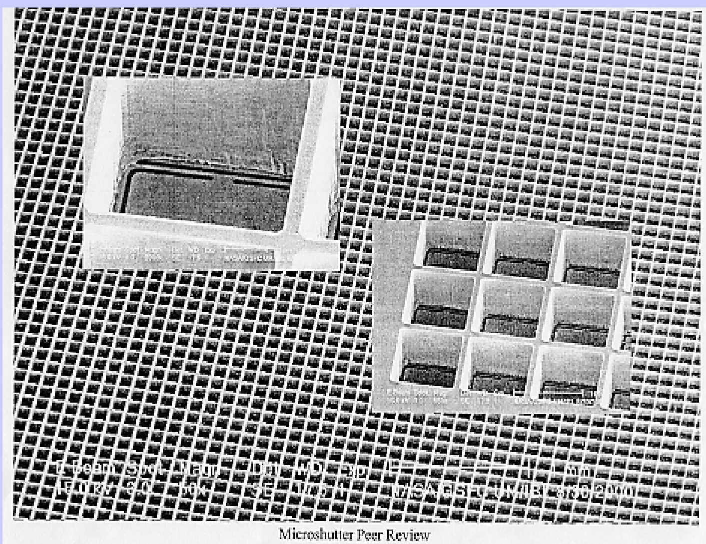
Agenda

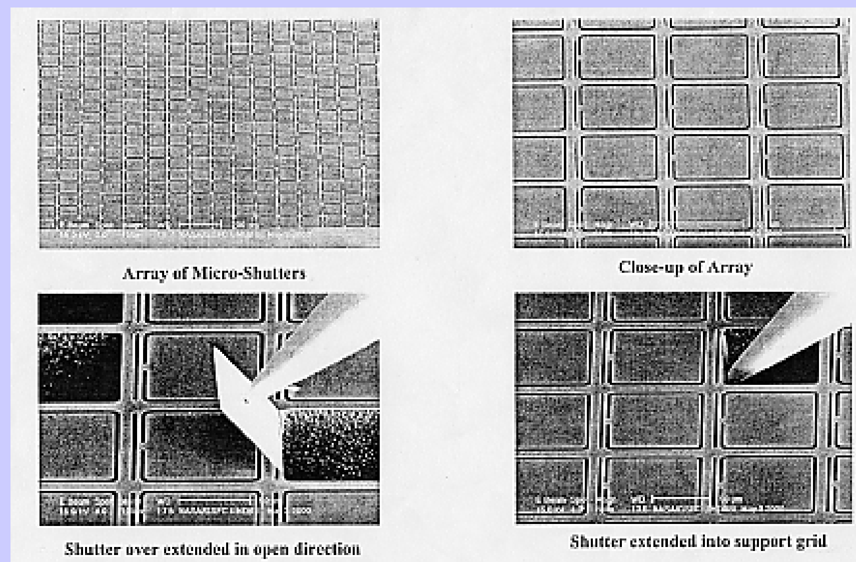
1. Background
2. Problem Definition
3. Analysis Challenges
4. Finite Element Analysis Approach
5. Analysis Models
6. Finite Element Analyses Results
7. Discussions and Conclusions

Magneto-structural Simulation of a MEMS Micro-shutter

Background

- Micro-shutters are transmissible filters in a space-based Multi-object Spectrograph (MOS). They form an array of addressable pixels requiring open and closed positions. Each is about 100X100 um.
- Three-layer structure: aluminum with .5 um, iron-cobalt with .2 um, and silicon nitride with .2 um.





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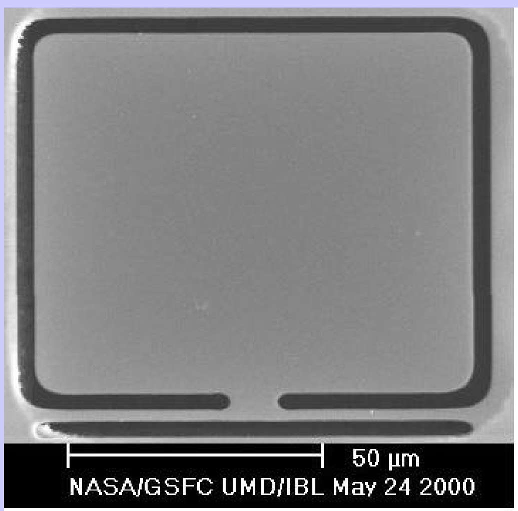
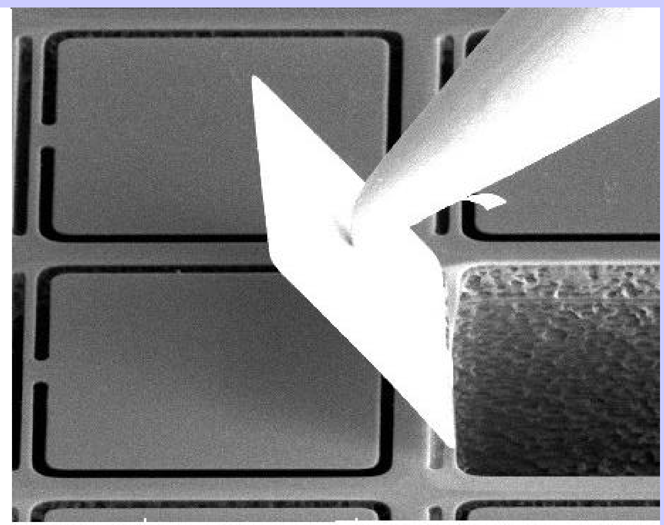
Magneto-structural Simulation of a MEMS Micro-shutter

Background

- Its operation involved a large 90° rotation against a torsion spring.
- Manufactured using MEMS technology.





