Numerical Simulation of Micro-Assembly Techniques in MEMS Devices

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ABSTRACT

This paper presents research on numerical simulation of the micro-assembly of MEMS devices. Recent developments in MEMS devices – making use of multiple deposition layers, micro-fabricated hinges, and actuators – have enabled fabrication of MEMS devices that can deform out of plane. Applications include latching mechanisms and tilting mirrors.

The simulation methodology has been developed which allows a MEMS designer to take into account the required actuation forces, interfacing mechanisms, and time constraints for micro-assembly. The simulation results rely on multi-stage contact analysis, dynamic analysis, and large displacement theory. Results will be presented for two case examples.

1 INTRODUCTION

Current MEMS CAD tools arose from the need to move beyond pure Finite Element Analysis to model MEMS-specific phenomena. Additional modeling scenarios, such as gear movement and latching mechanisms, have arisen for which simulation is desirable.

For the simulation of the micro assembly of MEMS devices, there has been little work implemented thus far. Because micro assembly is a multi-step, multi-contact problem, there are several challenging issues which must be solved, including numerical convergence vs. computational expense.

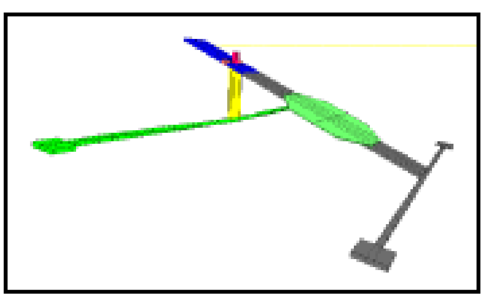

Figure 1: Micro-assembly

Even for single step assembled structures, it is difficult to reach convergence in the numerical analysis. There are two reasons for this: (I) it is a time dependent, highly non-linear problem and (II) it is a multi-step contact problem. Latching structures typically have multiple contact pairs which may or may not activate simultaneously. In addition, the structures are non-rigid, implying that mutual post-contact deformations must be taken into account. These factors combine to make numerical convergence difficult.

Once the assembly is complete, it is desirable to simplify the model in order to reduce convergence problems and save computation expense. This simplification requires the development of a new strategy and algorithm to capture the topology of the single assembly analysis and apply it to the global structure.

A second new algorithm must be developed to solve the problem of physical overlap in the contact areas which can result in the global model. Physical overlap results from the need to limit the computational expense of the simulation, thereby introducing some numerical error. The need for a stabilization algorithm is clear when a study is done of the numerical tolerances and computational expense required for multi-contact analyses. If analysis is continued without correcting this error, incompatiblities will arise in the construction of the next required physical mesh.

2 IMPLEMENTATION IN INTELLISUITE™

IntelliSuite™ is the first commercial MEMS software package to feature coupled 3-D dynamics analysis, allowing for such analyses as frequency vs. voltage bias and RF switching time. Dynamic analysis required a solution to the convergence problem in highly non-linear, time dependent analyses. A balance must be achieved between numerical convergence, time dependencies, and computational expense. This balance was accomplished through the use of large displacement theory.

A new MEMS simulation methodology has been introduced which allows, for first time, the analysis of micro-assembled structures. With the addition of micro assembly simulation capabilities, IntelliSuite™ becomes the only MEMS software tool capable of modeling the latching mechanisms which frequently control current MEMS devices.

Recent advancements allow for the definition of multiple contact steps, during which only a few contact pairs are activated simultaneously. Simplifications relating to the device performance and geometry are employed to reduce the number of simultaneously active contact pairs. Finally, special stabilization algorithms are introduced in the local model.

New algorithms define the relationship between the different parts of the latching mechanism, allowing the program to relate the local model to the global model. A second algorithm was developed to separate the mechanical mesh created during the contact analysis from the mesh required for further physical analysis, whether it is electrostatic, fluidic, or another mesh type.

IntelliSuite™ has solved both the local and global multi-contact dynamic problem, becoming the only MEMS software tool capable of handling comprehensive three-dimensional assembly analysis. This topic includes multi-contact, multi-step non-rigid contact analysis; global multi-assembled post-contact vibration analysis; and multi-physics coupled analysis.

3 RESULTS

3.1 Multi-Contact Deformable Mirror

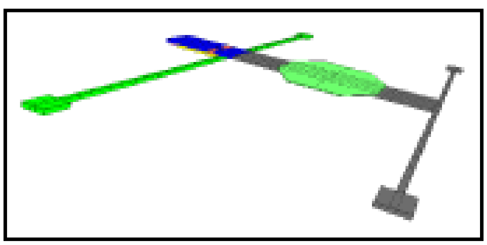

Figure 2: IntelliSuite™ model of a latching device prior to actuation

The solution presented in this paper allows for the analysis of latching mechanisms; an example is shown in Figure 1. The top arm is separated from the lower arm by an air gap of 1.0 micron. The device is bounded at the four contact pads, located at the ends of torsional beams.

To actuate the structure, a pressure is applied to plate attached to the lower beam, causing it to rotate upwards. The plate will then contact the upper beam and slide along, pushing the top plate upwards until latching occurs (Figures 3 and 4).

