Simulation of a Micro-Scale Out-of-plane Compliant Mechanism

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18th September 2014, Cambridge, England
Introduction

In this work we present the simulation of a micro-scale large displacement compliant mechanism called the Tsang suspension. It consist of a flat micro-plate anchored down by two springs on either side, that can rotate out-of-plane and maintain its vertical assembly by simple single-axis actuation.

Fig. 1 SEM image of fabricated and assembled SU-8 Tsang Suspension.
Introduction

Tsang structures can be used in applications such as micro-mirrors [3], free-space optics [4-6] and RF systems [7]. Out-of-plane electro thermal actuators have been fabricated using the Tsang suspension, where an actuator design was connected to the springs instead of the plate [8]. Tsang suspensions have also been used in thermal isolation of sensors [9,10].

Fig. 2 Left: Electro-thermal micro-gripper for an out-of-plane mirror in Silicon [2]. Right: Several Tsang suspensions (Silicon and Polyimide) hold an elevated platform with a 2 axis thermal accelerometer [3].
Simulation Design

The Tsang suspension is composed of symmetric springs, an unanchored platform, and the anchor pads (substrate), as shown in Figure 3. An in-plane force applied to the bottom edge of the central platform produces a complex deformation of the springs, which produces the desired out-of-plane motion of the central platform.

Figure 3: Illustration of a Tsang suspension layout with Spring Length (SL) = 200µm, Spring Width (SW) = 30µm, Number of Spring Beams (SB) = 4.
Simulation Design

• The design parameters investigated in this work were: the spring length (SL), the spring width (SW), and the number of spring beams (SB).
• The notation \{SL, SW, SB\} will be used to refer to a specific design. For example, the notation \{300, 20, 6\} refers to a Tsang suspension with SL = 300 \(\mu\)m, SW = 20 \(\mu\)m, and SB = 6.

![Diagram of parameters](image)

Figure 4: Representation of the parameters that were varied.
Simulation Design

In order to facilitate comparisons between various designs, a “standard design” Tsang suspension was established with the parameters $SL = 200 \ \mu m$, $SW = 30 \ \mu m$, and $SB = 4 \ \{200, 30, 4\}$. This was used as the base point for the various parameter variations investigated. The standard design was chosen since experience with SU-8 fabricated devices, has previously shown it as a reliable and stable design.

Figure 5: COMSOL model of a Tsang $\{200, 30, 4\}$
Use of COMSOL

• One of the challenges of Micro Electromechanical Systems (MEMS) is the direct measurement of their mechanical properties, due to the fact that the device’s dimensions are small, typically <1mm.
• We deal with a large displacement compliant mechanism with torsion.
• Complex to model analytically.
• Common solution is to use nonlinear finite element modeling.
COMSOL Simulation

- The structures were parametrically modeled in COMSOL.
- Material and boundary conditions were selected to represent the assembly process.
- The highly nonlinear option was selected to contemplate the large displacements of the structure.

Figure 6: Tsang suspension assembly in COMSOL.
Simulation Results

- Scanning Electron Micoscopy (SEM) was used to capture the top-view of the assembled structures.
- The simulation had good agreement with the experimental assembly.

Figure 7: Top view of simulation and SEM image. An example comparison angle, “theta-a” and “theta-b”. And displacement to vertical “d” are shown.
• The direction of the spring reaction force changes as the rotation angle of the plate increases.
• This reaction force initially attempts to restore the plate to its original flat position.
• A critical "toggle point" (change-over point) is reached, where the reaction force begins to act towards the substrate (self-locking mechanism).

Isometric View

Top View

Side View

a) Angle of rotation versus lateral displacement of the Tsang suspension with SL = 200 μm, SW = 30 μm, SB = 4.

b) Spring reaction force versus lateral displacement, with same design parameters.
Simulation Results

Figure 8: Graphs showing the effect of varying the different parameters as percentage variation of the standard design \{200,30,4\}

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Conclusions

- The Tsang suspension and its design parameters were studied using COMSOL Multiphysics.
- Changes in the reaction forces and displacement required for assembly were determined.
- Clear trends are observed when varying design parameters.
- This work provides greater insight into the operation of Tsang suspensions and provides designers with tools for designing their own implementation.
Thank You!
References