Magneto-structural Simulation of a MEMS Micro-shutter

Background

- Earlier concepts involved electro-static actuation methods requiring voltages which were too high for space applications.
- Magnetic Actuation is being considered. An animation created in Maya by Tim Carnahan of NASA/GSFC illustrates the concept of magnetic actuation.

Problem Definition

- Create a finite element simulation capable of modeling the behavior of a micro-shutter as a tri-pole magnet is traveling adjacent to it.
- Finite element models should predict the magnetic field applied onto the array and calculate the applied forces on the shutters.
- Finite element models should predict the structural response of the micro-shutter in terms of deformation, stresses and reactions at the torsion bar support.

Analysis Challenges

- Magnetic problem size, relative sizes and open domain issues.
- Magnet movement as a result of which the field is also moving.
- Magnetic model air morphing and re-meshing.
- Models and solution dimensionality, i.e. 2-D versus 3-D.
- Structural large deformation and large strains.
- Mesh size and consistency between fields.

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Analysis Challenges

- Coupling of the magnetic and structural fields. Two coupling approaches; direct or matrix and load vector or sequential method

Direct

$$\begin{bmatrix} [K_{11}] & [K_{12}] \\ [K_{21}] & [K_{22}] \end{bmatrix} \begin{Bmatrix} [u_1] \\ [u_2] \end{Bmatrix} = \begin{Bmatrix} [f_1] \\ [f_2] \end{Bmatrix}$$

Sequential

$$\begin{bmatrix} [K_{11}] & [\,0\,] \\ [\,0\,] & [K_{22}] \end{bmatrix} \begin{Bmatrix} [u_1] \\ [u_2] \end{Bmatrix} = \begin{Bmatrix} [f_1] \\ [f_2] \end{Bmatrix}$$

Finite Element Analysis Approach

- 2-D magnetic analysis, and hybrid 2 and 3-D structural analysis.
- Two-model magnetic analysis. Field global model with the magnet and local sub-model without the magnet.
- Enforce compatibility of potential between both model.
- Structural model uses 2-D plane stress and a 3-D beam for the torsion bar. Compatibility between both domains is enforced using MPC’s.
- Parametric modeling to facilitate morphing and re-meshing.

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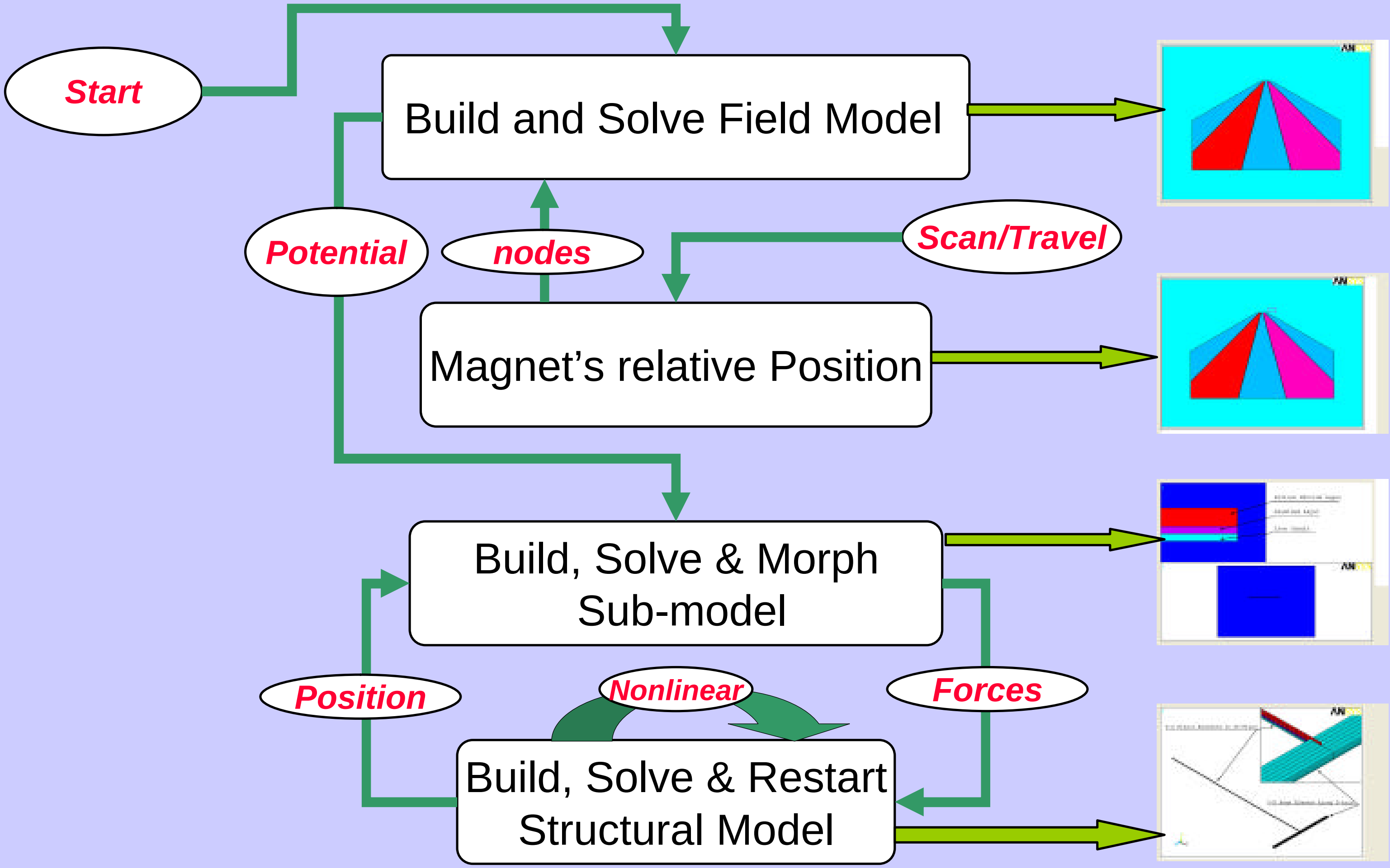
Finite Element Analysis Approach



