ECCE 550/ME550 Simulation Lab 1:
Matlab Simulation of a Bistable Mechanism

1 Introduction

Bistable mechanisms are useful MEMS devices that toggle between two stable positions. A force is required to move the device from its fabricated configuration (or first stable position) to its second stable position, but no external force is required to maintain that second stable position. Two example applications are electrical switches and inertial threshold sensors. We will be simulating a bistable device that is fully compliant (no pin joints) and displaces rectilinearly. A scanning electron micrograph (SEM) of one such device is shown in figure 1. You will fabricate one later in the semester using SU-8 such as the bistable device shown in figure 2.

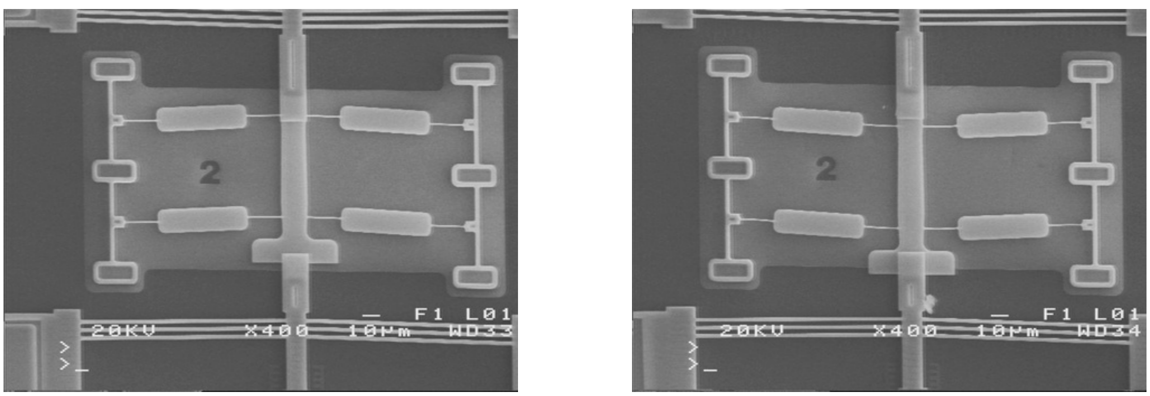

Figure 1: Fully compliant bistable mechanism (FCBM) in its two stable positions. Fabricated using the SUMMiT V process.

2 Proceedure

The FCBM can be modeled using a Pseudo-Rigid-Body-Model (PRBM) where the compliant elements are estimated as rigid segments connected with springs. A schematic of

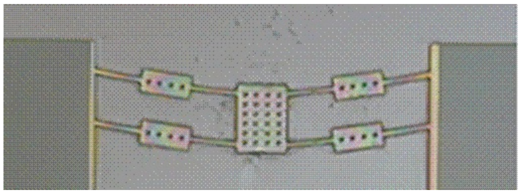 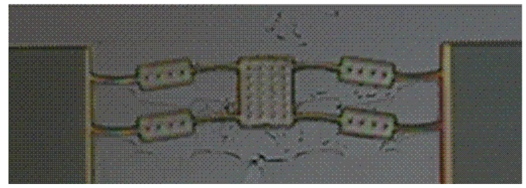

Figure 2: SU-8 FCBM you will fabricate later in the semester.

the PRBM is in figure 3. Due to symmetry only one quarter of the mechanism needs to be simulated. Using this model an estimate of force (F) versus displacement (δ_2) can be obtained.

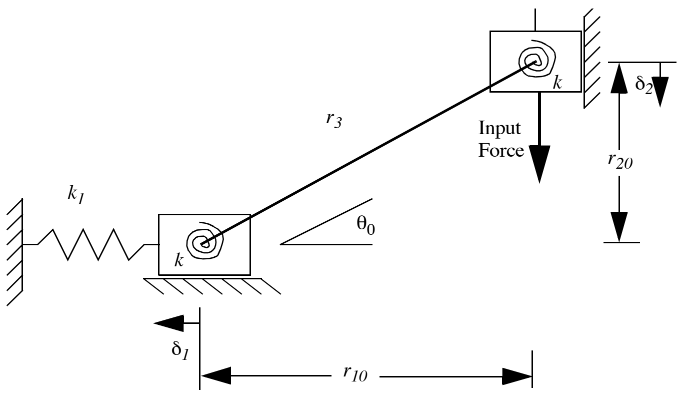

Figure 3: PRBM for one leg of the FCBM.

The width of the flexures (w), the length of the flexures (ℓ), the out-of-plane thickness (t), the modulus of elasticity (E), the initial angle (θ_0), and the dimension (r_{10}) are given. The independent variable is δ_2, the deflection of the center portion of the mechanism. Dependent parameters are calculated as follows.

$$k = \frac{tw^3E}{12\ell}$$

$$k_1 = \frac{Etw}{2l}$$

$$r_3 = \frac{r_{10}}{\cos(\theta_0)}$$

$$r_{20} = r_{10}\tan(\theta_0)$$

$$r_2 = r_{20} - \delta_2$$

$$\theta = \sin^{-1}(r_2/r_3)$$

$$\delta_1 = r_3 \cos(\theta) - r_{10}$$

$$\psi = \theta_0 - \theta$$

The parameter ψ refers to the angle the rigid link rotates from the initial angle θ_0.

$$F = \frac{k_1 r_2 (r_3 \cos(\theta) - r_{10})}{\sqrt{r_3^2 - r_2^2}} + \frac{2k\psi}{\sqrt{r_3^2 - r_2^2}}$$

Using these relationships, write a Matlab function that takes a vector of given parameters as an input and outputs corresponding vectors of displacements and forces.

3 Units

Because MEMS parts normally have lengths on the scale of microns, it is helpful when modeling them to use a consistent set of units that relies on a base length of micrometers. Table 1 gives a convenient set of consistent units for MEMS modeling. Note that the units for Young's modulus in the equations above correspond to the units for stress.

Table 1: A consistent set of units for modeling MEMS devices.

Quantity	Units	Quantity	Units
Length	μm	Mass	ng
Time	μs	Stress	MPa
Force	μN	Energy	pJ
Power	μW	Voltage	V
Current	μA	Resistance	MΩ
Capacitance	pF	Charge	pC

Table 2: FCBM Parameters.

Parameter	*SUMMiT*	*SU-8*	
w	1.5	7	μm
t	2	30	μm
ℓ	17.1	100	μm
r_{10}	171	298	μm
θ_0	0.042	0.105	radians
E	165	4.4	GPa

4 Deliverables

Turn in a professional memo that describes the force/displacement relationship (graph) for two FCBMs using the parameters in table 2. Discuss the implications of the force/displacement curve in relation to bistable behavior. For example–but not limited to–where is the second stable position, how much force is required to get there, and what does negative force imply?