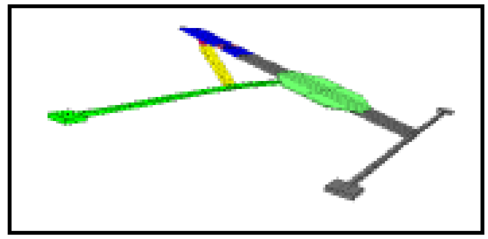

Figure 3: Sliding contact

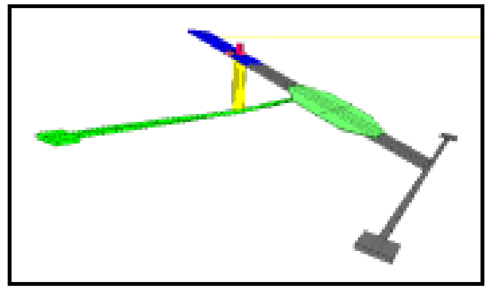

Figure 4: Latching position

The path of the structure can be analyzed by plotting the z-displacement of the endpoint of the lower beam and the reaction forces in the lower beam's contact pads over time.

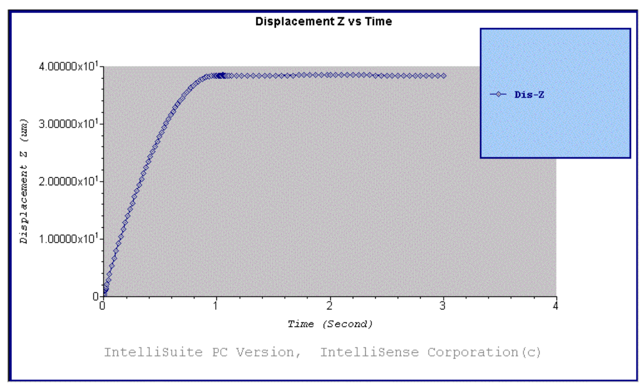

Figure 5: Z-displacement of the lower beam due to the applied pressure and latching over time

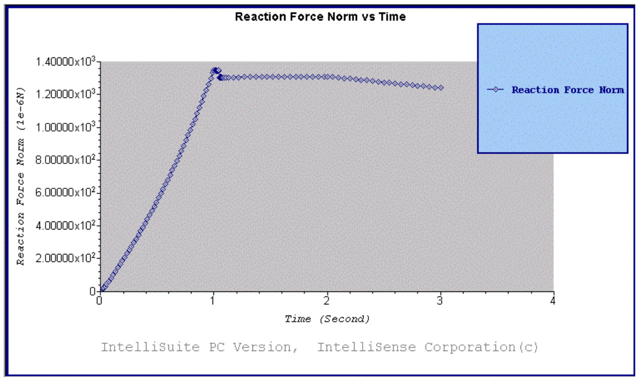

Figure 6: Reaction forces of the lower beam contact pad to the applied pressure and latching over time

3.2 Lateral Gear

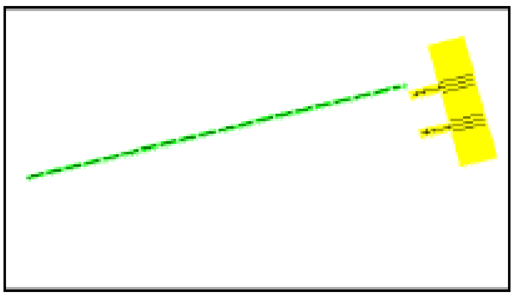

Figure 7: IntelliSuite™ model of a lateral gear device prior to actuation

The solution presented in this paper also allows for the analysis of linked motion devices (e.g. gears). An example is shown in Figure 7. The top tooth of the lateral gear begins 10 microns below the beam, which is cantilevered at the opposite end. The motion of the lateral gear is constrained to one-dimentional translation.

To actuate the structure, the final displacement of the lateral gear is specified. The upper tooth will contact the cantilevered beam, deflecting the tip upward. When the end of the tooth reaches the end of the beam, the beam snaps down into the area between the two teeth. As the gear continues to move upwards, the process repeats itself with the second tooth (Figures 8 and 9).

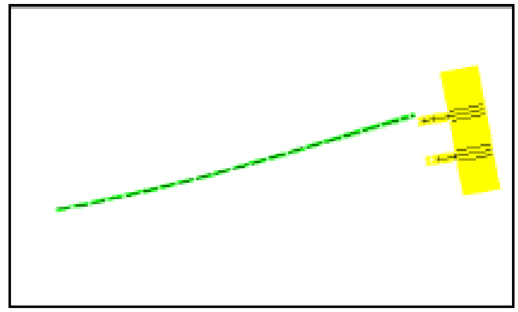

Figure 8: Beam deflection

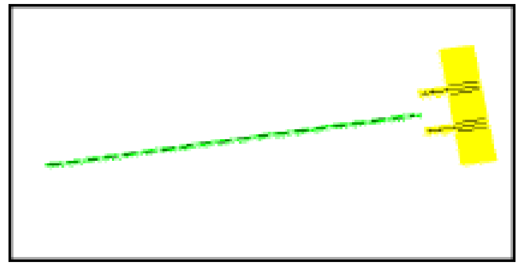

Figure 9: Transition to next gear tooth

4 CONCLUSIONS

Micro-assembly techniques are being used in a wide array of modern MEMS devices. IntelliSuite is the first software package for MEMS to successfully model the phenomena that occur during these processes.

By dividing the process into multiple contact steps, implementing large displacement theory, and separating the local model from the global model, the computation time of these simulations has been greatly reduced without sacrificing numerical convergence or time dependencies.

5 REFERENCES

[1] C. Gallegos, Y. He, J. Marchetti, F. Maseeh, "Accurate Fully-Coupled Natural Frequency Shift due to Voltage Bias and Other External Forces," Copyright IEEE, 1999.