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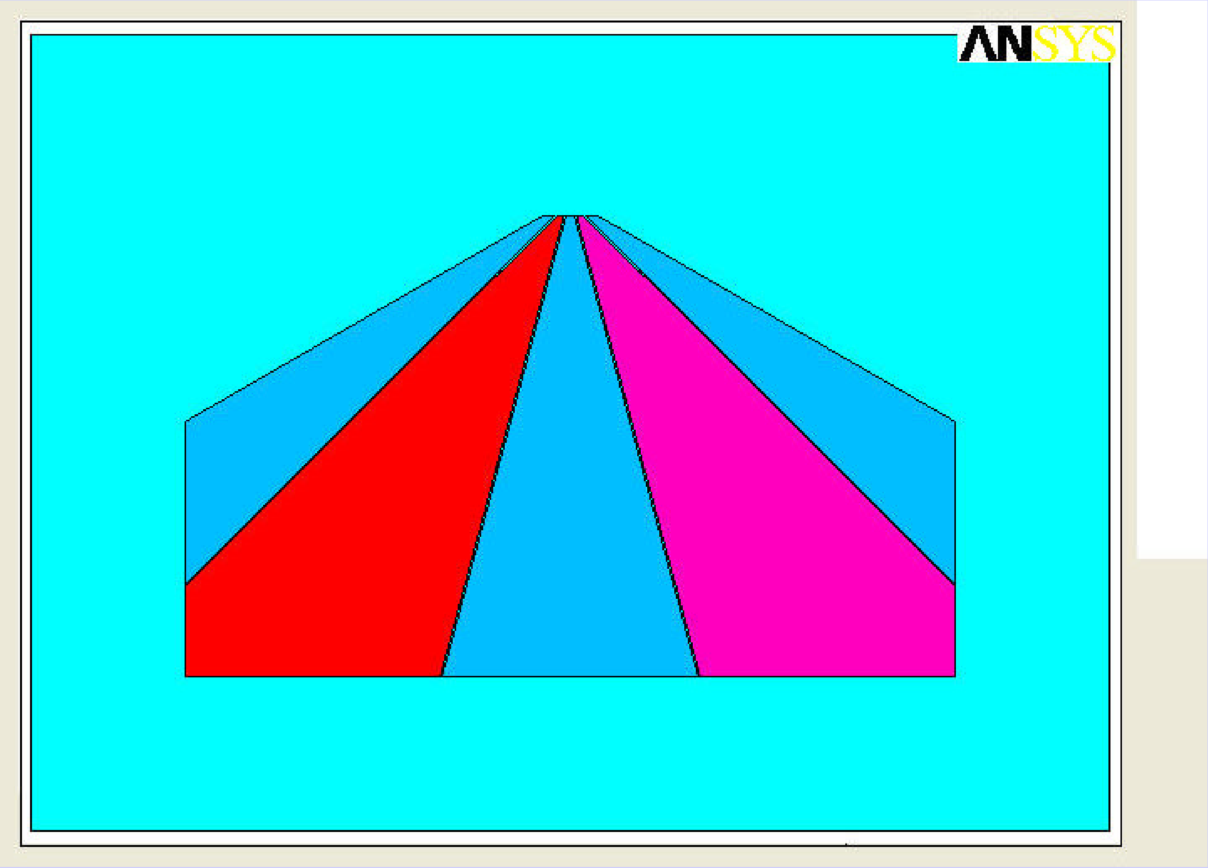
Analysis Models

