Long-range Elastic Guidance Mechanisms for Electrostatic Comb-drive Actuators

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Abstract

The range of motion and output force of the often used electrostatic comb-drive with folded flexure straight guidance, as shown in Figure 1, is limited by sideways instability due to poor sideways stiffness of the folded flexure at relatively large deflections [1]. For example at displacements larger than 20 times the leaf-springs thickness (*t*), the stiffness in *x*-direction has decreased by several orders of magnitude, causing sideways snap-in leading to limited travel and poor output force. The individual leaf-springs of the folded flexures would have to be 20µm thick and 5mm long for a output force of at least 100µN over a range of ±100µm. The stress due to deformation is generally not a limiting factor. We have designed,

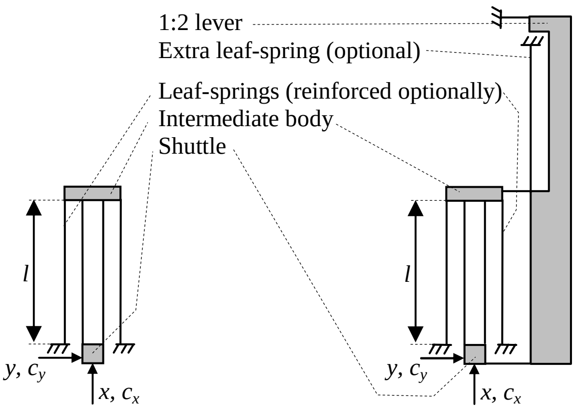


Figure 1. The Folded flexure on the left, and the exact constraint folded flexure using a 1:2 lever and using an extra leaf-spring on the right.

modeled, fabricated and tested several Watt's and 'Exact constrained folded flexures'. The combined device area of comb-drive and suspension has been minimized given a range of motion of 200µm, and an output force (electrostatic force minus elastic deformation force of the guidance) of at least 100µN over the full range of motion using a voltage limitation of 80V. The best performing mechanism, the 'Exact constraint folded flexure', shows that, compared to the folded flexure, the total device area has been reduced by a factor of 2.8 and the output force has been increased by a factor of 1.4 as shown in Table 1.

Table 1. Comparison of several modeled elastic guidance mechanisms

	Folded flexure	Exact constraint folded flexure	Double Watt's
Range of motion	100 µm	100 µm	100 µm
Min. output force over range	100 µN	140 µN	300 µN
Area of 2 mechanisms	4.5 mm^2	1.2 mm^2	7.2 mm^2
Area of actuator	0.85 mm^2	0.63 mm^2	0.67 mm^2
Performance: $F_{max} \cdot x_{max} / A_{total}$	3.2 mN·m/m^2	12 mN·m/m^2	7.0 mN·m/m^2

1 Cause of low Support Stiffness

The main cause of the decreased *x*-stiffness of a folded flexure is that at a given *y*-displacement of the shuttle, a load in the *x*-direction on the shuttle will influence the *y*-position of the intermediate body. This geometric coupling to the flexure's bending compliance leads to reduced *x*-stiffness. This problem is solved by constraining the intermediate body to half the displacement of the shuttle [2] by a 1:2 lever (Figure 1). The mechanism design has been modeled with an elastic multibody software program [3]. A clear improvement is shown in Figure 2. Further improvements are reinforcing the leaf-springs over 5/7th of their lengths [2], and constraining the 1:2 lever in the *x*-direction by adding an extra leaf-spring in the *x*-direction. For comparison the performance is calculated by multiplying the maximum output force (just before pull-in, and at maximum stroke) by the maximum stroke, divided by the occupied area of the total mechanism and comb-drive as shown in Table 1. Figure 3a shows the performance of an 'Exact constrained folded flexure' as a function of several design variations.