Magnetic Global Field Model



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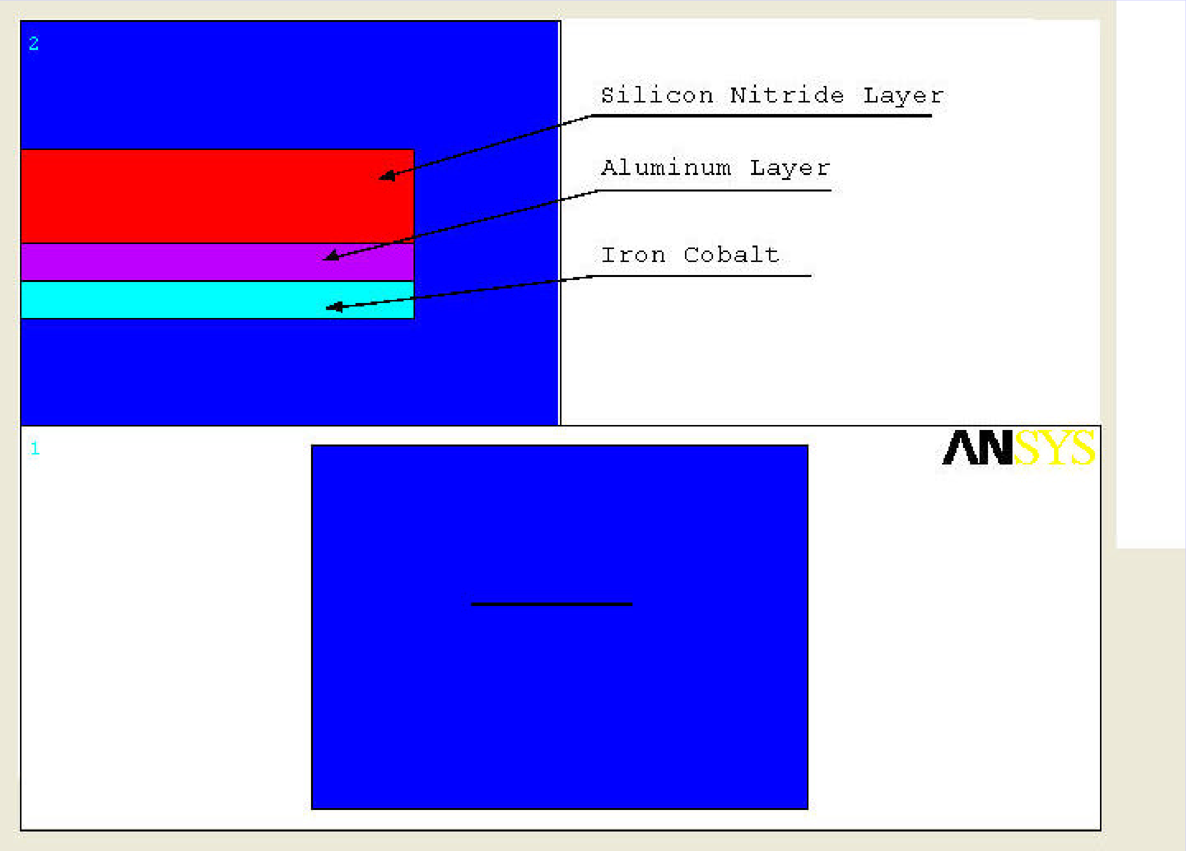
Analysis Models

Magnetic Local
Sub-model



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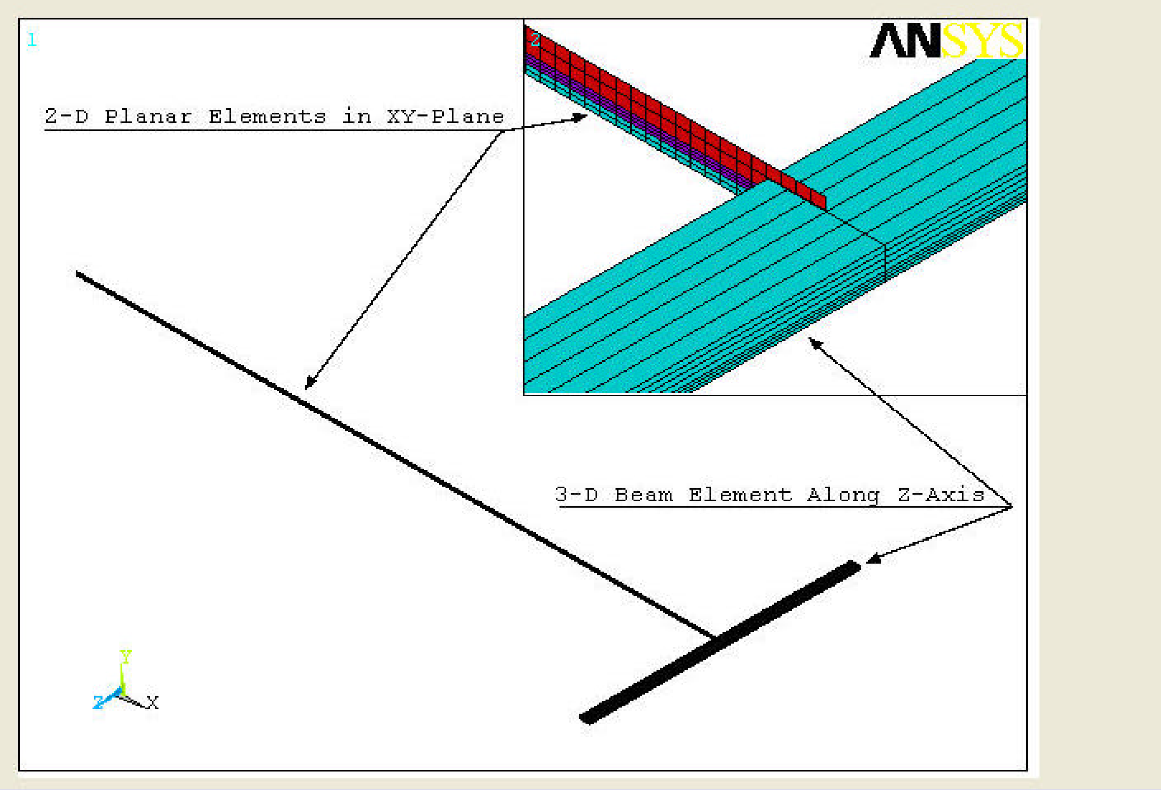
Analysis Models

Hybrid Structural Model



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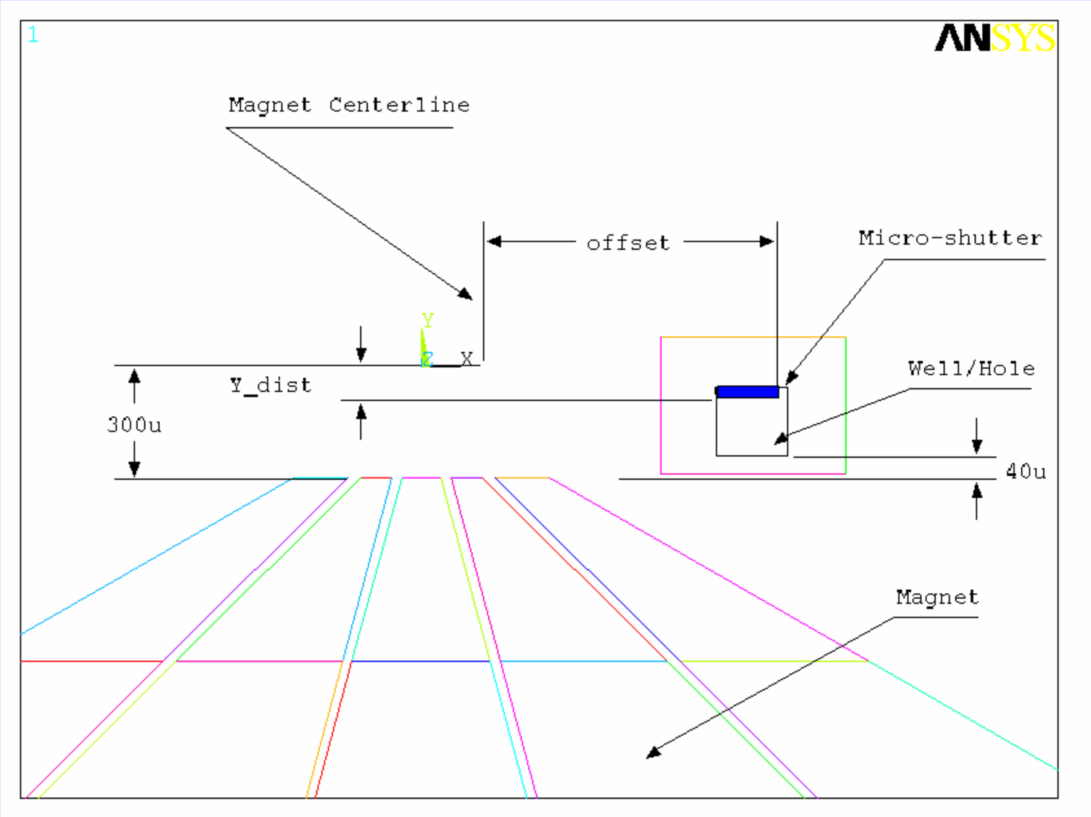
Analysis Models

Model Parameters



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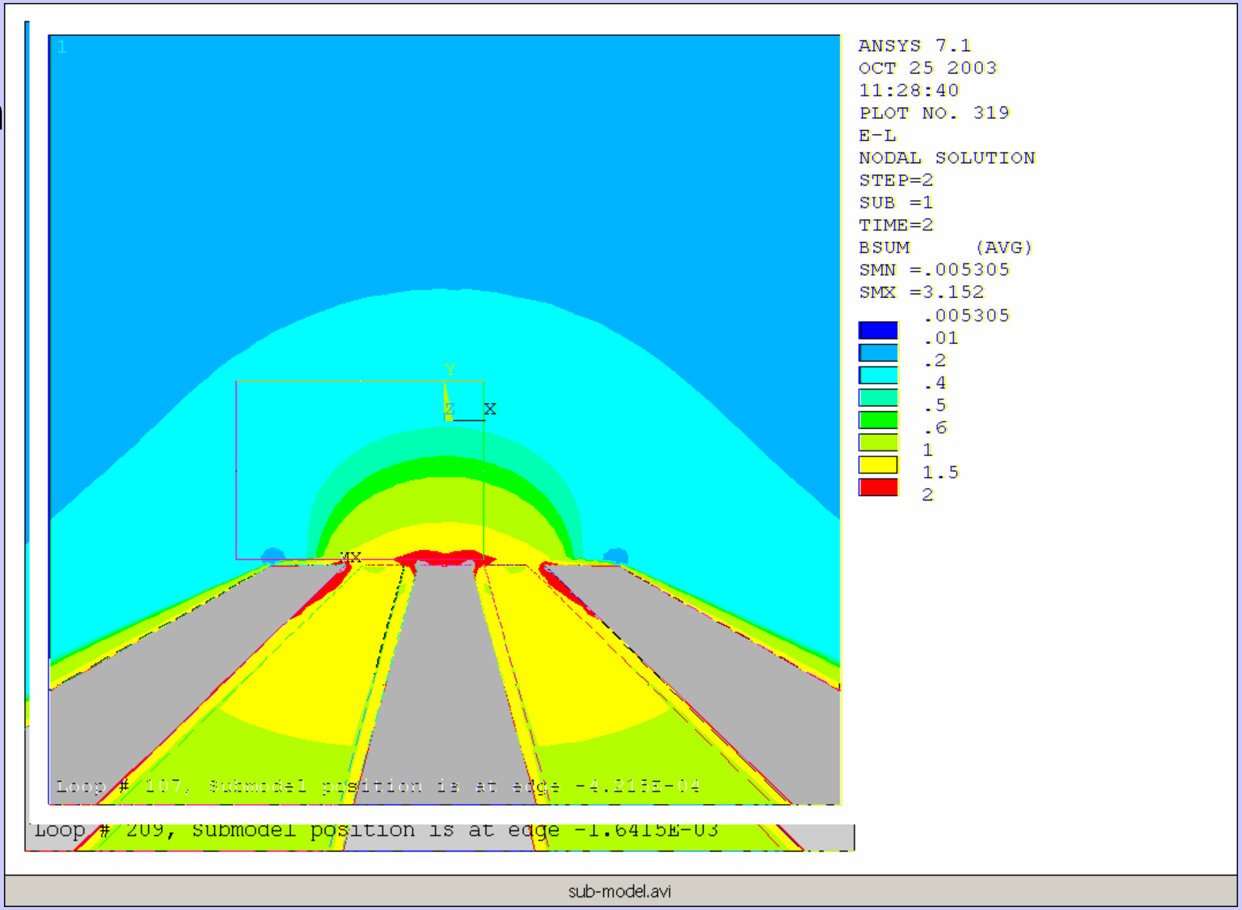
Finite Element Analyses Results