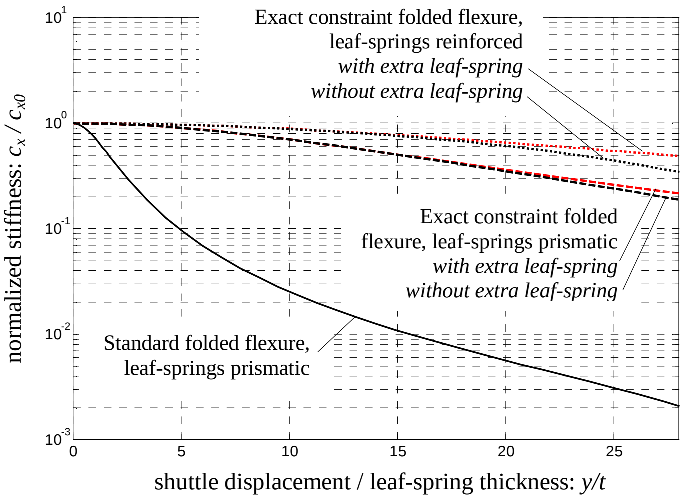
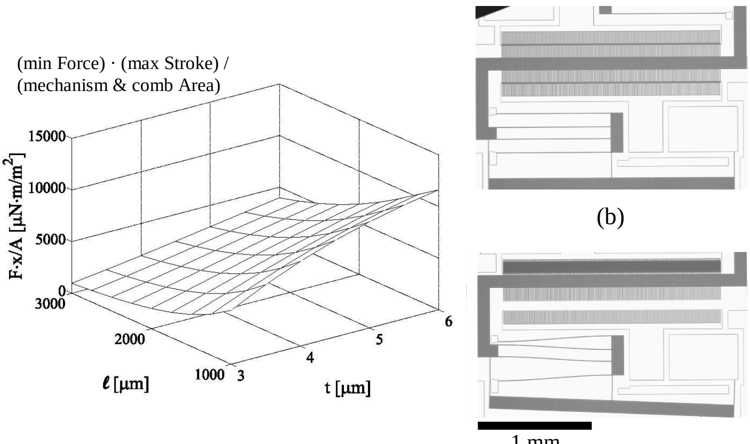


Figure 2. Axial stiffness reduction at deflection of several modeled design variations of the 'Exact constraint folded flexure' and a standard folded flexure as a reference, where the shuttle is constraint in the *y*-direction.



(a) (c)

Figure 3. (a) Performance of the 'Exact constraint folded flexure' for varying thickness (*t*) and length (*l*) of the flexures. The leaf-springs are prismatic and no extra flexure is incorporated. (b) Microscope pictures of the undeflected and (c) 100μm deflected 'Exact constraint folded flexure'.

2 Measurement and Fabrication

The devices are fabricated in a SOI wafer, by DRIE and vapor HF release etching. Figures 3b, 3c and 4 show microscope pictures of the fabricated devices in neutral and at 100μm deflected position. For both mechanisms the first Eigenfrequencies, calculated and measured, are shown in Table 2. The difference between the measured and calculated values is mainly caused by leaf-spring thickness variation due to etching. It is currently subject of improvement. Voltage−displacement measurements showed that in accordance to the models the long strokes did not lead to pull-in.

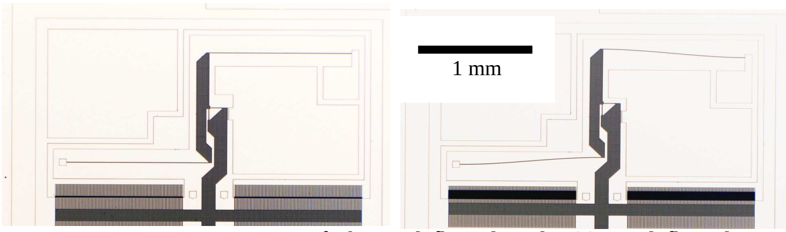


Figure 4. Microscope pictures of the undeflected and 100μm deflected Watt's mechanism.

Table 2. Measured and simulated first Eigenfrequencies

	Measured [Hz]	Calculated [Hz]	Error
Exact constraint folded flexure	401	462	15%
Watt's mechanism	551	498	-10%

Conclusion

When using a long range of motion, the 'Exact constraint folded flexure', out performs the folded flexure; given a range of motion of 200μm the total device area has been reduced by a factor of 2.8 and the output force has been increased by a factor of 1.4.

References

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