Sub-model / Magnetic Position - Animation



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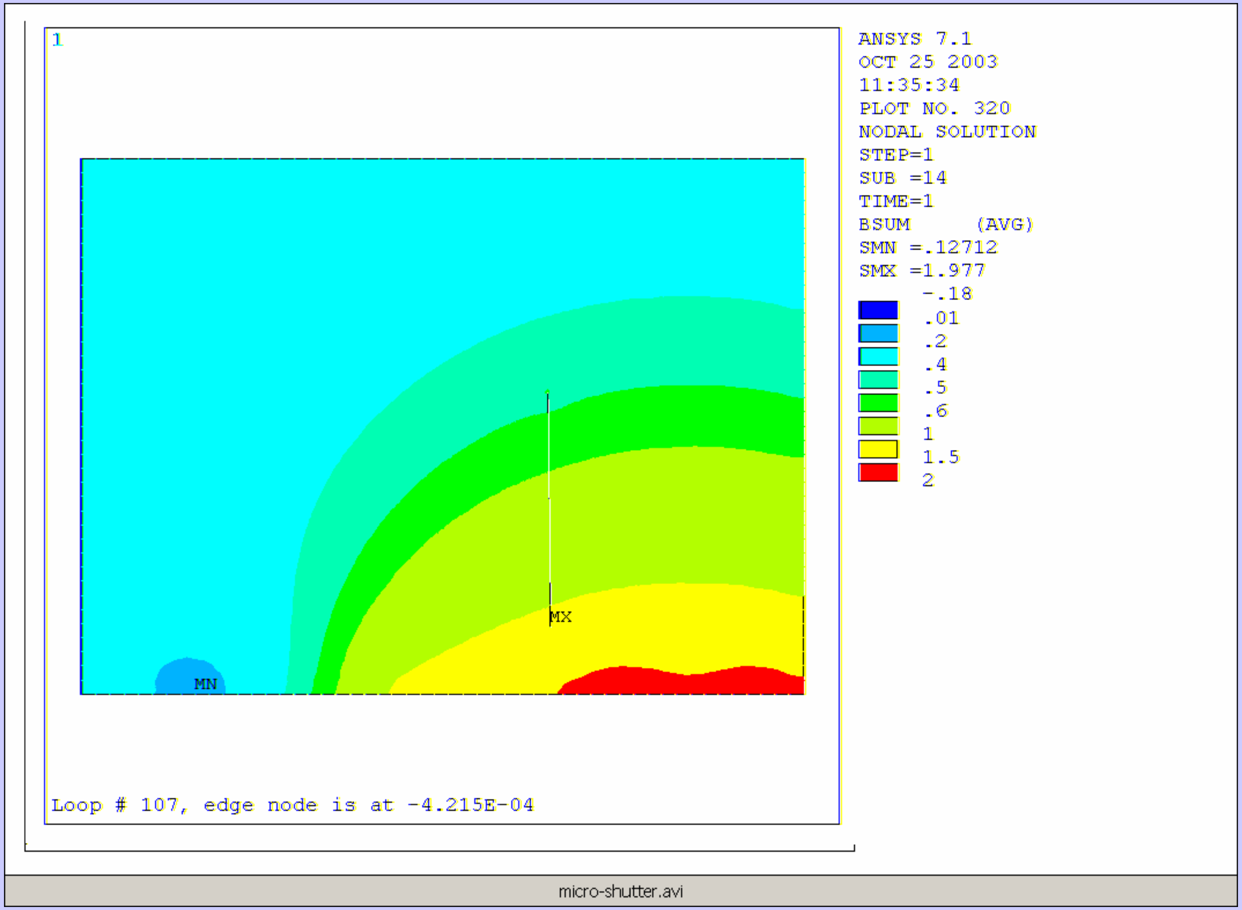
Finite Element Analyses Results

Micro-shutter Position - Animation



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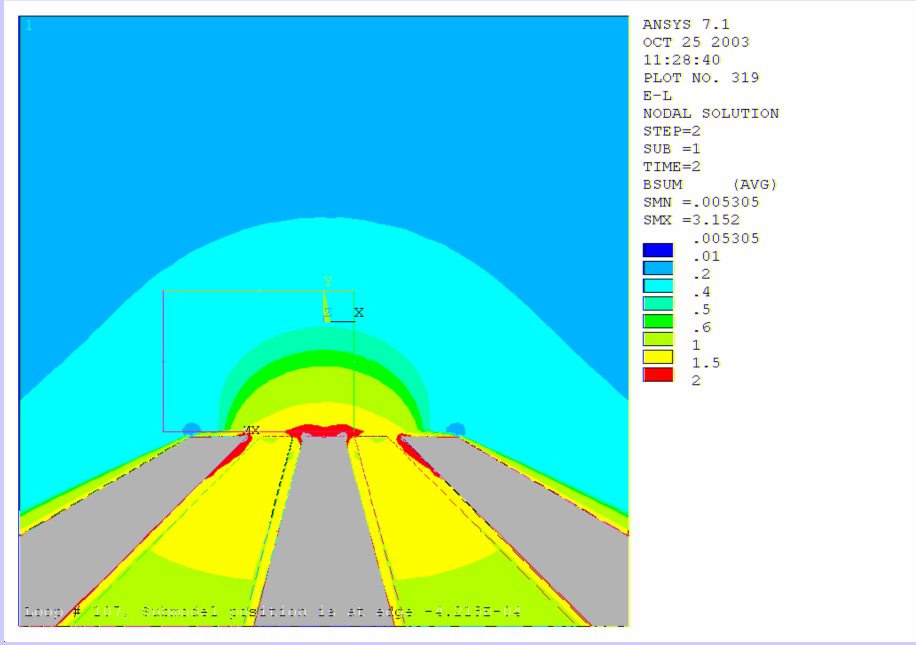
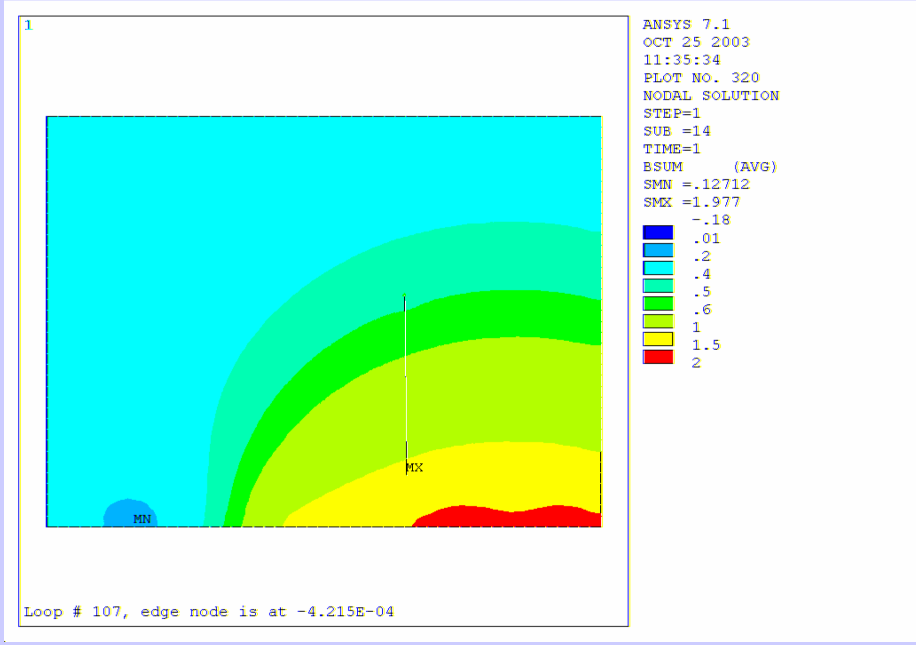
Magneto-structural Simulation of a MEMS Micro-shutter

Finite Element Analyses Results

Magnetic Flux and Micro-shutter at 90º Position





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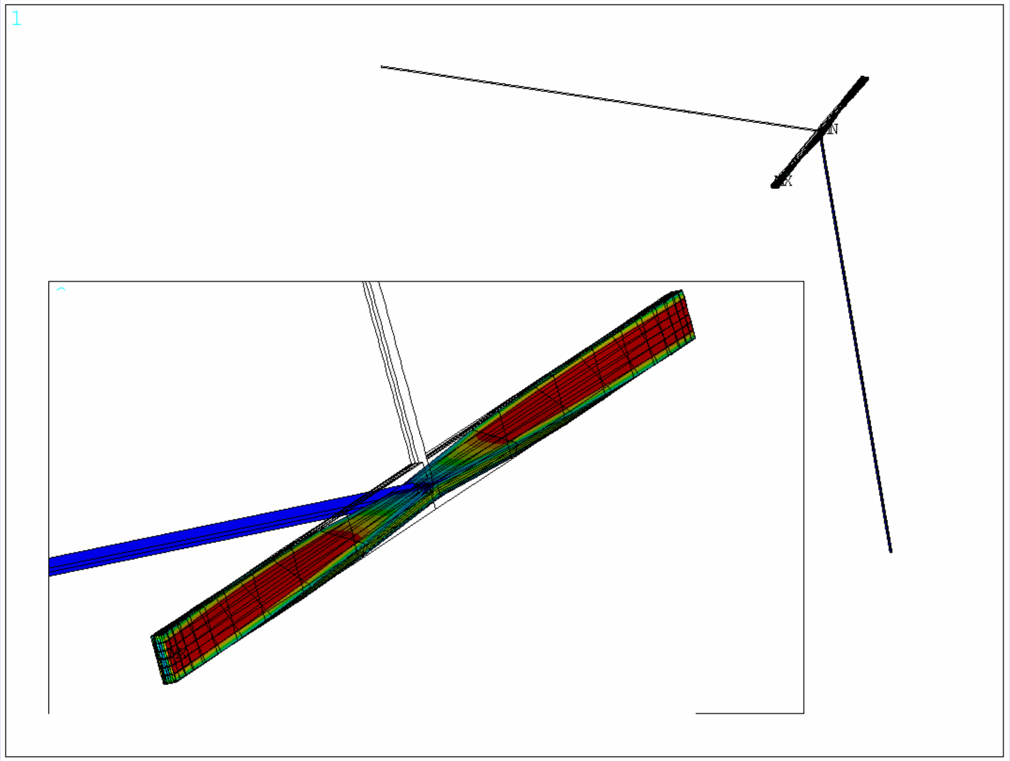
Magneto-structural Simulation of a MEMS Micro-shutter

Finite Element Analyses Results

Von-Mises Stress at 90º Position



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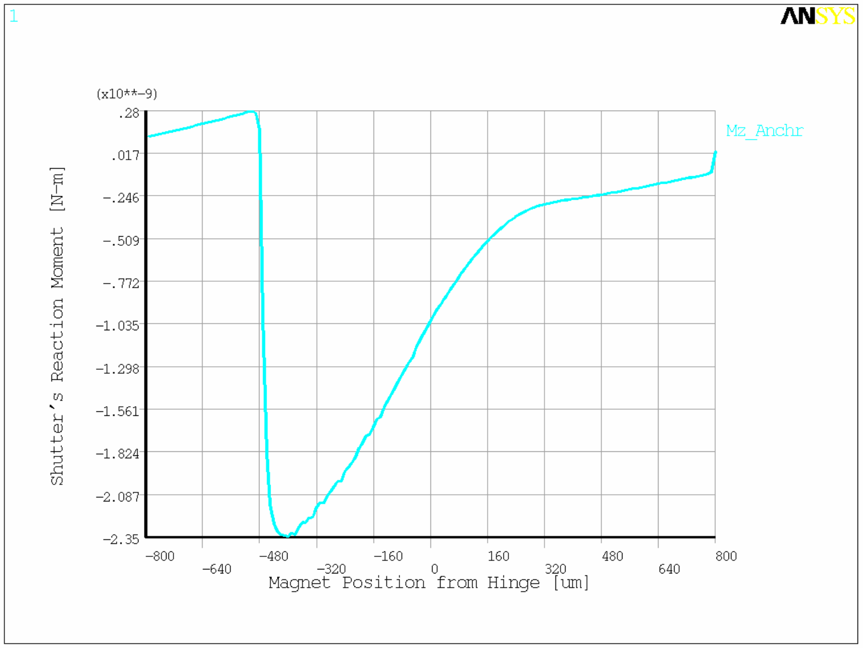
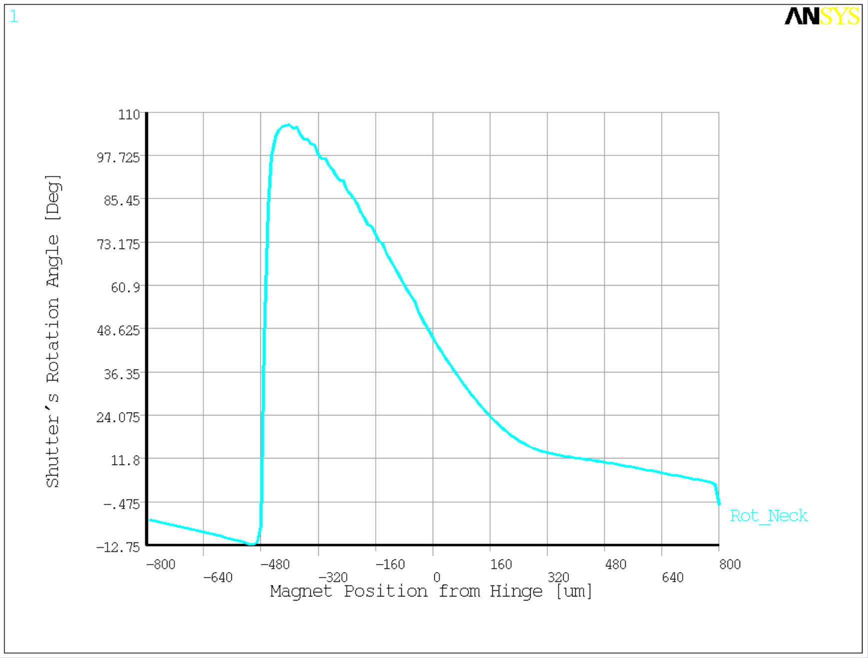
Finite Element Analyses Results

Hinge Moment and Micro-shutter Rotation Angle





Discussions and Conclusions

- Models and procedures for analyzing the magneto-structural behavior of a MEMS micro-shutter with hybrid two and three dimensional models are created. The mixing of two and three dimensional elements in the same analysis database is found challenging. A significant milestone is reached in stabilizing the solution process in this database.

- The application of the sub-modeling approach to pass magnetic field potential from the field model to the local magnetic model is the key for the success of the modeling approach presented.

- Two approaches are tried for solving the magneto-structural models; the directly coupled and the sequentially coupled approached. Although the directly coupled is mathematically more rigorous, it does not converge, and the sequentially coupled approach converges and is found numerically more stable.

Discussions and Conclusions

- The reaction forces, reaction moment and the rotation of the micro-shutter shows "numerical noise" which is more sever in coarser finite element meshes.
- All models and procedures created use parametric representation of model geometry and loading sequences and as such they provide good tools for what-if analysis scenarios.
- The finite element results correlate closely with the lab results for magnetic actuation.
- The peak values for reaction forces and the moment at the hinge are consistent with those obtained by NASA's analyst in different analysis.
- No hysteresis magnetic effect are addressed. This could be significant for subsequent actuation of the micro-shutter, which will be incorporated in a future modeling effort.

Acknowledgments / Notes

- The Authors thank NASA GSFC for Supporting the Analysis work involved
- We recognize the contribution of Bill R. Bulat of ANSYS, Inc. and Matthew J. Mehalic of Mallett Technology

- A complete technical paper will be published in the 2004 International ANSYS Conference